Essays on Multinational Production and International Trade

by

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To my father, Luis Raul Alviarez Croce

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ABSTRACT

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This dissertation studies the determinants and the consequences of multinational production. Using unique datasets and extending extant theories, it analyzes two channels by which multinational networks affect economic performance: comparative advantage and intra-firm trade.

In the first chapter, "Multinational Production and Comparative Advantage," I assemble a unique industry-level dataset of foreign affiliate sales to document a new empirical regularity: multinational production is disproportionately allocated to industries where local producers exhibit comparative disadvantage. Then, it shows analytically and quantitatively that multinational production raises average productivity while lowers sectoral productivity dispersion in the host economy. By inducing a larger transfer of technology in sectors where the host economy is relatively less productive, multinational production weakens the host country's comparative advantage. To measure these channels, this paper incorporates sectoral heterogeneity into a Ricardian general equilibrium model of trade and multinational production. The model is estimated to measure the extent of technology transfers across countries and sectors as well as to quantify the welfare effects of multinational activity. The heterogeneity of foreign affiliate sales across sectors is quantitatively important in accounting for welfare gains from multinational activity. In particular, gains from multinational production are 15 percentage points higher compared with a counterfactual scenario in which foreign affiliate sales are homogeneous across sectors. Furthermore, as a consequence of the impact of multinational production on comparative advantage,

gains from trade are about half of what they would be without sectoral heterogeneity in multinational activity (10 percent rather than 19 percent).

The second chapter, coauthored with Ayhab Saad, focuses on the interaction between multinational production and intra-firm trade in the global economy. A salient empirical regularity of multinational production (MP) is that foreign affiliate sales decrease with trade costs, a fact that is at odds with the proximity-concentration theory of multinational activity. As a response, intra-firm trade, from parents to foreign affiliates, has been combined with standard models of *horizontal* MP to generate complementarities between trade and MP that deliver gravity-style predictions for foreign affiliate sales. Nevertheless, two other stylized facts pose further challenges to this attempt to rationalize the gravity of MP. First, as documented by (Ramondo et al., 2014) intra-firm trade is not common across foreign affiliates but rather concentrated among a small set of large multinational firms. Second, as shown in this paper, not only firms in the upper tail of the firm size distribution are subject to gravity forces, but also sales of relatively small foreign affiliates are significantly affected by geographical barriers even when they rarely conduct intra-firm transactions. Two puzzles emerge: (i) why is intra-firm trade concentrated among the largest multinational firms? and (ii) what are the mechanisms that drive affiliate sales in the lower tail of the distribution to obey gravity forces, even in the absence of intra-firm trade?

In this paper we construct a framework to address these questions. To account for the extensive margin of intra-firm trade and the gravity of MP for firms of all sizes, including those that do not engage in intra-firm trade; this paper develops a multi-country model of heterogeneous firms, in which parents decide whether or not to supply foreign affiliates with intermediate inputs and if so, optimally decide the fraction that will be imported from the parent company. In our model an affiliate's marginal cost is affected by the parent's decision regarding the method of knowledge transfer. On the one hand, exporting intermediate inputs embodying knowledge to an affiliate entails the standard iceberg-type trade costs as well as a fixed cost of establishing an adequate platform to carry on cross-border transactions within the boundaries of the firm. On the other hand the marginal cost of direct knowledge transfer from parent to affiliates through remotely communication increase with geographical barriers but rise less than the costs of exporting intermediate inputs. As a result, in equilibrium (i) only the most productive multinational firms choose to export to their affiliates and (ii) foreign sales for both the affiliates who import from their parent and those who do not are affected by gravity forces.

CHAPTER I

Multinational Production and Comparative Advantage

1.1 Introduction

Multinational firms are responsible for a large fraction of global output, employment, and trade. Their production is almost twice as high as world exports and they account for 20–25 percent of manufacturing employment in developed countries.[1] Given the relevance of multinational production, an extensive literature in international economics searches for the key forces driving the patterns of production of multinational firms around the world. Among the most common explanatory factors are the differences in factor prices across countries and differences in the cost of exporting relative to the cost of producing abroad. The bulk of existing literature, however, uses a one-sector framework. The role of relative productivity differences across sectors—or comparative advantage—has received considerably less attention, in spite of the significant heterogeneity observed in multinational production (MP) at the sectoral level.

To examine the interaction between multinational production and productivity at the sectoral level, this paper assembles a novel dataset of bilateral foreign affiliate sales that, for the first time, incorporates the sectoral dimension into a multi-country framework. Using this unique dataset of MP sales for thirty-five countries, nine tradable sectors, and one non-tradable sector, this paper establishes a new stylized fact: foreign affiliate sales are larger in sectors where the host economy exhibits comparative disadvantage. Building on this fact, this paper shows that comparative

[1] World Investment Report, UNCTAD (2011).

advantage plays a crucial role in determining the sectoral allocation of multinational production, with less-productive sectors receiving the largest fraction of MP relative to output.

Multinational production, unlike trade, entails a direct transfer of technology across countries, which increases productivity in the host economy.[2] This paper shows, both analytically and quantitatively, that multinational production weakens a country's comparative advantage. Multinational activity not only closes the absolute technology gap across countries, it also reduces the relative productivity gap across sectors. By inducing larger transfers of technology into comparative disadvantage sectors—due to the relatively large presence of MP—multinational production weakens the host country's comparative advantage.

The welfare implications of the interaction between comparative advantage and multinational production are significant. This paper shows that by omitting the sectoral heterogeneity of MP sales, and therefore its impact on comparative advantage, existing uni-sectoral models of trade and MP systematically overstate the gains from trade and understate the gains from MP. Thus, distinguishing between the absolute and comparative advantage effects of MP is essential to improve our understanding, and the quantification, of the impact of multinational production.

Three main questions are addressed by this paper. The first is whether the observed uneven allocation of MP across sectors is significantly related to differences in sectoral productivity. The second question is whether multinational activity affects a country's comparative advantage by affecting the average productivity of each industry differently. Third, the paper evaluates analytically and quantitatively, the welfare implications of the interaction between MP and comparative advantage.

In order to answer these research questions, this paper assembles a novel dataset that provides detailed information on production and employment of foreign affiliates in each host country, distinguishing the sector of operation and the source country where the parent firm is located. These data of bilateral MP activity at the sectoral level contains information of thirty-five countries, nine tradable sectors, and one non-tradable sector for the period 2003–2007. Using this data we establish the following

[2]Recent empirical literature has shown a positive and significant impact of foreign affiliate activity on host country aggregate productivity. By opening a subsidiary abroad—greenfield—or by acquiring an existing company in the target market, multinational production activity brings innovation in products and processes through adoption of new machinery and organizational practices, improving the overall level of technology in the host economy. See (e.g., Guadalupe et al., 2012; Alfaro and Chen, 2013; Chen and Moore, 2010; Arnold and Javorcik, 2009). By using instrumental variables estimation(Fons-Rosen et al., 2013) finds that the higher productivity of multinational affiliates over local producers is due to investors cherry-picking firms with high future growth potential.

new stylized facts about MP activity at the sectoral level: (1) for each source-host country pair, the MP share on output is significantly heterogeneous across sectors; (2) sectoral heterogeneity remains even after aggregating foreign affiliate sales for each host-sector pair, across all source countries; and (3) MP activity is disproportionately allocated to industries where local producers exhibit comparative disadvantage.

To capture these stylized facts, analytically and quantitatively, we incorporate differing productivity levels across industries into a Ricardian general equilibrium model of trade and multinational production. The model features asymmetric MP and trade barriers; multiple factors of production (labor and capital); differences in factor and intermediate input intensities across sectors; a realistic input-output matrix between sectors; inter- and intra-sectoral trade; and a non-tradable sector. By combining these features into a unified framework, this paper offers the first set of productivity estimates at the sectoral level for local producers as well as for the entire economy. Compared with uni-sectoral models, this paper offers more reliable estimates of fundamental technology, since it effectively isolate the technology corresponding to local producers. Notice that total factor productivity calculated directly from data at the sectoral level does not distinguish between the productivity corresponding to local producers from overall productivity. Because the presence of multinational firms implies a transfer of technology into the host market, we proceeded to disentangle the productivity corresponding to local producers from the overall sectoral productivity. Breaking down the productivity by its ownership structure allows us to evaluate the extent to which sectoral differences in local producers' productivity determine the uneven allocation of foreign affiliate sales across sectors. Separating local and overall productivity also allows us to measure the extent and sectoral heterogeneity of the technology transfer implied by multinational activity.

The analytical results and quantitative estimations reveal that the effect of multinational production on the state of technology is higher in those sectors in which local producers are relatively less productive, implying that MP weakens a country's comparative advantage. Four analytical predictions emerge from the model. The first two highlight the channels of interaction between sectoral productivity differences and MP patterns in any equilibrium. The other two are concerned with the general equilibrium responses of aggregate trade flows and welfare in a counterfactual scenario where the MP-to-output ratios are homogeneous across sectors. The four analytical predictions are: (1) relative sectoral differences in *local* producers' productivity determine the sectoral allocation of MP in the host economy; (2) sectors with a larger MP share will have higher productivity increases due to multinational activity;

(3) any deviation from homogeneous MP shares across sectors—holding aggregate MP volumes relative to output constant—leads to larger gains from MP than what is implied by uni-sectoral models; (4) gains from trade are lower than they would be if MP were to affect productivity in all sectors homogeneously.

The assembled dataset is then used to quantitatively estimate the parameters of the model and also to test the model's analytical predictions. In particular, for each country-sector pair, we extract the productivity of local producers and show that, compared with all producers in the economy, local producers have a larger dispersion of relative productivity across sectors. This implies that the comparative advantage of all producers in the economy—both local and foreign firms—is weaker than the comparative advantage corresponding exclusively to local producers. These differences are explained by the larger presence of MP in sectors where local producers in the host economy are relatively less productive. As a result, the productivity enhancement due to MP is uneven and biased toward sectors in which local firms exhibit comparative disadvantage. These results are robust to potential selection effects, wherein the least productive firms exit because of the higher competition imposed by foreign firms; and they are also robust to the presence of knowledge spillovers through which local producers can benefit from the superior technology used by their foreign counterparts.[3]

Three counterfactual exercises are conducted to explore quantitatively the impact of MP on welfare, based on the estimated parameters. First, we show that the heterogeneity of foreign affiliate sales across sectors is quantitatively important in accounting for welfare gains associated with MP. In particular, these gains are 15 percentage points higher compared with a scenario of homogeneous multinational production. Second, we calculate the consequences for trade flows and welfare when we allow multinational activity to affect only the average productivity of the host economy, while keeping comparative advantage intact. Results show that the gains from trade are nearly twice as large as in the benchmark estimation, where MP changes both absolute and comparative advantage—19 percent compared with 10 percent. Consequently, recognizing that sectoral differences in MP allocation affect the comparative advantage of the host country is crucial for understanding the apparently modest gains from trade found in the literature. Finally, we evaluate the role of MP in the production of non-tradables and its potential effects on the competitiveness of

[3]Technology transfer and technology diffusion are used interchangeably. Note that these are different from knowledge spillovers, a term we reserve for the process by which domestic firms learn from foreign affiliates operating in the same market.

tradable sectors. Results show that welfare increases by 4.6 percent, and the price index of tradables decreases by 1.6 percent, when we allow foreign affiliates to operate in the non-tradable sector.

This paper contributes to a voluminous body of research on economic growth and international technology diffusion (e.g., Alvarez et al., 2011; Chaney, 2012; Rodríguez-Clare, 2007; Li, 2011). In these models, international technology transfer is a mechanism that explains economic growth, but most of them leave unspecified the channels through which this type of diffusion takes place. An exception is (Li, 2011), who assesses the impact of trade on knowledge by using data on payments for international trade in royalties, license fees, and information-intensive services for a sample of thirty-one countries. This paper differs from previous research in that it uses multinational bilateral sales at the sectoral level to measure quantitatively the extent of technology transfer associated with MP. In particular, for this exercise a dataset is assembled for a sample of thirty-five countries and ten sectors for the period 2003–2007.

This paper is also closely related to previous efforts to quantify the impact of multinational production in a general equilibrium framework. (Ramondo and Rodríguez-Clare, 2013a) develop a general equilibrium model of trade and multinational production under perfect competition to measure the gains from openness associated with the interaction of trade and MP. Using a similar framework, (Shikher, 2012) measures the extent of technology diffusion across countries. (Arkolakis et al., 2013) develop a quantitative multi-country general equilibrium model of monopolistic competition in which the location of innovation and production is endogenous and geographically separable. There are important differences between the present work and those papers, however. First, they use a uni-sectoral framework, and therefore by design they are silent with respect to how multinational production affects relative technology differences across sectors in the host economy. This gap is filled by estimating a multi-sector general equilibrium model of trade and multinational production, which offers a set of productivity estimates at the sectoral level for local producers exclusively as well as for the entire economy. A second difference in this paper is that it provides more reliable estimates of local producers' productivity and allows for asymmetries in multinational production barriers at the industry level.[4]

[4]Previous literature uses measures of effective labor and the fraction of workers in the R&D sector to estimate a country's productivity. This could potentially be a misleading indicator given that an important fraction of the private R&D in developed countries is conducted by foreign affiliates. Instead, this paper uses a gravity equation derived from a sectoral model of trade and multinational production to estimate jointly the technology parameters, as well as trade and MP barriers, for every

An important way in which this paper contributes to the literature pertains to welfare gains from trade. (e.g., Caliendo and Parro, 2014; Costinot et al., 2012; Levchenko and Zhang, 2012; Hsieh and Ossa, 2011) incorporate sectoral heterogeneity, intermediate input usage, and sectoral linkages in order to understand the contributions of these components to the welfare increase associated with a reduction in trade barriers. To highlight the interaction between multinational activity and a country's comparative advantage, this paper extends the structure of these models by expanding the firm's set of choices to allow the possibility of serving a country through multinational production.

Finally, this paper joins in the debate on whether the primary motive for MP is (1) to satisfy final demand—*horizontal MP* (e.g., Ramondo et al., 2013; Bernard et al., 2009, 2011; Guadalupe et al., 2012), or (2) to take advantage of international differences in factor prices by producing intermediate inputs that will be used by the parent firm or by another affiliate in a third country in later stages of the production process—*vertical MP* (e.g., Antras and Helpman, 2004a; Alfaro and Chen, 2013). The existence of a negative and significant relationship between sectoral MP sales and total factor productivity is consistent with a horizontal view of MP activity where foreign affiliates compete with local producers to satisfy the host market.

The remainder of the paper is organized as follows. Section 1.2 discusses the pattern of multinational production at the sectoral level. Section 1.3 lays out the theoretical framework and derives analytical results on the impact of sectoral dispersion in MP on gains from trade and gains from multinational activity. Section 1.4 sets up the quantitative framework and estimates the parameters of the model. Section 1.5 presents the results and discusses the effect of MP on comparative advantage. Section 1.6 measures the welfare gains of multinational activity. Section 1.7 concludes.

1.2 Empirical Facts: MP and Comparative Advantage

1.2.1 Data Description

The analysis of the relationship between multinational production and relative technology differences across sectors requires three types of information: (1) production and employment of foreign affiliates in each host country, distinguishing the sector of

country-sector pair in the sample.

operation and the source country where the parent firm is located; (2) bilateral trade data at the country-sector level; and (3) country-level macroeconomic indicators such as sectoral output and employment.

This paper assembles a dataset of foreign affiliate sales, employment, and number of affiliates, which adds a sectoral dimension to the aggregate bilateral data used in previous work.[5] The dataset contains information for thirty-five countries,[6] nine tradable sectors, and three non-tradable sectors.[7] This dataset enables the breakdown of domestic production and employment into their corresponding foreign and domestic components at the sectoral level. Each observation is a triplet formed by the source country, host country, and sector, averaged over the period 2003–2007. Table 2.1 in the Tables and Figures section shows the list of countries in the sample.

This dataset includes information only for majority-owned foreign affiliates, that is, those in which 50 percent or more of the control is exerted by a foreign country.[8] The main source of information is unpublished OECD data, drawn from the International Direct Investment Statistics and the Statistics on Measuring Globalisation. For European countries that do not belong to the OECD, information is drawn from the Foreign Affiliates Statistics provided by Eurostat. Section 1.8.2 in the Appendix provides detailed information about the construction and validation of the dataset.

Note that the activities of foreign affiliates are measured not by foreign direct investment (FDI) but rather by their real activities. The use of these data has several advantages. First, the data we use considers only majority-owned foreign affiliates, whereas a foreign direct investment dataset considers all affiliates in which 10 percent or more of their equity capital is foreign-owned. The extent of ownership is important,

[5] In contrast to bilateral trade data, which is available for many countries at different levels of sectoral disaggregation, there is no systematic dataset of bilateral MP sales broken down by sectors. An exception is (Fukui and Lakatos, 2012), which is also an attempt to introduce a sectoral dimension to bilateral data on foreign affiliate sales. The methodology used in constructing the dataset for the present paper differs substantially from theirs, mainly in the primary sources of information used and the methods implemented. A discussion of the differences between the two datasets is presented in section 1.8.2 in the Appendix.

[6] All thirty-five countries are reporting countries. A reporting country is one that reports or declares the foreign affiliate activity. The other country involved in the transaction is called the partner country. The activity reported by the reporting country could refer either to the sales of affiliates from other countries operating in its territory—or inward MP—or to the sales of locally based multinationals with affiliates operating in foreign markets—or outward MP.

[7] The nine tradable sectors are all manufactures. The non-tradable sectors are construction; wholesale, retail trade, restaurants and hotels; and transport, storage, and communication. Agriculture and mining sectors were excluded, as well as some service sectors for which data on production were not available.

[8] A country secures control over a corporation by owning more than half of the voting shares or otherwise controlling more than half of the shareholders' voting power.

given that a transfer of technology is more likely to occur if the parent exerts a strong control over its affiliates, and it is unclear how much control a 10-percent investor has over an affiliate. Second, having majority-owned affiliates ensures that the source country is where the parent company is located, while FDI statistics register only the country of the immediate investor, even when the capital is passing through a third country.

1.2.2 Sectoral Multinational Production

There are three necessary conditions for comparative advantage to be weakened by multinational activity. First, foreign affiliates must be large enough to affect aggregate productivity in host economies. Second, the presence of multinational activity in total production must be significantly heterogeneous across sectors. And third, the heterogeneous allocation of MP across sectors must be related to comparative advantage; in particular, MP must be disproportionately allocated to comparative disadvantage sectors. In this section, we provide evidence of each of these conditions, which guides the model and the quantitative exercise carried out in later sections.

1.2.2.1 Relevance of Multinational Production

The presence of multinational firms in a given host market can be measured by the share of MP in total output, which is calculated by summing up the production of all foreign-controlled firms, regardless of where their parent firms are located. Let I_{hs}^j denote the sales of source country s in location h in sector j, and I_h^j denote the production in sector j in country h regardless of the nationality of the producers. The MP share is given by:

$$MP\text{share}_h^j = \sum_{s \neq h} \frac{I_{hs}^j}{I_h^j} = \frac{\sum_{s \neq h} I_{hs}^j}{I_h^j}$$

where the relative importance of a given source country s in country h and sector j is given by $\sum_{s \neq h} \frac{I_{hs}^j}{I_h^j}$.[9] Table 1.8 in Tables and Figures reports summary statistics on the share of MP for the countries in the sample. As the first column in the table shows, foreign affiliates account for 24 percent of the production of tradables and 28 percent of non-tradables. There is an important variation in the presence of MP across countries, though. For some countries, MP in tradables accounts for more than

[9]Note that MP does not include the production of domestic multinationals. It considers only the output being produced by foreign affiliates of multinational parents based abroad.

40 percent of the output (e.g., Canada, United Kingdom, Poland, Romania, among others), while it accounts for only 5 percent in others (e.g., Greece, Israel, Japan, New Zealand). For non-tradables, the presence of foreign activity can be more pervasive in some countries, accounting for up to 84 percent of total production.[10]

The presence of multinational production in many countries is patently visible. The second and fourth columns in Table 1.10 in Tables and Figures display the number of source countries with multinational operations in each reported country and the number of host countries in which they keep operations abroad, respectively. Of thirty-five declaring countries in the sample, twenty-four serve as host of multinational operations for more than ten source countries; and twenty-two countries have multinational operations in more than ten host countries. However, there is significant variation across countries. The United Kingdom, Germany, and the United States have affiliates in most foreign markets and they host operations for many source countries, whereas Australia, Greece, and New Zealand host MP operations for no more than two source countries. The third and fifth columns in Table 1.10 represent the weighted average of the MP share of each reported country as host and source, respectively.[11] As can be observed in some high-income OECD economies, such as Austria, Canada, Sweden, and the United Kingdom, there is a very high presence of foreign firms, with about 40 percent of the output in tradables in the hands of foreign affiliate firms. Some countries, such as Japan, are an important source of MP (accounting for 25 percent of total Japanese production), while in contrast, the relative importance of foreign multinational corporations in Japan is limited (foreign affiliates' production reaches only 10 percent of total output).

1.2.2.2 Cross-Sector Heterogeneity of Multinational Production

There is clear heterogeneity in MP across sectors. Figure 1.9 shows this heterogeneity pattern for four selected host economies. The x-axis represents the source countries; the y-axis represents the sectors; and the bubbles represent the MP shares for each source-host-sector triplet. Source countries with more presence in the host economies

[10] As revealed by the input-output tables, non-tradables are an important component of the set of intermediate inputs used by all industries. On average, about 40 percent of the intermediate inputs used by an industry are from the non-tradable sector, which implies that the effect of multinational production on the technology of non-tradables could have a sizable impact on the structure of prices in all sectors of the economy. Section 1.6.4 provides an analysis of what would happen in a scenario where multinational production in the non-tradable sector is prohibitively costly.

[11] Averages are weighted by relative size of the sector in the host economy.

will have bigger bubbles in most sectors.[12] Nevertheless, for each source country operating in a given host economy, there is a great deal of heterogeneity in MP shares among sectors—which can be seen by the difference in the size of the bubbles in each vertical alignment. Also notice that the patterns of MP among sectors within a source country, represented by each vertical alignment of bubbles, are substantially different across source countries, which suggests that these patterns are not driven by sector-specific characteristics.[13] A similar pattern emerges if we examine the same four economies as before, but now each of them represents a source instead of a host country, as shown in Figure 1.10. As before, we are interested in the heterogeneity of the bubble size among sectors for each host economy.[14]

It is noteworthy that the MP heterogeneity among sectors still remains even after aggregating MP across all source countries that operate in the host market. In fact, MP shares aggregated across source countries exhibit substantial heterogeneity among sectors within a country as well as across countries within a sector. Figures 1.11 and 1.12 in Tables and Figures show these patterns for all of the countries in the sample. As an illustration, Figure 1.11 focuses on France and the United Kingdom. For instance, for some sectors in the United Kingdom, MP as a share of output is less than 20 percent, but in other sectors, MP accounts for more than 60 percent of local production. More important, this heterogeneity is not explained by sector-specific characteristics. Figure 1.12 shows that within any sector, there is an important variation in the MP output ratio across countries. For instance, in chemicals, some countries have only 5 percent of their output in the hands of foreign affiliates, while in other countries more than 60 percent of their chemical production comes from multinational companies.

1.2.3 MP Sales and Productivity: A Negative Relationship

The observed heterogeneity of MP among sectors does not follow a random pattern. Instead, MP shares are negatively correlated with sectoral productivity. To measure productivity at the sectoral level, we calculate the total factor productivity or Solow residual (T) for the set of countries for which data were available on labor and capital endowment and intermediate inputs, as well as a price deflector for these components.

Table 1.12 shows the results of the correlation as well as the coefficient of the

[12]Differences in the average size of the bubble across source countries can be explained in part by the size of the source country and its distance from the host country.

[13]The patterns shown in this illustration are representative of most countries in the sample.

[14]Similarly, differences in the average size of the bubble across host countries can be explained by factors such as market size and distance from the source country, among others.

regression between the share of MP for each source-host-sector triplet ($MP\text{share}^{j}_{hs}$) and the ratio of productivities (TFP_h/TFP_s). To further explore the variation among sectors within a given source-host country pair, the second column of Table 1.12 shows the results after including source-host fixed effects, which capture all country-pair-specific characteristics that may explain the relation between productivity and MP shares. The estimated coefficient is negative and significant; Figure 1.14 depicts the conditional correlation between the two variables. The relationship between MP and productivity holds even after aggregating foreign affiliate sales for each host-country pair, across all possible source countries. Figure 1.1 shows the negative correlations between productivity and the share of MP in each host country-sector pair. The relationship between relative productivity and the cross-sector variation of MP shares constitutes preliminary evidence supporting the predictions that emerge from the model presented in next section.

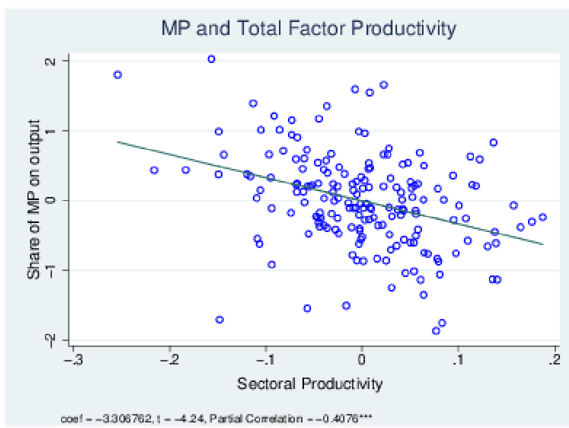


Figure 1.1: MP and Comparative Advantage

To ensure the robustness of this result, we perform a set of sensitivity checks using different samples and alternative definitions of the variables of interest. The fact that some sectors are more suitable for multinational activity than others could raise concerns about the stability of the relationship after controlling for characteristics that are specific to a given sector but common across all source-host country pairs in the sample. The third column in Table 1.12 shows that the results hold after including the sector fixed effects in the specification.

Another potential concern is the extent to which the size of foreign affiliate sales in a given host country might be influenced by the tax strategies followed by the parent firm (Hines 2003). Results could be biased, for instance, in cases where the tax regime is host-sector–specific, and therefore not controlled by the set of fixed effects included in the specification. To alleviate this concern, we use the share of employment as an alternative measure of MP activity, since it is less subject to manipulation for tax reasons. As Table 1.15 shows, results are robust to this definition of MP activity.

Although the mechanism highlighted in this paper is based on a horizontal perspective of multinational activity, both horizontal and vertical MP sales coexist in reality. Even when is not possible to disentangle horizontal from vertical MP, it is possible to make some inferences based on the commercial international transactions of multinationals. A roughly way to distinguish between vertical and foreign MP sales is by analyzing the destination markets of the foreign affiliates production. In particular, the share of foreign affiliate output sold back to the source country, where the headquarters is located, is likely to be vertical MP sales.[15] It is even possible that sales to a third country are not meant to satisfy final consumers—using the host economy as an export platform—but to continue a following stage of the production process within the firm. Therefore, subtracting foreign affiliate exports from total MP sales in a given country-sector pair gives us the part of MP sales that take place in the host market, which almost certainly are driven by a horizontal motive. Unfortunately, while the dataset assembled in this paper has information on sales, employment, and number of affiliates per source-host-sector triplet, it does not have information on international trade transactions—exports and imports—by foreign affiliate firms.

Nevertheless, to address concerns about the influence of vertical MP on the relationship between productivity and MP activity, we explore the correlation between MP sales and sectoral productivity using Bureau of Economic Analysis (BEA) data for U.S. multinationals operating abroad. The BEA dataset contains information about foreign affiliate sales, value added, imports, and exports, from which we can construct domestic sales of foreign U.S. affiliates abroad. Note that domestic sales of foreign affiliates likely underestimate horizontal MP, given that part of affiliate exports are meant to satisfy final demand in other markets, using the host country as an export platform. Therefore, domestic sales are a conservative measure of the multinational production conducted by U.S. foreign affiliates with horizontal motives. This does allow us, however, to explore the mechanism highlighted in this paper in a cleaner way. As reported in Figure 1.16 (and Figure 1.17), the results are similar: U.S. foreign affiliate sales as a share of output are relatively higher in sectors where

[15] Note that this is not always the case, given that an MP-horizontal firm could produce abroad and ship the final goods back home to satisfy final demand rather than selling to their parent or another related party firm. This scenario can take place if the cost of the input bundle is low enough that the gains from reduction in input cost more than compensate for the transportation cost from the host market to the source country.

the host economies have comparative disadvantage. This relationship is even stronger when using value added instead of output.

There are some necessary observations to be made in this regard. First, more than two-thirds of foreign affiliate sales occur in the host market.[16] Second, most countries in our sample are middle- and high-income OECD countries, which makes the vertical hypothesis less appealing.[17] Third, even when the observed MP sales are indeed a reflection of both horizontal and vertical multinational production, if the majority of MP sales were vertical, we would expect either none or a positive correlation between MP and sectoral productivity.[18]

More important, this relationship remains stable when using different datasets to calculate the total factor productivity (TFP) for each country-sector pair. In particular, we use the Structural Analysis Database (STAN) as well as the Groningen Growth and Development Centre (GDDC) database to test for this relationship. Alternatively, we use the productivity estimates obtained from a multi-sector trade model, which increases the coverage of countries and sectors; those estimates are highly correlated with the previous TFP measures. Finally, we also test this relationship using the dataset constructed by Fukui et al. (2012). Our main results are remarkably similar.

1.3 Model

In order to illustrate the mechanism of the model analytically, this section presents a two-country, two-sector model of trade and multinational production. In Section 1.4, the model is generalized to make it quantitatively informative by including asymmetric MP barriers; multiple factors of production (labor and capital); differences in factor and intermediate input intensities across sectors; a realistic input-output matrix between sectors; inter- and intra-sectoral trade; and a non-tradable sector.

Allowing countries to interact through trade and MP in a multi-sectoral environment has important analytical and quantitative implications compared with the

[16]Using BEA data, Ramondo et al. (2012) report that the median manufacturing affiliate receives none of its inputs from its parent firm, and sells 91 percent of its production to unrelated parties, mostly in the host country.

[17]Vertical foreign affiliates tend to produce intermediate inputs abroad to take advantage of low factor prices. Then, the intermediate inputs are exported to their parent company or other affiliates within the organization.

[18]Foreign affiliates that are vertically integrated could benefit from operating in sectors where local producers are relatively more productive. This would be the case if, for instance, foreign firms can use specialized workers from the comparative advantage industry, which increases productivity and lowers the cost of production of intermediate inputs.

benchmark, a uni-sectoral MP-trade model developed by (Ramondo and Rodríguez-Clare, 2013a). Those implications can be summarized in the following four analytical predictions: (1) relative sectoral differences in *local* producers' productivity determine the sectoral allocation of MP in the host economy; (2) sectors with a larger MP share will have higher productivity increases due to multinational activity; (3) gains from trade are lower than they would be if MP were to affect productivity in all sectors homogeneously; and (4) any deviation from homogeneous MP shares across sectors—holding aggregate MP volumes relative to output constant—leads to larger gains from MP than what is implied by uni-sectoral models.

1.3.1 A Simple Model: Environment

Consider an economy with two countries, and labor as the only factor of production. There are two sectors $j = \{a, b\}$, and each has an infinite number of varieties produced with constant returns to scale, indexed by ω. In every country and sector, each variety is produced by many firms engaging in perfect competition. Both sectors are subject to international trade and MP barriers.

Let s denote the source country of the technology, h the host country, and m the destination market. In order to serve any given market at the lowest possible price, a firm in sector j chooses between (1) producing at home s and exporting to the destination market m; (2) building up an affiliate at the destination market m to produce and sell locally (h=m); or (3) setting a foreign affiliate in a third country ($h \neq m$) used as an export platform, to ship goods to the final destination m.[19]

A firm that chooses to produce at home to serve country m uses its technology to full extent, but faces a transportation cost of exporting (d^j_{ms}). A firm that chooses to produce at the destination market instead (h=m) completely avoids the transportation cost of exporting but suffers a loss in productivity when implementing its technology in a foreign country (g^j_{hs}). In addition, if the foreign affiliate uses a third country h to produce and export to country m, it also faces the transportation cost associated with exporting from h to m (d^j_{mh}).

Technology: Each source country s has a technology to produce each variety ω, at home and abroad. Let $z^j_{hs}(\omega)$ denote the number of units of the ωth variety in sector j that can be produced with one unit of labor by a firm from a source country

[19]Note that, without symmetry, an export platform can exist even in a two-country setting. A country may find it profitable to produce abroad to satisfy the home market if factor prices are low enough overseas. This pattern of production does not reflect vertical MP; in this case, the purpose of producing in a foreign country is to produce final goods rather than intermediate inputs.

s that is located in host country $h = \{1, 2\}$.

The technology of each country s in sector j ($\mathbf{z_s^j}$), is described by a vector in which each element represents the source country's productivity in each host country h (z_{hs}^j).

$$\mathbf{z_s^j}(\omega) \equiv \left\{ z_{1s}^j(\omega), z_{2s}^j(\omega) \right\} \quad \forall i, j = \{1, 2\}. \tag{1.1}$$

Then, the productivity of a source country s in sector j ($\mathbf{z_s^j}$) is drawn independently across goods, countries, and sectors from a multivariate Frechet distribution.[20].

$$F_s^j(\mathbf{z}) = exp\left\{ -T_s^j \left[(z_{1s}^j)^{-\theta} + (z_{2s}^j)^{-\theta} \right] \right\}. \tag{1.2}$$

Equation (1.2) states that productivities across locations are related in two ways. First, they are drawn from a distribution with the same location parameter, or mean productivity (T_s^j): a higher T_s^j leads to a larger productivity draw on average, at home and abroad. Note that regardless of the location of production, the mean productivity that matters is the productivity of the source country s. Second, the stochastic component of the productivity is governed by the dispersion parameter θ, which is assumed to be common across countries and sectors and reflects idiosyncratic differences in technology know-how across varieties in any given sector j. The larger is θ, the lower is the dispersion of productivities within a sector. Finally, albeit productivities across locations are drawn from a distribution with the same mean (T_s^j) and variance (θ), productivities are assumed to be independent across host countries.[21]

Therefore, productivity differences in this model are characterized by: (1) differences in relative productivity across industries (T_s^1/T_s^2)—or Ricardian comparative advantage at the industry level; and (2) intra-industry heterogeneity governed by θ. In this stochastic model, a higher T_1^a ($T_1^a > T_2^a$) captures the idea that country 1 is relatively better at producing z_{h1}^a goods in any host country h—including its own

[20]Note that whenever $z_{hs}^j(\omega) = 0$ for $s \neq i$ $\forall \omega \in \{0, 1\}$ and $\forall j = 1, 2$, then the model collapses to a multi-sector general equilibrium model of international trade without multinational production (e.g., Caliendo and Parro, 2014; Levchenko and Zhang, 2012)

[21]The assumption of independence across locations corresponds to a particular case of a more general specification in which the degree of correlation among the elements of vector $\mathbf{z_s^j}$ is governed by the parameter ρ in the equation below

$$F_s^j(\mathbf{z}) = exp\left\{ -T_s^j \left[(z_{1s}^j)^{-\theta/(1-\rho)} + (z_{2s}^j)^{-\theta/(1-\rho)} \right]^{1-\rho} \right\}.$$

The simplified assumption used in this paper ($\rho = 0$) gives us the tractability to rely on gravity equations to estimate the parameters of interest. It also allows us to compare our results with previous work that has focused on the estimation of the mean productivity parameters using trade data at the sectoral level.

market. But whatever the magnitude of T_s^j, country 2 may still have lower labor requirements for some varieties. This does not imply that country 1 should only produce varieties from sector a in any given location h, but instead that it should produce relatively more of these goods.

Production: In providing variety ω in sector j to any country m, country s's firms have two strategies available to them, from which they will choose the most cost-efficient one. These strategies are:

(1) *Exporting from home country*: A firm can use its technology to produce at home and export to market m, in which case the source of technology and the location of production are the same ($h = s$). The output of variety ω in sector j produced at home to serve market m is given by:

$$Q_{mhs}^j(\omega) = Q_{mss}^j(\omega) = L_s^j \left(\frac{z_{ss}^j(\omega)}{g_s^j} \right) = L_s^j z_{ss}^j(\omega), \tag{1.3}$$

where $z_{ss}^j(\omega)$ represents the productivity of a firm when it produces at home. There are no additional costs (or efficiency losses) for operating in its own market; therefore, $g_{ss} = 1$.

(2) *Multinational production*: A firm could set an affiliate in any other location $h \neq s$, and from there sell to market m:

$$Q_{mhs}^j(\omega) = L_h^j \left(\frac{z_{hs}^j(\omega)}{g_{hs}^j} \right). \tag{1.4}$$

The output level associated with MP depends on the factor endowments in the country where production takes place (L_h^j); the penalty associated with implementing the home country's technology abroad ($g_{hs}^j > 1$); and the productivity of firms from country s producing at location h ($z_{hs}^j(\omega)$). The penalty parameter g_{hs}^j is a deterministic measure of the efficiency losses a country faces in producing in some location outside home, which is source-host-sector–specific and common across varieties. Therefore, a higher g_{hs}^j reflects lower productivity of affiliates from s in h, for all varieties in sector j.

Finally, output in each sector j is produced using a CES production function that aggregates a continuum of varieties $\omega \in [0, 1]$ that do not overlap across sectors. Q_h^j is a CES aggregate and $Q_h^j(\omega)$ is the amount of variety ω used in production in sector j and country h. The elasticity of substitution across varieties ω is denoted by ε_j.

$$Q_h^j = \left(\int_0^1 Q_h^j (\omega)^{\frac{\varepsilon_j - 1}{\varepsilon_j}} d\omega \right)^{\frac{\varepsilon_j}{\varepsilon_j - 1}}. \tag{1.5}$$

Note that in a two-country environment, the host country and the destination country are the same ($h = m$).

Preferences: Preferences are Cobb-Douglas over the broad sectors of the economy.[22]

$$Y_m = (Y_m^a)^{\xi_m} \left(Y_m^b\right)^{1-\xi_m}, \tag{1.6}$$

where ξ_m denotes the Cobb-Douglas weight for sector a. The resources constraint faced by consumers in this two-country, two-sector model is given by:

$$P_m Y_m = p_m^a Y_m^a + p_m^b Y_m^b = w_m L_m, \tag{1.7}$$

where Y_m^j represents the expenditure of country m on sector j goods and p_m^j is the price of the sector j composite.

Trade and MP Costs: Trade frictions take the standard iceberg form. Formally, it is assumed that for each unit of variety ω shipped from country of production h to the target country m, only $1/d_{mh}^j$ arrives, with d_{mh}^j such that $d_{mh}^j = 1$ and $d_{mh}^j < d_{mk}^j d_{kh}^j$ for any country k, ruling out any third-country arbitrage opportunities.[23] More important, trade barriers are not symmetric $\left(d_{mh}^j \neq d_{hm}^j\right)$, and they can be decomposed into a symmetric component $\left(d_{mh}^j\right)$ and a specific (exporter-sector) component $\left(d_h^j\right)$.

Barriers to investment are described in a similar manner. These are non-symmetric as well $\left(g_{hs}^j \neq g_{sh}^j\right)$, and they can also be decomposed into a symmetric component $\left(g_{hs}^j\right)$ and a specific (source-sector) component (g_s^j). These modeling choices for trade and MP barriers will be discussed in detail in Section **??** in the Appendix.

Market Structure: The features of the model outlined above imply that producing one unit of variety ω in sector j in country h with technologies from country s requires $g_{hs}^j / z_{hs}^j (\omega)$ input bundles. Since labor is the only factor of production, the cost of an input bundle is given by:

$$c_h^j (\omega) = w_h^j. \tag{1.8}$$

[22] In the N-sector, N-country model, the preferences are generalized to a CES specification, adding flexibility to the elasticity of substitution across sectors.

[23] The last property is binding only in an $N > 2$ model, such as the one presented in the next section.

Equation (1.8) is based on the assumption that every firm operating in country h uses the local input bundle regardless of its country of origin.[24] Under perfect competition and given the assumptions made for trade and investment barriers, the price at which country s can supply variety ω in sector j to country m, when producing in country h, is equal to:

$$p^j_{mhs}(\omega) = \left(\frac{c^j_h g^j_{hs}}{z^j_{hs}(\omega)} \right) d^j_{mh}. \tag{1.9}$$

Therefore, seller s will choose the location $h = \{1, 2\}$ that allows him to reach country m with the lowest possible price, $p^j_{ms}(q) = min\left\{p^j_{m1s}(\omega); p^j_{m2s}(\omega)\right\}$. Conditional on each provider being at the cheapest possible location, consumers in market m will choose to buy from the source technology country $s = \{1, 2\}$ that offers the lowest price $p^j_m(\omega) = min\left\{p^j_{m1}(\omega); p^j_{m2}(\omega)\right\}$.

Hence, the probability that country m imports good ω in sector j from country h, using technologies from country s, is given by:

$$\pi^j_{mhs} = \underbrace{\left(\frac{T^j_s {\Delta^j_{ms}}^{-\theta_j}}{T^j_1 {\Delta^j_{m1}}^{-\theta_j} + T^j_2 {\Delta^j_{m2}}^{-\theta_j}} \right)}_{\text{Term 1}} \underbrace{\left(\frac{{\delta^j_{mhs}}^{-\theta_j}}{{\delta^j_{m1s}}^{-\theta_j} + {\delta^j_{m2s}}^{-\theta_j}} \right)}_{\text{Term 2}}, \tag{1.10}$$

where $\Delta^j_{ms} = \left[\left(\delta^j_{m1s}\right)^{-\theta_j} + \left(\delta^j_{m2s}\right)^{-\theta_j} \right]^{-\frac{1}{\theta_j}}$ and $\delta^j_{mhs} = d^j_{mh} c^j_h g^j_{hs}$.

The right-hand side of equation (1.10) can be easily interpreted as the product of two independent events: Term 1 on the left describes the event whereby a producer from country s is the lowest-price supplier of ω in country m independently of the location of production. Term 2 on the right describes the event whereby country h is the host country that offers the lowest cost of production for source country s selling to market m. In this equation, π^j_{mhs} represents the share of goods in sector j that country m buys from firms located in country h whose source is country s. π^j_{mhs} collapses to the following equation:

$$\pi^j_{mhs} = \left[\frac{T^j_s {\delta^j_{mhs}}^{-\theta_j}}{T^j_1 {\Delta^j_{m1}}^{-\theta_j} + T^j_2 {\Delta^j_{m2}}^{-\theta_j}} \right], \tag{1.11}$$

The actual price paid by consumers in country m to buy goods in sector j is given

[24] This assumption implies that foreign affiliates do not require input bundles from the source country s to produce variety ω in the host country h. The assumption is made only for simplicity, to better highlight the channel proposed in this paper.

by:

$$p_m^j = \Gamma_j \left(T_1^j {\Delta_{m1}^j}^{-\theta_j} + T_2^j {\Delta_{m2}^j}^{-\theta_j} \right)^{-\frac{1}{\theta_j}}, \tag{1.12}$$

where $\Gamma_j = \left[\Gamma \left(\frac{\theta_j + 1 - \varepsilon_j}{\theta_j} \right) \right]^{\frac{1}{1-\varepsilon_j}}$ and Γ is the Gamma function.

Trade and MP Shares: The share of goods that country m imports from country h $\left(\pi_{mh}^j\right)$, can be calculated by aggregating π_{mhs}^j across all source countries. Therefore, the probability that country m will buy a sector j variety from country h is calculated by summing up the probabilities of importing goods produced in country h using technologies from every source country s, including itself:

$$\pi_{mh}^j = \pi_{mh1}^j + \pi_{mh2}^j$$

By substituting (1.11) in the above equation, we get:

$$\pi_{mh}^j = \frac{\widetilde{T_h^j} \left(c_h^j d_{mh}^j \right)^{-\theta}}{\widetilde{T_1^j} \left(c_1^j d_{m1}^j \right)^{-\theta} + \widetilde{T_2^j} \left(c_2^j d_{m2}^j \right)^{-\theta}}, \tag{1.13}$$

where $\widetilde{T_h^j}$ is the *effective technology* and is given by:

$$\widetilde{T_h^j} = T_1^j {g_{h1}^j}^{-\theta} + T_2^j {g_{h2}^j}^{-\theta}. \tag{1.14}$$

The above equation states that in the presence of multinational production, the set of available technologies for each country is enlarged. Each country-sector pair has an effective productivity that equals its local productivity in that sector plus the productivity of the foreign affiliates producing in the country, discounted by the investment barriers g_{hs}^j. How much a country could benefit from foreign technologies depends on the barriers to MP represented by g_{hs}^j, which limit the host economy's capacity to absorb the productivity of foreign affiliates from country s, so as to enhance their overall productivity. Note that technology $\widetilde{T_h^j}$ is not available to all—local and foreign— producers in country h. Instead, each firm producing in host country h uses technology from its own source country T_s^j and $\widetilde{T_h^j}$. The model does not internalize the potential knowledge spillovers that may take place from foreign to local producers. The productivity in the host country is enlarged as a result of the coexistence of local and foreign producers with different levels of technology, and not because local producers become more productive by learning from their foreign counterparts.

The value of foreign output in sector j, produced in country h using country s's technologies to serve country m, is then given by $\pi^j_{mhs} p^j_m Q^j_m$, where $p^j_m Q^j_m$ is the total expenditure on sector j goods by consumers in country m.[25] Total output of foreign affiliates from country s located in country h can be calculated by summing foreign affiliate sales over all destination markets (m). Thus, total MP in sector j by affiliates from country s located in country h is given by:

$$I^j_{hs} = \pi^j_{1hs} X^j_1 + \pi^j_{2hs} X^j_2 \quad \forall j = \{1, 2\},$$

where $X_m = p^j_m Q^j_m$. Substituting (12) in the former expression, we get:

$$I^j_{hs} = \frac{T^j_s \left(g^j_{hs} c^j_h\right)^{-\theta}}{\left(p^j_h\right)^{-\theta}} \Xi^j_h, \tag{1.15}$$

where $\Xi^j_h = \sum_{m=1}^{2} \left(d^j_{mh} p^j_h / p^j_m\right)^{-\theta} X^j_m = I_h \left(\frac{X_h}{X_{hh}}\right)$[26] Therefore, the share of goods produced in country h with s technologies—or MP share—is given by:

$$y^j_{hs} = \frac{I^j_{hs}}{\sum_i I^j_{hs}} = \frac{I^j_{hs}}{I^j_h} = \frac{T^j_s \left(g^j_{hs}\right)^{-\theta}}{\widetilde{T}^j_s}. \tag{1.16}$$

1.3.2 Welfare: Analytical Predictions

Welfare in country h is given by the indirect utility function and corresponds to real income:

$$W_h = \prod_{j=a,b} \frac{w_s}{\left(p^j_s\right)^{\xi_j}}, \tag{1.17}$$

[25]Note that for a given host and source country pair (h, s) π^j_{mhs} is not mutually exclusive across destination countries (m), given that some foreign affiliates could serve more markets than others

[26]Normalizing the bilateral trade shares by the share of country s's expenditure devoted to locally produced goods $\left(\hat{x}^j_{hh} = \frac{X^j_{hh}}{X^j_h}\right)$ yields:

$$\frac{\hat{x}^j_{mh}}{\hat{x}^j_{hh}} = \left(d^j_{mh} \frac{p^j_h}{p^j_m}\right)^{-\theta}$$

$$X^j_{mh} = \hat{x}^j_{hh} \left(d^j_{mh} p^j_h / p^j_m\right)^{-\theta} X^j_m$$

Summing over m:

$$I^j_h = \sum_m X^j_{mh} = \hat{x}^j_{hh} \sum_m \left(d^j_{mh} p^j_h / p^j_m\right)^{-\theta} X^j_m$$

$$I^j_h = \hat{x}^j_{hh} \Xi_h$$

The optimal sectoral factor allocations must satisfy $I^j_h = \frac{w_h L^j_h}{\alpha_j \beta_j}$; therefore, Ξ^j_h can be rewritten as a function of observables only: $\Xi^j_h = \frac{1}{\hat{x}^j_{hh}} \frac{w_h L^j_h}{\alpha_j \beta_j} = I_h \left(\frac{X_h}{X_{hh}}\right)$.

where p_h^j is the price in country h of goods in sector j (see equation (1.12)). An expression for w_h/p_h^j as a function of local producers' technology $\left(T_h^j\right)$, along with the expenditure share on domestically produced goods (π_{hh}^j) and the share of goods produced domestically by local producers (y_{hh}^j), can be derived using equation (1.15) when $h = s$:

$$\frac{w_h}{p_h^j} = \left(T_s^j\right)^{\frac{1}{\theta}} \left(y_{hh}^j\right)^{-\frac{1}{\theta}} \left(\pi_{hh}^j\right)^{-\frac{1}{\theta}}, \tag{1.18}$$

where $y_{hh}^j = \frac{I_{hh}^j}{I_h^j}$ and $\pi_{hh}^j = \frac{X_{hh}^j}{X_h^j}$.

Taking the product of (1.18) for both sectors and weighting by ξ_j, we derive an expression for real wages in country h:

$$W_h = \prod_{j=a,b} \left[\left(T_h^j\right)^{\frac{1}{\theta}} \left(y_{hh}^j\right)^{-\frac{1}{\theta}} \left(\pi_{hh}^j\right)^{-\frac{1}{\theta}}\right]^{\xi_j}. \tag{1.19}$$

Following (Levchenko and Zhang, 2013), in deriving analytical predictions for welfare, it is further assumed that the expenditure shares in the two sectors are equal ($\xi_j = 1/2$). Therefore, welfare is expressed by:

$$W_h = \frac{w_h}{\left(p_h^a p_h^b\right)^{\frac{1}{2}}} = \left(T_h^a T_h^b\right)^{\frac{1}{2\theta}} \left(\pi_{hh}^a \pi_{hh}^b\right)^{-\frac{1}{2\theta}} \left(y_{hh}^a y_{hh}^b\right)^{-\frac{1}{2\theta}}. \tag{1.20}$$

In addition, it is assumed that the average productivity in both countries is the same, and that they differ only in their comparative advantage. Therefore, country 1 in sector a has the same productivity as country 2 in sector b, and country 2 in sector a has the same productivity as country 1 in sector b: $T_1^a = T_2^b$ and $T_1^b = T_2^a$. Without loss of generality, let us assume that country 2 has comparative advantage in sector a ($T_2^a > T_1^b$), and also that trade and investment barriers are symmetric along country pairs as well as across sectors:

$$d_{12}^j = d_{21}^j = d \quad \forall j = \{a, b\}$$

$$g_{12}^j = g_{21}^j = g \quad \forall j = \{a, b\}$$

The assumption with regard to productivities, utility function, and symmetry in trade barriers and investment barriers, together with the normalization of the labor endowments, ensures that in general equilibrium wages are equal in the two countries ($w_1 = w_2 = 1$), which have been normalized to one.

1.3.2.1 Analytical Prediction 1: MP sales are disproportionately higher in comparative disadvantage sectors.

Proposition I.1. *In a two-country, two-sector world economy, the lower the technology of country 1 in sector a (country 1's comparative disadvantage sector) relative to sector b, the higher the probability that firms from country 2 will produce in sector a relative to sector b in country 1.*

Proof. See Appendix (1.10.1).

When T_1^a increases, the comparative disadvantage of country 1 in sector a is weaker, reducing the proportion of MP in sector 1 carried out by country 2 firms. When T_2^a increases, the comparative disadvantage of country 1 in sector a is more pronounced, increasing the proportion of multinational production in sector 1 carried out by country 2 firms.[27] This analytical prediction finds empirical support in the negative and significant relationship between productivity and MP shares at the sectoral level.

1.3.2.2 Analytical Prediction 2: The higher the heterogeneity of MP across sectors, the higher the gains from MP.

Analogous to trade, the gains from MP are the proportional change in country h's real wage as one moves from a counterfactual equilibrium with trade but no MP (investment barriers are prohibitively costly) to the actual equilibrium with positive MP and trade flows. Using equation (1.18) and comparing the results both with and without MP, we get an expression for the welfare gains:

$$GMP_h = \frac{W^s_{g>0}}{W^s_{g\to\infty}} = \left[\frac{\sum_{j=a,b} \left(1 + \frac{T_1^{\neq j}}{T_1^j} d^{-\theta}\right)}{\sum_{j=a,b} (1 + (dg^j)^{-\theta}) + \frac{T_1^{\neq j}}{T_1^j}(g^{j^{-\theta}} + d^{-\theta})} \right]^{-\frac{1}{2\theta}}, \tag{1.21}$$

$$GMP_h = W^h_{g>0}/W^h_{g\to\infty} = \left(y^a_{hh} y^b_{hh}\right)^{-\frac{1}{2\theta}} \left(\frac{\pi^a_{hh}\pi^b_{hh}}{\bar{\pi}^a_{hh}\bar{\pi}^b_{hh}}\right)^{-\frac{1}{2\theta}}, \tag{1.22}$$

[27] A similar argument can be constructed for the following case: when T_2^b increases, the comparative disadvantage of country 2 in sector a is weaker, reducing the proportion of MP in sector a carried out by country 2 firms in that sector.

where $\bar{\pi}^{j}_{hh}$ is the domestic demand share in the counterfactual equilibrium with no MP, and where the MP shares are given by:

$$\left(y^{a}_{hh}y^{b}_{hh}\right)^{-\frac{1}{2\theta}} = \left(\frac{T^{a}_{h}}{\widetilde{T}^{a}_{h}}\frac{T^{b}_{h}}{\widetilde{T}^{b}_{h}}\right)^{-\frac{1}{2\theta}} .$$

Proposition I.2. *The higher the heterogeneity of MP across sectors, the higher the gains from MP. When the share of domestically produced goods is the same across sectors ($y^{a}_{hh} = y^{b}_{hh}$), the gains from MP attain a minimum. Therefore, uni-sectoral trade-MP models understate the actual gains from MP as long as $y^{a}_{hh} \neq y^{b}_{hh}$.*

Proof. See Appendix (1.10.3).

Note that gains from trade depend on the heterogeneity of the effective productivity parameters—*effective or Ricardian comparative advantage*—and not on the heterogeneity of the fundamental productivity parameters—*fundamental comparative advantage*—while the gains from MP depend on the heterogeneity of fundamental productivities across sectors. The latter is reflected in differences in MP shares across sectors, as countries will have less MP as a share of total production in their fundamental comparative advantage sectors, and more MP in their fundamental disadvantage sectors. Figure 1.2 depicts the actual gains from MP in the two-sector analytical model as well as the gains from MP implied by uni-sectoral models of trade and MP (denoted by the horizontal dashed line).

In Section 1.4, actual data on manufacturing production and MP sales are used for a sample of ten sectors and thirty-five countries to assess the magnitude of the disparities between the gains from MP implied by both uni-sector and multi-sector models of trade and MP.

1.3.2.3 Analytical Prediction 3: Gains from trade are lower the more heterogeneous the technology upgrade across sectors.

Formally, gains from trade are the proportional change in real wages in country h as we move from a counterfactual equilibrium, with MP but not trade; to the actual equilibrium, with both MP and trade.

From equation (1.20), the gains from trade are expressed as:

$$W^{h}_{d>0}/W^{h}_{d\to\infty} = GT_{h} = \left(\pi^{a}_{hh}\pi^{b}_{hh}\right)^{-\frac{1}{2\theta}} . \tag{1.23}$$

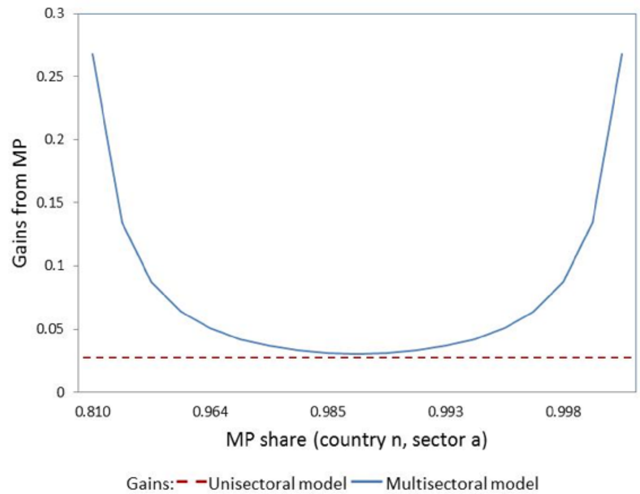


Figure 1.2: Sectoral Heterogeneity and Gains from MP

As can be observed in equation (1.23), gains from trade are a function of trade shares and the dispersion parameter θ, similar to the result obtained in a multi-sector trade-only model.[28] Nevertheless, the focus of this paper is to understand to what extent the gains from trade are affected by the reduction in effective productivity differences induced by multinational production.

Given the fact that labor is the only factor of production and wages are equal to one,[29] equation (1.13) collapses to:

$$\pi^j_{mh} = \frac{\widetilde{T^j_h}}{\widetilde{T^j_h} + d^{-\theta}\widetilde{T^j_2}} = \frac{\widetilde{T^j_h}/T^j_1}{(1 + (dg^j)^{-\theta}) + \frac{T^{\neq j}_h}{T^j_h}({g^j}^{-\theta} + d^{-\theta})}. \qquad (1.24)$$

[28]The focus of this paper is on measuring gains from trade based on primitives rather than on observables. For a complete review of the literature on this topic, see (Costas et al., 2012) and (Levchenko and Zhang, 2013)

[29]Investment barriers are now $g^a_{12} = g^b_{21}$ and $g^a_{21} = g^b_{12}$. Given the rest of the assumptions, wages are still the same across countries.

Substituting (1.24) in (1.23), the expression for gains from trade (GT) is:

$$GT = \left[\frac{\left(\widetilde{T_h^a}/T_h^a\right)\left(\widetilde{T_h^b}/T_h^b\right)}{\left((1+(dg^a)^{-\theta}) + \frac{T_h^b}{T_h^a}(g^{a-\theta} + d^{-\theta})\right)\left((1+(dg^b)^{-\theta}) + \frac{T_h^a}{T_h^b}(g^{b^{-\theta}} + d^{-\theta})\right)} \right]^{-1/2\theta}. \tag{1.25}$$

Proposition I.3. *The more heterogeneous the technology upgrade across sectors toward comparative disadvantage sectors, the lower the dispersion of effective technologies and the lower the gains from trade.*

Proof. See Appendix (1.10.2).

The result stated in Proposition 2 is illustrated in Figure 2, which shows the percentage difference between the gains from trade implied by a proportional technology transfer across sectors $\left(\widetilde{T_1^a}/T_1^a = \widetilde{T_1^b}/T_1^b\right)$ and the actual gains from trade, as a function of the dispersion in T_h^j across sectors, measured by the standard deviation between T_h^a and T_h^b. Greater relative sectoral productivity differences lead to larger disparities between the gains in the actual equilibrium and the gains in the counterfactual scenario.

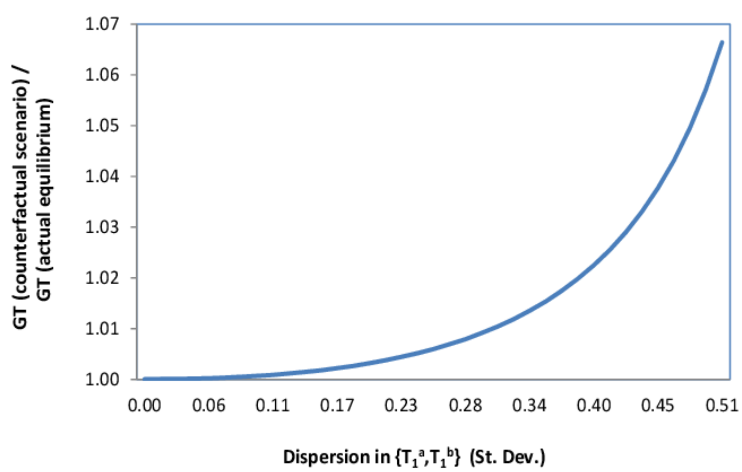


Figure 1.3: MP Technology Transfer and Gains from Trade

Ricardian comparative advantage at the industry level plays an important role in the magnitude and sectoral distribution of technology transfer that takes place when firms decide to produce overseas. Results indicate that the stronger the reduction in comparative advantage due to MP, the lower the estimated gains from trade. Also, the stronger the comparative advantage of local producers in the host country, the bigger the effect of MP on the observed differences in relative technology across sectors.

1.4 Quantitative Framework

In order to take the model to the data, in this section we quantitative estimate a multi-country multi-sector version of the model, with labor and capital as factors of production, intermediate inputs, and inter-linkages across sectors. This environment incorporates N countries and $J+1$ sectors; the first J sectors are tradables and the $J+1$ sector is a non-tradable. Both capital K_h and labor L_h are mobile across sectors and immobile across countries; and w_h and r_h represent the wage rate and the rental return of capital, respectively.

Finally, with $N > 2$, firms have the option to locate a foreign affiliate directly in the destination market to serve it locally or in a third country, used as an export platform, to ship goods to the final destination. In addition to g^j_{hs}, a firm that uses a third country h to produce and export to country m also faces the transportation cost d^j_{mh} associated with exporting from h to m. Note that in order to serve any foreign market with a variety from sector $J+1$, the only option is to locate a plant in the target market. Therefore, for all non-tradable varieties, the host economy and the destination market are necessarily the same ($h = m$).

The main equations of the model are extended below in order to incorporate multiple countries, multiple tradable sectors, a non-tradable sector, capital, intermediate inputs usage, and linkages across sectors.

Preferences: Utility of the representative consumer in country m is linear in the composite final good Y_m, and is given by:

$$Y_m = \left(\sum_{j=1}^{J} \omega_j^{\frac{1}{\eta}} \left(Y_m^j\right)^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}\xi_m} \left(Y_m^{J+1}\right)^{1-\xi_m}, \tag{1.26}$$

where ξ_m denotes the Cobb-Douglas weight for the tradable sector composite good and Y_m^{J+1} is the non-tradable sector composite good. The elasticity of substitution between the tradable sectors is denoted by η, and ω_j is the test parameter for tradable sector j. Note that the consumer's utility is CES on tradable sectors, allowing η to be different from one (in the previous section, with Cobb-Douglas preferences,

η=1). Moreover, in the quantitative exercise, ξ_m will vary across countries, to capture the positive relationship between income and the non-tradable consumption shares observed in the data.

Production: Production of variety ω in sector j, by firms from country s producing in country h in order to sell to market m, is given by:

$$Q_{mhs}^{j}(\omega) = \left[\left(L_h^j\right)^{\alpha_j}\left(K_h^j\right)^{1-\alpha_j}\right]^{\beta_j}\left[\prod_{k=1}^{J+1}\left(Q_s^k\right)^{\gamma_{kj}}\right]^{1-\beta_j}\left(\frac{z_{hs}^j(\omega)}{g_{hs}^j}\right),$$

where value-added-based labor intensity is given by α_j, while the share of value added in total output is given by β_j—both of which vary by sector. The weight of intermediate inputs from sector k used by sector$j$ is denoted by γ_{kj}. Therefore, the unit cost c_h^j is given by:

$$c_h^j = \left[\left(w_h^j\right)^{\alpha_j}\left(r_h^j\right)^{1-\alpha_j}\right]^{\beta_j}\left[\prod_{k=1}^{J+1}\left(p_h^k\right)^{\gamma_{kj}}\right]^{1-\beta_j}. \tag{1.27}$$

Technology: Any firm gets a productivity draw $z_{hs}^j(\omega)$ in each of the N possible host countries h, as described by the vector below:

$$\mathbf{z_s^j}(\omega) \equiv \left\{z_{hs}^j(\omega)\right\}_{h=1}^{N} \quad \forall s = 1, ...N,$$

where $\mathbf{z_s^j}(\omega)$ is drawn independently across goods, countries, and sectors from a multivariate Frechet distribution:

$$F_s^j(\mathbf{z}) = exp\left[-T_s^j\left(\sum_s\left(z_{hs}^j\right)^{-\theta_j}\right)\right]. \tag{1.28}$$

Productivities $z_{hs}^j(\omega)$ are assumed to be independent across host countries.

Market Structure: The probability that country m will import good ω in sector j from country h, using technologies from country s, is given by:

$$\pi_{mhs}^j = \frac{T_s^j\left(\Delta_{ms}^j\right)^{-\theta_j}}{\sum_k T_k^j\left(\Delta_{mk}^j\right)^{-\theta_j}}\cdot\frac{\left(\delta_{mhs}^j\right)^{-\theta_j}}{\sum_m\left(\delta_{mhs}^j\right)^{-\theta_j}}. \tag{1.29}$$

The actual price of any variety in sector j in country m is given by:

$$p_m^j = \Gamma_j \left(\widetilde{\Delta_m^j}\right)^{-\frac{1}{\theta_j}} = \Gamma_j \left(\sum_s T_s^j \left(\Delta_{ms}^j\right)^{-\theta_j}\right)^{-\frac{1}{\theta_j}}. \tag{1.30}$$

Closing the Model: Given the set of prices $\left\{w_h, r_h, P_h, \left\{p_h^j\right\}_{j=1}^{J+1}\right\}_{h=1}^{N}$, we first describe how production is allocated across countries and sectors. Let Q_h^j denote the total sectoral demand in country h and sector j. Q_h^j is used for both final consumption $\left(p_h^j Y_h^j\right)$ and intermediate inputs in domestic production of all sectors. How much all sectors k in country h require from sector j depends on the world demand of country h's sector j goods, $\sum_{k=1}^{J+1}(1-\beta_k)\gamma_{j,k}\left(\sum_{m=1}^{N}\sum_{h=1}^{N}\pi_{mhs}^k p_m^k Q_m^k\right)$. Therefore, the goods market clearing condition is given by:

$$p_h^j Q_h^j = p_h^j Y_h^j + \sum_{k=1}^{J+1}(1-\beta_k)\gamma_{j,k}\left(\sum_{m=1}^{N}\sum_{s=1}^{N}\pi_{mhs}^k p_m^k Q_m^k\right) \qquad \forall j = \{1, ..., J+1\},$$

where $\sum_{m=1}^{N}\sum_{s=1}^{N}\pi_{mhs}^{J+1} = 0$ whenever $m \neq h$. Also note that in this specification the requirements of every tradable sector k for inputs from sector j depend on $\pi_{mh}^k = \sum_{s=1}^{N}\pi_{mhs}^k$, which is the probability that country m will import from country h regardless of the origin of the technology used in production. Also, the requirements of the non-tradable sector $J+1$ from any other sector j depend on $\pi_{hh}^{J+1} = \sum_{s=1}^{N}\pi_{hhs}^{J+1}$, where π_{hhs}^{J+1} is the probability that country h will produce in non-tradable sectors using the technologies from country s's foreign affiliates.

The goods market clearing condition stated above takes into account that the majority of world trade is in intermediate inputs, and the fact that a good is traded several times before being consumed, as well as the existence of two-way input linkages between the tradable and non-tradable sectors.

Solving for the consumer's problem, the final demand of sector j in country h is given by:

$$Y_h^j = \xi_h \frac{w_h L_h + r_h K_h}{p_h^j} \frac{\omega_j \left(p_h^j\right)^{1-\eta}}{\sum_{k=1}^{J}\omega_k \left(p_h^k\right)^{1-\eta}} \qquad \forall j = \{1, ..., J\},$$

and

$$Y_h^{J+1} = (1-\xi_h)\frac{w_h L_h + r_h K_h}{p_h^{J+1}} \qquad j = J+1.$$

Trade: In each tradable sector j, some varieties ω are imported from abroad and some varieties ω are exported to the rest of the world. Country k's exports and imports in sector j are given by:

$$EX_k^j = \sum_{m \neq k}^{N} \sum_{s=1}^{N} \pi_{mks}^j p_m^j Q_m^j \quad IM_k^j = \sum_{h \neq k}^{N} \sum_{s=1}^{N} \pi_{khs}^j p_k^j Q_k^j,$$

and total exports and total imports are given by:

$$EX_k = \sum_{j=1}^{J} EX_k^j \qquad IM_k = \sum_{j=1}^{J} IM_k^j.$$

The trade balance condition will equalize $IM_k^j = EX_k^j$ as well as $IM_k = EX_k$.

Multinational Production: The value of MP in tradable sector j from country s in country h to serve country m is $\pi_{mhs}^j p_m^j Q_m^j$, where $p_m^j Q_m^j$ is the total expenditure on goods on tradable sector j by country m. Thus, total MP in tradable sector j by country s in country h is:

$$I_{hs}^j = \sum_m \pi_{mhs}^j p_m^j Q_m^j \quad \forall j = 1, ..., J, \tag{1.31}$$

$$I_{hs}^{J+1} = \pi_{hhs}^{J+1} p_h^{J+1} Q_h^{J+1} \quad j = J+1. \tag{1.32}$$

Total inward MP in country h from the rest of the world in sector j can be obtained by summing (1.31) and (1.32) over all source-of-technology countries s.

$$I_h^j = \sum_s I_{hs}^j \ \ \forall j = 1, ..., J+1.$$

In the same way, outward MP in tradable sector j by country s in country h is given by:

$$O_{hs}^j = \sum_m \pi_{mhs}^j p_m^j Q_m^j \quad \forall j = 1, ..., J, \tag{1.33}$$

$$O_{hs}^{J+1} = \pi_{hhs}^{J+1} p_h^{J+1} Q_h^{J+1} \quad \jmath = J+1. \tag{1.34}$$

Similarly, total outward MP from country s to the rest of the world in sector j can be obtained by summing (1.33) and (1.34) over all location-of-production countries h:

$$O_s^j = \sum_h O_{hs}^{J+1} \ \ \forall j = 1, ..., J+1.$$

Factor Allocations: The factor allocations are now calculated across sectors. The total production revenue in tradable sector j in country h is given by $\sum_{m=1}^{N}\sum_{i=1}^{N}\pi_{nsi}^{j}p_{n}^{j}Q_{n}^{j}$. The optimal sectoral factor allocations in country h and tradable sector j must thus satisfy:

$$\sum_{m=1}^{N}\sum_{s=1}^{N}\pi_{mhs}^{j}p_{m}^{j}Q_{m}^{j}=\frac{w_{h}L_{h}^{j}}{\alpha_{j}\beta_{j}}=\frac{r_{h}K_{h}^{j}}{\left(1-\alpha_{j}\right)\beta_{j}}. \tag{1.35}$$

For the non-tradable sector $J+1$, the optimal factor allocations in country m are given by:

$$\sum_{s=1}^{N}\pi_{hhs}^{J+1}p_{h}^{J+1}Q_{h}^{J+1}=\frac{w_{h}L_{h}^{J+1}}{\alpha_{J+1}\beta_{J+1}}=\frac{r_{h}K_{h}^{J+1}}{\left(1-\alpha_{J+1}\right)\beta_{J+1}}. \tag{1.36}$$

1.4.1 Estimating the Model's Parameters: $\widetilde{T}_{h}^{j}$, T_{h}^{j}, g_{hs}^{j}, and d_{mh}^{j}

In this section, we estimate the sector-level technology parameters for local producers (T_{h}^{j}) in thirty-five countries, nine tradable sectors, and one non-tradable sector, in two steps. First, the effective technology parameter ($\widetilde{T}_{h}^{j}$) is estimated by fitting the structural trade gravity equation implied by the model, using trade and production data.[30] In this step, we also estimate the bilateral trade cost at the sectoral level. Then, we proceed to estimate the corresponding MP barriers at the sectoral level by fitting the structural MP gravity equation implied by the model using foreign affiliate sales data and production data for local firms.[31] Finally, using the effective technology parameters and the MP barriers, we calculate the effective technology parameters for

[30]The gravity equations are derived from the model under the assumption that productivity draws are uncorrelated across host countries. Ramondo and Rodriguez-Clare (2011) use aggregated multinational production data to calibrate h and d assuming two alternative values for ρ, $\rho=0$ and $\rho=0.5$. The goodness of the model measured by how it matches the patterns of the data is extremely similar in both cases. The only variable where $\rho=0$ performs better is in accounting for foreign affiliate exports. As pointed out by (Ramondo and Rodríguez-Clare, 2013a) and more recently by (Tintelnot, 2012), this is a consequence of the limitations of a model of MP that excludes the fixed cost of operating an affiliate overseas. However, this simplified assumption buys us the tractability of using the gravity equation for trade and MP, which is directly comparable to previous work that has focused on the estimation of the mean productivity parameters using trade data at the sectoral level.

[31]For every country h and sector j, the production of local producers $\left(I_{hh}^{j}\right)$ is calculated by subtracting the production of foreign affiliates from total production.

every country-sector pair, solving the following system of equations:

$$\widetilde{T}_h^j = \sum_s T_s^j {g_{hs}^j}^{-\theta} \quad \forall j = 1 : J+1$$

The effective productivity estimates that emerge from the gravity equation reflect the average productivity of all producers in a given sector of the economy. Controlling for factor and intermediate input prices, as well as for trade barriers, a country that produces a larger share of its domestic demand exhibits a high effective productivity. A relatively high effective productivity could be a reflection of highly productive local producers, but it could also be a reflection of the access to superior technologies available to foreign affiliates operating in the host market. Intuitively, a country that produces a larger share of its output using domestic technologies has a higher relative fundamental productivity. Conversely, if the share of foreign affiliate production is high, the country has a relatively low state of technology in that sector. Therefore, the mean of the absolute difference between T_h^j and its effective counterpart $\tilde{T}_h^j$ in each sector is a measure of the absolute transfer of technology generated by MP, while the difference in the dispersion of effective and fundamental technology across sectors is a measure of the effect of MP on comparative advantage.

1.4.1.1 Multinational Production and Trade Gravity Equations

The capacity to relate the model to observables in the data relies on the properties derived from the seminal work of Eaton and Kortum (2002). In particular, the average spending in country m on goods produced in country h by affiliates from country s is equal over all exporters and sources of technology, implying that the share of goods country m buys from country h using country s technologies is also the share of its expenditure on these goods.

$$\pi_{mhs}^j = \frac{X_{mhs}^j}{X_m^j}. \tag{1.37}$$

By summing π_{mhs}^j across all source countries s,[32] we obtain county h's trade shares, reflecting the probability that country m will import sector j goods produced in country h, regardless of the source of the technology used in production (π_{mhs}^j):

$$\pi_{mh}^j = \sum_s \pi_{mhs}^j = \sum_s \frac{X_{mhs}^j}{X_m^j} = \frac{X_{mh}^j}{X_m^j}. \tag{1.38}$$

[32]Note that π_{mhs}^j is independent across source countries, because a given source country s would not set operations in two different host countries h in order to serve a given market m.

Substitute the derived expression for π^j_{mhs} (see equation (1.29)) in equation (1.38):

$$\frac{X^j_{mh}}{X^j_m} = \sum_s \left[\frac{T^j_s \left(g^j_{hs}\right)^{-\theta_j} \left(c^j_h d^j_{mh}\right)^{-\theta_j}}{\sum_s T^j_s \sum_k \left(g^j_{ks}\right)^{-\theta_j} \left(c^j_k d^j_{mk}\right)^{-\theta_j}} \right]$$

$$\frac{X^j_{mh}}{X^j_m} = \frac{\widetilde{T^j_h} \left(c^j_h d^j_{mh}\right)^{-\theta_j}}{\sum_k \widetilde{T^j_k} \left(c^j_k d^j_{mk}\right)^{-\theta}}, \tag{1.39}$$

where $\widetilde{T^j_h} = \sum_s T^j_s \left(g^j_{hs}\right)^{-\theta_j}$. This implies that the effective technology ($\widetilde{T^j_h}$) employed by a country to produce and compete in the international market is a combination of the average productivity of the local producers in sector j and the average productivity of the foreign affiliates operating in the domestic market. But the local economy has a limited capacity to absorb foreign technologies, reflected by the cost of producing in a foreign market (g^j_{hs}).

To get the specification that will be taken to the data, equation (1.39) is divided by country m's normalized import share:

$$\frac{X^j_{mh}/X^j_m}{X^j_{mm}/X^j_m} = \frac{\widetilde{T^j_h} \left(c^j_h d^j_{mh}\right)^{-\theta}}{\widetilde{T^j_m} \left(c^j_m\right)^{-\theta}}. \tag{1.40}$$

Taking logs to both sides of the equation, we get the trade gravity equation:

$$\ln\left(\frac{X^j_{mh}}{X^j_{mm}}\right) = \ln\left(\widetilde{T^j_h} \left(c^j_h\right)^{-\theta}\right) - \ln\left(\widetilde{T^j_m} \left(c^j_m\right)^{-\theta}\right) - \theta \ln\left(d^j_{mh}\right). \tag{1.41}$$

Next, we derive a gravity equation for bilateral MP to identify MP barriers (g^j_{hs}) and the state of technology of local producers (T^j_h) for every country h and sector j in the sample.

The volume of foreign affiliate sales from source country s in host country h depends on two things: (1) the size of the markets foreign affiliates can access from the host country, including the host market itself; and (2) the probability that foreign affiliates from country s, by locating in market h, offer the lowest possible price to consumers in market m (π_{mhs}). Therefore, the sales of foreign affiliates from country s located in country h in sector j are given by:

$$I^j_{hs} = \sum_m \pi_{mhs} X^j_m$$

$$I_{hs}^{j} = \frac{T_s^j \left(g_{hs}^j c_h^j\right)^{-\theta}}{\sum_s \sum_k T_s^j \left(g_{ks}^j\right)^{-\theta} \left(c_k^j d_{hk}^j\right)^{-\theta}} \sum_m \frac{d_{mh}^j{}^{-\theta} \times \left(p_h^j\right)^{-\theta}}{\left(p_m^j\right)^{-\theta}} \cdot X_m^j,$$

$$I_{hs}^{j} = \frac{T_s^j \left(g_{hs}^j c_h^j\right)^{-\theta}}{\left(p_h^j\right)^{-\theta}} \Xi_h^j \tag{1.42}$$

where $\Xi_h^j = \sum_m \left(\frac{d_{mh}^j p_h^j}{p_m^j}\right)^{-\theta} X_m^j = \frac{X_h^{j\,2}}{X_{hh}^j}$,

$$\frac{I_{hs}^j}{\Xi_h^j} = \frac{I_{hs}^j}{X_h^j} \frac{X_{hh}^j}{X_h^j} = \frac{T_s^j \left(g_{hs}^j c_h^j\right)^{-\theta}}{\left(p_h^j\right)^{-\theta}}. \tag{1.43}$$

In this equation, the term I_{hs}^j / X_h^j represents the output share of country s's foreign affiliates in the total output of country h in sector j; while X_{hh}^j / X_h^j corresponds to the share of spending in country h on goods produced in country h, regardless of the source of the technology used in production.

Dividing I_{hs}^j / Ξ_h^j by its counterpart in the host country (I_{hh}^j / Ξ_h^j), we get:

$$\frac{I_{hs}^j / \Xi_h^j}{I_{hh}^j / \Xi_h^j} = \frac{T_s^j \left(g_{hs}^j\right)^{-\theta}}{T_h^j}. \tag{1.44}$$

This expression is analogous to the one for bilateral trade flows presented in equation (1.40). The only difference is that the unit cost of country h's input bundle cancels out of the gravity equation. Using technology from country s to produce in country h entails hiring factors of production and buying intermediate input in the host country h. Taking logs at both sides of equation (1.44), we get our preferred normalization for estimation:

$$\ln \left(\frac{I_{hs}^j}{I_{hh}^j}\right) = \ln \left(T_s^j\right) - \ln \left(T_h^j\right) - \theta \ln \left(g_{hs}^j\right). \tag{1.45}$$

Equation (1.45) implies that countries with a higher state of technology in sector j should have larger market shares, both abroad and domestically. Therefore, a relatively larger share of their domestic production should be in the hands of local producers and they should also have a greater presence in foreign markets in sector j relative to other countries. Conversely, less productive countries should have higher shares of production in the hands of foreign producers and smaller market shares abroad.

Bilateral Barriers to Multinational Production and Trade: g^j_{hs} and d^j_{mh}

To estimate MP and trade bilateral cost at a sectoral level, we assume a relationship between d^j_{mh} and g^j_{hs}, and observable data. In particular, the log of iceberg trade cost $\ln(d^j_{mh})$ and the log of iceberg MP cost $\ln(g^j_{hs})$ are modeled as a linear function of distance, and whether countries share a common border, common language, regional trade agreements, and common currency:

$$\ln\left(d^j_{mh}\right) = d^j_k + b^j_{mh} + lan^j_{mh} + CU^j_{mh} + RTA^j_{mh} + ex^j_h + \nu^j_{mh}, \qquad (1.46)$$

$$\ln\left(g^j_{hs}\right) = d^j_k + b^j_{hs} + lan^j_{hs} + CU^j_{hs} + RTA^j_{hs} + source^j_s + \mu^j_{hs}, \qquad (1.47)$$

where d_k represents an indicator variable of the distance between countries m and h lying in the kth distance interval. Intervals are measured in miles: $[0, 350]$, $[350, 750]$, $[750, 1500]$, $[1500, 3000]$, $[3000, 6000]$ and $[6000, max]$. The variable b^j indicates whether two countries share a common border; lan^j, whether they have a common language; CU^j, whether they belong to a currency union; and RTA^j, whether they are part of a regional trade agreement. Finally, ν^j_{mh} and μ^j_{hs} denote the error terms of the trade and MP gravity equations, respectively. They reflect the trade and MP cost coming from all other factors and are assumed to be orthogonal to the regressors for estimation proposes. These features of trade cost are similar to those of (Eaton and Kortum, 2002a), and are extended to the specification of MP cost. Additionally, based on empirical evidence showing that the elasticity of trade volumes to trade barriers varies significantly across sectors (Do and Levchenko, 2007), we allow each of these bilateral variables to have a different effect on trade (d^j_{mh}) and MP cost (g^j_{hs}) across sectors.

The asymmetric specification of the trade barriers in equation (1.46) follows Waugh (2010), who includes an exporter effect $\left(ex^j_h\right)$. This represents the extra cost to country h of exporting a good to country m in sector j. In order to account for bilateral trade volumes and relative price data, Waugh argues that trade cost must be systematically asymmetric, with less developed countries facing a higher cost of exporting relative to more developed countries.[33]

Following a similar argument, our specification for MP barriers includes a source effect $(source^j_s)$, which represents the extra cost to country s of producing a good in

[33] In the data, tradable prices are unresponsive to a country's income level. Including an importer effect in the trade cost specification will predict that less developed countries face higher prices relative to more developed countries, a prediction that is inconsistent with the data. Therefore, the assumption that less developed countries face higher costs of importing, compared with more developed countries, is not appealing.

country h in sector j. More specifically, less developed countries face systematically higher cost to produce overseas.[34] The inclusion of a source effect produces estimates that are consistent with the observed patterns of prices and income data. Three empirical observations are highlighted. First, the majority of the output is produced by local producers—home bias—and it is positively correlated with the country's income level. Second, there is a systematic correlation between bilateral MP shares and relative level of development: the larger the difference in relative income, the larger the disparity in bilateral MP share between two countries. Finally, tradable and non-tradable prices are positively correlated with income per worker. Section **??** in the Appendix presents evidence to support the chosen specification in equation (1.47).

1.4.1.2 Estimated State of Technology: T_h^j and $\widetilde{T}_h^j$

In order to recover the effective technology parameters $\widetilde{T}_h^j$ and trade cost d_{mh}^j implied by the pattern of trade at the sectoral level, we estimate trade gravity equation (1.41), from which $-ln\left(\widetilde{T}_m^j (c_m^j)^{-\theta}\right)$ is recovered as an imported fixed effect.

$$\ln\left(\frac{X_{mh}^j}{X_{mm}^j}\right) = \underbrace{\ln\left(\widetilde{T_h^j}\left(c_h^j\right)^{-\theta}\right)}_{\text{exporter fixed effect}} \underbrace{-\ln\left(\widetilde{T_m^j}\left(c_m^j\right)^{-\theta}\right)}_{\text{importer fixed effect}}$$
$$\underbrace{-\theta d_k^j - \theta b_{mh}^j - \theta lan_{mh}^j - \theta CU_{mh}^j - \theta RTA_{mh}^j - \theta ex_h^j}_{\text{bilateral observables}} \underbrace{-\theta \nu_{mh}^j}_{\text{error term}}. \tag{1.48}$$

Isolating $\widetilde{T}_m^j$ from the estimated importer fixed effect entails a two-step procedure, as proposed by (Shikher, 2012).[35] First, we compute the cost of an input bundle in host country h and sector j (c_h^j), which is a function of wages w_h, return of capital r_h, and intermediate input prices p_h^j (see equation (1.27)). There are data available for w_h and r_h, but intermediate input prices at the sectoral level are not observable. Therefore, tradable prices in each sector-country pair $\left(p_h^j\right)$, are obtained using both the estimated importer fixed effect and data on share of expenditure on domestic goods $\left(X_{hh}^j/X_h^j\right)$. Finally, c_h^j is constructed to disentangle $\widetilde{T}_m^j$ from the importer fixed

[34]There appears to be no precedent in the estimation of asymmetric barriers for MP at either the aggregate or the sectoral level. Previous efforts assume an aggregate and symmetric specification, where the cost that country s faces to produce in country h is equal to the cost country h faces to produce in country s. See (e.g., Ramondo and Rodríguez-Clare, 2013a; Arkolakis et al., 2013; **?**)

[35]See section 1.12.1 in the Appendix for details.

effect. The bilateral trade cost d^j_{mh} is computed based on the estimated coefficients:

$$\widehat{d}^j_{mh} = \exp\{\widehat{d}^j_k + \widehat{b}^j_{mh} + \widehat{lan}^j_{mh} + \widehat{CU}^j_{mh} + \widehat{RTA}^j_{mh} + \widehat{ex}^j_h + \widehat{\mu}^j_{mh}\}.$$

To estimate the bilateral sector-level MP cost $\left(g^j_{sh}\right)$, we fitted the following gravity equation:

$$\ln\left(\frac{I^j_{hs}}{I^j_{hh}}\right) = \underbrace{\ln\left(T^j_s\right)}_{\text{source fixed effect}} - \underbrace{\ln\left(T^j_h\right)}_{\text{host fixed effect}} \tag{1.49}$$

$$\underbrace{-\theta d^j_k - \theta b^j_{hs} - \theta lan^j_{hs} - \theta CU^j_{hs} - \theta RTA^j_{hs} - \theta source^j_s}_{\text{bilateral observables}} \underbrace{-\theta\mu^j_{hs}}_{\text{error term}},$$

where g^j_{hs} is computed based on the estimated coefficients:

$$\widehat{g}^j_{hs} = \exp\{\widehat{d}^j_k + \widehat{b}^j_{hs} + \widehat{lan}^j_{hs} + \widehat{CU}^j_{hs} + \widehat{RTA}^j_{hs} + \widehat{source}^j_s + \widehat{\mu}^j_{hs}\}.$$

Note that the exporter $\widehat{ex}^j_h$ and the source $\widehat{source}^j_s$, components of the trade and MP cost, respectively, are calculated using the exporter (source) and importer (host) fixed effect estimated from the corresponding trade (MP) gravity equations. In particular:

$$\widehat{ex}^j_h = -1/\theta\,[\text{importer fixed effect+exporter fixed effect}]\,,$$

$$\widehat{source}^j_s = -1/\theta\,[\text{source fixed effect+host fixed effect}]\,.$$

Finally, using $\widehat{g}^j_{hs}$ and $\widetilde{T}^j_s$ for every country pair and sector j, we solve for the system of equations (1.50) in order to recover the technology parameters of local producers (T^j_s):

$$\widetilde{T}^j_h = \sum_i (g^j_{hs})^{-\theta} T^j_s \quad \forall h, s = 1, ...J+1, \tag{1.50}$$

$$\begin{bmatrix} \widetilde{T}^j_1 \\ \widetilde{T}^j_2 \\ .. \\ .. \\ \widetilde{T}^j_N \end{bmatrix} = \begin{bmatrix} g^j_{11} & g^j_{12} & .. & .. & g^j_{1N} \\ g^j_{21} & g^j_{22} & .. & .. & g^j_{2N} \\ .. & .. & .. & .. & .. \\ .. & .. & .. & .. & .. \\ g^j_{N1} & g^j_{N2} & .. & .. & g^j_{NN} \end{bmatrix} \times \begin{bmatrix} T^j_1 \\ T^j_2 \\ .. \\ .. \\ T^j_N \end{bmatrix}.$$

The estimates derived from this procedure constitute the baseline for the analysis that follows. Note that the estimates of trade costs include the residual from the trade gravity regression ($\widehat{\mu}^{j}_{mh}$). This, together with the estimated fixed effects, ensures that the model exactly fits the observed bilateral trade for every sector. This is not the case for MP sales, however. Although the residual from the MP gravity equation is also included in the MP cost calculation, in our baseline estimation we solve for the fundamental technology parameters $\left(T^{j}_{h}\right)$ using the system of equations in (1.50) rather than relying on the source and location fixed effects estimated in the MP gravity equation (1.49).

To ensure robustness, we estimate the productivity of local producers (T^{j}_{h}) with the MP gravity equation, by exponentiating the host fixed effect. Then, the effective technology parameters ($\widetilde{T}^{j}_{h}$) are computed, solving for each equation in (1.50) independently for each country. In this case, we match bilateral MP exactly—given the estimated MP cost and the fixed effect from the MP gravity—but we do not match bilateral trade flows. The estimated technology parameters under both methods are highly correlated (0.78) and in fact the second approach yields a more pronounced difference in the pattern of comparative advantage between local and foreign producers. We choose to estimate the overall productivity from the trade gravity equation in order to obtain estimates consistent with the ones obtained in trade-only models where there is no separation between the overall and local productivity.

Note that the stochastic approach developed by Eaton and Kortum (2002) implies that every country should buy a non-zero amount of goods from every country-sector pair, and also should host operations for all source countries in each sector. In fact, the MP bilateral matrix in each sector has many recorded zeros, even at a high level of aggregation. This has consequences in the estimation of the gravity equations above as well as in the computation of the equilibrium. The gravity equations are estimated using Pseudo Poisson Maximum Likelihood (PPML), suggested by Santos Silva and Tenreyro (2006), to alleviate any bias from log-linearizing (equations 1.45 and 1.41) in the presence of heteroskedasticity and the omission of zero trade flows. Results are not much different when compared with the ones obtained by ordinary least squares (OLS), although as expected the OLS overestimates the elasticity of trade and MP flows to distance and other resistance variables. Regarding the computation, when computing the equilibrium, we set trade and MP cost to be arbitrarily large for the instances in which X^{j}_{mh} and I^{j}_{hs} are zero.

1.5 Multinational Production and Comparative Advantage

This section describes the basic patterns in how estimated sector-level technology varies across local and foreign producers for all of the countries in the sample. In particular, we measure the effect of MP activity on the strength of comparative advantage. Using bilateral multinational gross output and international trade data at the sectoral level, two measures of production technology are estimated. The first corresponds to the technology of *local* producers (i.e., excluding foreign affiliates) (T_s^j), while the second corresponds to the state of technology of *all* producers in the economy ($\widetilde{T}_s^j$). Two sets of results are presented for the countries' relative technology: with respect to the United States and with respect to the global frontier. The global frontier in each sector is calculated by taking the geometric mean of the two highest values of $\widetilde{T}_s^j$.

The baseline analysis uses the dispersion of productivities within each sector ($\theta = 4.2$), which is the preferred value of Simonovska and Waugh (2010). As a robustness check, results are presented for two alternative values for the dispersion parameter: (1) the preferred estimation of Eaton and Kortum (2002), θ=8.28; and (2) a sectoral θ_j estimated by Caliendo and Parro (2012).[36]

1.5.1 Local and Overall Productivity Patterns

Table 1.1 presents descriptive statistics of relative technologies both for local producers and for all producers. The first column reports the percentage change in the mean absolute distance to the frontier across all tradable sectors between local producers' productivity $(T_n^j)^{\frac{1}{\theta}}$ and all producers' productivity $(\widetilde{T}_n^j)^{\frac{1}{\theta}}$, a measure of the change in absolute advantage due to MP $\left[\left(\widetilde{T}_n^j/T_n^j\right)^{\frac{1}{\theta}} - 1\right]$. The second column reports the percentage change in the coefficient of variation across tradable sectors between local producers' productivity $(T_n^j)^{\frac{1}{\theta}}$ and all producers' productivity $(\widetilde{T}_n^j)^{\frac{1}{\theta}}$. The latter can be interpreted as a measure of the change in comparative advantage implied by foreigner affiliate activity. In particular, the coefficient of variation across sectors is computed for $(\widetilde{T}_n^j)^{\frac{1}{\theta}}$ and $(T_n^j)^{\frac{1}{\theta}}$ and the percentage change between them $\left[\frac{CV(\widetilde{T}_n^j)^{\frac{1}{\theta}}}{CV(T_n^j)^{\frac{1}{\theta}}} - 1\right]$ is recorded. Larger negative changes imply greater reduction in productivity dispersion across sectors and thus greater reduction in comparative advantage attributable

[36]See Table 1.18 in Tables and Figures for the values of θ_j by sector under this specification.

to the effect of MP. Conversely, positive values imply that a country's comparative advantage has become stronger—productivity dispersion increases—as a consequence of MP.

Table 1.1: Change in Absolute and Comparative Advantage

	Variable	Mean
Group 1 (10 countries)	ΔCV	-0.19
	ΔT	0.09
Group 2 (25 countries)	ΔCV	-0.29
	ΔT	0.17
All sample (35 countries)	ΔCV	-0.25
	ΔT	0.14

For different values of θ the results are remarkably similar. The correlation between the T_i^j's estimated under $\theta = 8.28$ and the ones estimated under the baseline ($\theta = 4.2$) is above 0.90. Also, the average change in comparative advantage due to MP is similar for both values of θ, -0.24 and -0.25, respectively. Moreover, there is a strong positive correlation in the change in absolute advantage (0.50) and comparative advantage (0.48) under alternative values of θ.

The left panel in Table 1.2 ranks countries based on the average technology upgrade allowed by MP. In particular, Czech Republic, Poland, Lithuania, Hungary, and Austria are the countries where absolute advantage has been affected most by the activity of foreign affiliates in their local markets, while Israel, Greece, Belgium, Australia, and New Zealand have seen the smallest increase in their mean productivity. In the right panel in Table 1.2, countries are ranked according to the change in productivity dispersion between $(T_h^j)^{\frac{1}{\theta}}$ and $(\widetilde{T}_h^j)^{\frac{1}{\theta}}$. As can be seen, Austria, Poland, Czech Republic, Portugal, and Spain stand as the countries with the largest reduction in comparative advantage, while Bulgaria, France, Germany, and Latvia show the largest increase in relative difference in productivity across sectors. Finally, Norway, Greece, and the United Kingdom register the lowest reduction in relative technology difference across sectors.

Ranked by technology level, the top panel of Table 1.14 in the Tables and Figures shows the change in average and relative productivity for the ten most advanced countries, and the bottom panel groups the rest of the countries in the sample. For the

Table 1.2: Average and Relative Change in Productivity due to MP

Average Change		Relative Change	
Top 10: Largest Change Countries		Top 10: Largest Change Countries	
Czech Rep.	0.41	Poland	-0.53
Poland	0.35	Czech Rep	-0.52
Lithuania	0.30	Spain	-0.52
Hungary	0.29	Portugal	-0.52
Austria	0.24	Canada	-0.51
Netherlands	0.22	Austria	-0.48
Slovakia	0.22	Italy	-0.47
Portugal	0.22	Turkey	-0.43
Sweden	0.20	Russia	-0.42
Canada	0.17	Sweden	-0.41
Turkey	0.14	Slovenia	-0.39
Bottom 10: Smallest Change Countries		Bottom 10: Smallest Change Countries	
Finland	0.09	Japan	-0.14
France	0.07	Belgium	-0.08
Switzerland	0.06	Denmark	-0.07
Denmark	0.04	Greece	-0.06
Norway	0.04	United Kingdom	-0.06
New Zealand	0.04	Norway	-0.04
Australia	0.03	Latvia	0.05
Belgium	0.02	Germany	0.08
Greece	0.01	France	0.14
Israel	0.01	Bulgaria	0.14

Notes: This table reports the ten largest (top panel) and ten smallest (bottom panel) countries affected by MP, measured by the percentage change in the mean absolute distance to the United States in $T_{all}^{\frac{1}{\theta}} - T_{mp}^{\frac{1}{\theta}}$ across all tradable sectors.

set of countries with the highest effective technology, the mean productivity increases by 19 percent, while the differences in productivity across sectors are reduced by 9 percent due to multinational activity. The less advanced countries experience an even higher increase in mean productivity (17 percent) as well as a larger reduction in the heterogeneity of productivity across sectors (29 percent).[37] The difference in means across both groups is statistically significant, showing that, even when both groups are clearly affected by MP, the impact on absolute and comparative advantage is relatively larger in less advanced countries.[38]

1.5.2 The Effect of MP on Comparative Advantage

The results presented in the previous section suggest that MP is unevenly affecting the average sectoral technology. In particular, the technology boost generated by multinational firms operating in the host market is disproportionately larger in comparative disadvantage sectors. As mentioned in Section 1.1, this is in part a consequence of a larger foreign affiliate output share in low-productivity sectors.

Table 1.11 in Tables and Figures shows the correlation between the estimated average productivity of local producers (T_i^j) and the sectoral MP in country h. For most countries in the sample, the correlation is negative and statistically significant at the 10 percent level.[39] When all of the countries and sectors are pooled, after controlling for country- and sector-specific characteristics, the overall correlation is negative and significant at the one percent level (-0.304). Figure 1.4 shows the result of this conditional correlation along with a fitted regression line.[40]

To shed further light on whether sectors in which local producers show greater disadvantage are the ones that receive the biggest boost from MP, making the comparative advantage of the entire economy look weaker, consider the following regression:

[37]If instead of the entire sample, we compare the top ten and the bottom ten countries, the already highlighted differences become even more pronounced for the change in absolute advantage (0.22 for the bottom ten countries), while the change in the coefficient of variation stays virtually the same.

[38]These results are in line with the findings of Levchenko and Zhang (2011). Exploiting the temporal dimension, they found that over time countries increased their level of technology and also experienced a reduction in the dispersion of relative productivity across sectors.

[39]Similar results are obtained if instead MP is normalized by absorption, calculated as output minus exports.

[40]This correlation is similar to the one in Figure 1.1 presented in Section 1.1, but it replaces the calculated total factor productivity (TFP) with the state of technology estimated relying on the structure of the model

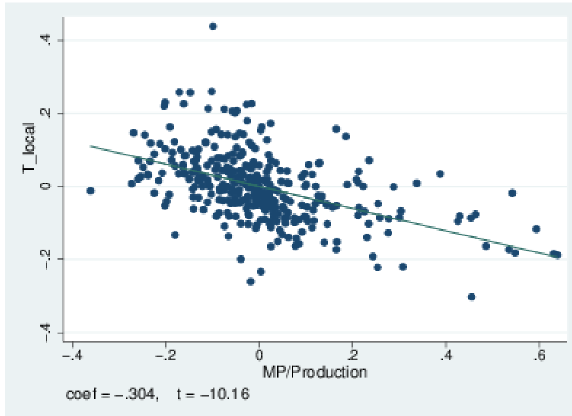


Figure 1.4: Multinational Production and Technology

$$log \left(\frac{\widetilde{T}_h^j}{T_h^j} \right)^{1/\theta_j} = \beta \cdot log \left(T_h^j \right)^{1/\theta_j} + \gamma_h + \gamma_j + \nu_{hj} \tag{1.51}$$

On the left-hand side of the equation is the technological upgrade in country h in sector j, $\left(\widetilde{T}_h^j / T_h^j \right)^{1/\theta_j}$, generated by multinational activity. On the right-hand side, the regressor of interest is the mean technology of local producers (T_h^j). The specification includes country and sector fixed effects.[41] The country effect captures the average change in productivity due to MP across all sectors in each country—the absolute advantage effect. The β coefficient picks up the impact of local producers' productivity on the relative difference between overall productivity and local producers' productivity. In particular, a negative β implies that relative to the country-specific average, the least productive sectors get the largest boost in technology from MP; see Table 1.3 and Figure 1.5 below. The results are robust to alternative estimations of average productivity and values of θ are illustrated in the Appendix A.

The results presented in this section stand as evidence of the role of MP in changing the pattern of comparative advantage in a country by affecting disproportionately more those sectors in which local producers exhibit relative disadvantage. In this context, sectoral trade models that ignore MP greatly understate the relative technology differences across sectors among local producers.

To capture the reduction in comparative advantage generated by multinational activity, we compute the change in average trade shares (X_{nn}^j / X_n^j) when the coefficient of variation of local producers' technology is one percent larger than the coefficient

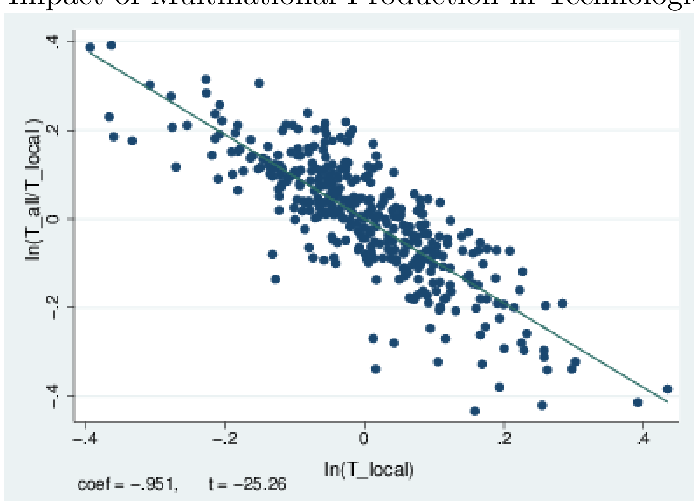
[41] All of the standard errors are clustered by country, to account for unspecified heteroskedasticity at the country level. All the results are robust, however, to clustering at the sectoral level.

Table 1.3: Pooled Regression Results

Dep.Variable: $ln\left(\widetilde{T}_h^j\right)^{1/\theta} - ln\left(T_h^j\right)^{1/\theta}$	
$ln\left(T_h^j\right)^{1/\theta}$	-0.951***
	(0.038)
Observations	315
R^2	0.850
Sector FE	yes
Coutry FE	yes

Notes: Standard errors clustered at the country level in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. This table reports the results of regressing the technology upgrade due to MP in host country h in sector j $\left(\widetilde{T}_h^j/T_h^j\right)^{1/\theta_j}$ on the productivity of local producers, $\left(T_h^j\right)^{1/\theta_j}$.

Figure 1.5: Impact of Multinational Production in Technological Change



Notes: This figure shows the conditional correlation of the technology upgrade due to MP in host country h in sector j $\left(\widetilde{T}_h^j/T_h^j\right)^{1/\theta_j}$ (vertical axis) and the productivity of local producers, $\left(T_h^j\right)^{1/\theta_j}$ (horizontal axis) after controlling for sector and country fixed effects.

of variation of all producers in the economy, while keeping constant the average productivity—or absolute advantage. In the next section, a counterfactual scenario is constructed to illustrate the trade implications of the actual reduction in comparative advantage due to MP.

The basic patterns of the data are illustrated with some examples for individual countries. Figure (1.18) present scatterplots of tradable sector productivity both for local producers and for the overall economy. On the x-axis, sectors are placed in order of their distance from the global productivity frontier, such that the local producers' comparative advantage sectors are furthest to the left. The two countries in the top panel, Canada and Portugal, show a pronounced weakening of comparative advantage according to our estimates. Japan does not exhibit much weakening of comparative advantage: while there is an average productivity increase, there is no systematic relationship in terms of distance to frontier between local producers and all producers in the economy.

1.6 Welfare Analysis

This section computes the welfare impact of MP taking into account the affects of multinational production on comparative advantage. After solving the model using the preferred estimates of parameters for technology, MP barriers, and trade barriers (following the algorithm set forth in Section 1.11 in the Appendix), we now proceed to evaluate the fit of the model as well as its implications for welfare.

1.6.1 Model Fit

The goodness of the model can be evaluated by how closely it matches the patterns of trade and MP data along several dimensions. Table 1.16 in Tables and Figures reports statistics from the data and the calibrated model. It reports the mean, the median, and the correlation between the model and the data for wages, return of capital, and manufactured imports as a share of GDP, as well as inward and outward MP as a share of total output. Figures 1.19, 1.20, 1.21, and 1.22 present the comparison between the model and the data for each of this variables.

First, the ability of the model to replicate the income differences across countries is tested by comparing the wages and return of capital in every country h relative to the United States. This is a non-trivial test for the model, for two reasons: (1) because trade and MP interact in every tradable sector, and (2) because the model includes a non-tradable sector, where multinationals have a significant presence. The median relative wages of the model (0.79) are very close to those reported in the data (0.71), although they are slightly higher in the model. The association between relative wages in the model and wages observed in the data is very high (0.92).

Second, even though the fundamental technology parameters and the MP barriers were not estimated to match the bilateral MP shares, the statistics presented for the model and the data are similar. Even when the model overestimates the share of total output produced by foreign affiliates, it is not by much—the median of the aggregate MP-to-output ratio is 0.30 in the model and 0.26 in the data, while the correlation equals 0.76. This is somewhat similar to the outcomes observed by comparing the production of a country's affiliates overseas with total production within the country's frontiers. Note that in the data the mean of the outward-MP-to-output ratio (0.21) is considerably higher than the median (0.09), which tells us that the distribution of outward MP to output is skewed to the left. The model replicates this pattern, as shown by a high correlation with the data (0.8).

Finally, we assess how well the model captures the trade patterns observed in the data. Looking at the ratio of total imports to GDP, we can see that the mean of the model and the mean of the data are very close and they have a high degree of correlation.

Next we use the model to construct a number of counterfactuals that allow us to understand the mechanism underlying the relationship between MP and comparative advantage.

1.6.2 Counterfactual 1: Gains from MP in a Multisectoral Model

As mentioned previously, gains from MP are defined by the proportional change in country h's real income per capita as we move from a counterfactual equilibrium with trade but no MP to the actual equilibrium. In a competitive model, total income equals the total returns to factors of production. Therefore welfare—or real income per-capita—is expressed by:

$$\frac{w_h + r_h k_h}{P_h}$$

The gains form MP are computed then by solving the baseline model, calculating the welfare, and comparing this welfare to a counterfactual scenario in which all countries are assumed to be open to trade but close to foreign producers. In order to assess the effect of heterogeneity in MP shares across sectors, Table 4 compares the gains from MP in a multi-sectoral model with the gains from MP in a uni-sectoral model. The latter by definition assumes that MP shares are the same across all sectors of the economy.

As can be observed in the table, the mean gains from MP are 15 percentage points higher in a multi-sector framework compared with a uni-sector framework. The real income increase following an opening to multinational activity is 27 percent compared to the 12 percent obtained in an scenario where MP shares are homogeneous across sectors. Either measured by the median or by the mean, the heterogeneity of foreign affiliate sales across sectors almost double the gains in welfare associated to MP activity. This exercise shows that uni-sector models significantly understate the gains from multinational activity. Similar to the effect in gains from trade due to sectoral heterogeneity (Levchenko and Zhang, 2013), deviations from equal MP shares across sectors due to comparative advantage, significantly increases the gains from MP.

Table 1.4: Gains from MP in a Multi-sectoral Model

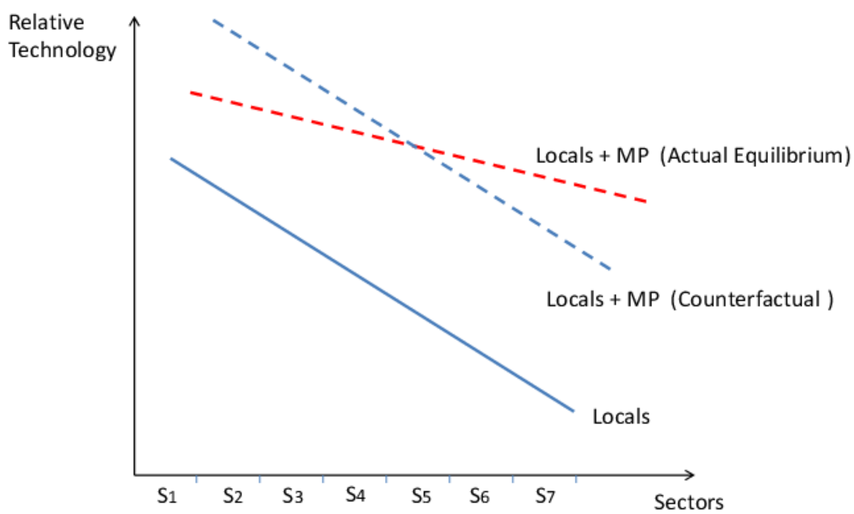
	Mean	Median	Std.Dev	Min	Max
	MP Gains (Multisector) (%)				
Counterfactual Vs Baseline	27.01	15.59	0.29	9.58	93.48
	MP Gains (Uni-sector) (%)				
Counterfactual Vs Baseline	12.03	8.42	0.17	0.02	79.35

1.6.3 Counterfactual 2: Proportional Technology Transfer

In order to assess the effect of MP on comparative advantage, this section presents a counterfactual scenario where MP changes only the average productivity of the economy, while keeping constant the country's comparative advantage. To achieve this outcome, we calculate the geometric average across sectors of the productivity of local producers $\left(T_h^j\right)$ and all producers in the economy $\left(\widetilde{T}_h^j\right)$. The ratio of the two tells us the average productivity increase due to multinational activity. The counterfactual effective productivity is calculated by increasing T_h^j by the increase factor $\frac{\left(\prod_{j=1}^{J} \widetilde{T}_h^j\right)^{1/J}}{\left(\prod_{j=1}^{J} T_h^j\right)^{1/J}}$ in every tradable sector j. Figure (1.6) illustrates this exercise.

$$\left(\widetilde{T}_h^j\right)_{\text{count}} = T_h^j \times \frac{\left(\prod_{j=1}^{J} \widetilde{T}_h^j\right)^{1/J}}{\left(\prod_{j=1}^{J} T_h^j\right)^{1/J}} \ \forall j = 1..J$$

Figure 1.6: Counterfactual 2: Proportional Technology Transfer



Notes: This figure displays the tradable-sector productivities, expressed as the ratio to the global frontier productivity for the overall economy (dash lines) and for local producers exclusively (solid blue line). The x-axis labels sectors in descending order of the ratio to the frontier of local producers productivity (so that the sectors where local producers are relative more productive are on the left). The dash red line represents the productivity for the overall economy in the actual equilibrium. The dash blue line represents the overall economy productivity in the counterfactual scenario in which MP affects all sectors proportionally. The average productivity is the same in the actual equilibrium and in the counterfactual scenario (blue dash line and red dash line)

Table 1.5 compares the gains from trade in the actual equilibrium with the counterfactual scenario. The magnitudes are substantial. The mean gains from trade in the counterfactual scenario are almost double the actual gains from trade, going from 10.39 percent to 19.05 percent for the average country in our sample, with a minimum

Table 1.5: Proportional Technology Transfer

	Mean	Median	Std Dev	Min	Max
	Gains from Trade (%)				
Actual Gains	10.39	9.28	0.05	1.19	24.53
Counterfactual	19.05	17.42	0.08	9.18	33.81
	Welfare Change (%)				
Baseline Vs Counterfactual	-3.55	-5.36	0.04	-13.34	1.13
	Trade Openness (%)				
Baseline Vs Counterfactual	13.32	10.21			

gain of 9.18 percent and a maximum of 33.8 percent. Next, comparing the change in real wage between the baseline and the counterfactual scenario, we find that the sole effect of MP on comparative advantage is expressed in a reduction in real wage of 3.55 percent. Trade openness, measured by the ratio of a country's trade (exports plus imports) to its GDP, is almost 13.3 percent higher in the counterfactual, where MP does not affect the country's comparative advantage.

If instead we impose a proportional increase in the productivity of local producers in all sectors such that it matches the observed aggregate trade shares, rather than the observed aggregate productivity, we get similar results.

1.6.4 Counterfactual 3: Multinational Production and Non-Tradables

Multinational production is the only option available for producers in the non-tradable sector to serve a foreign market. Therefore, it is not surprising that about 60 percent of MP activity is in non-tradables. Moreover, non-tradables account for a significant portion of the intermediate inputs used in the majority of tradable sectors. Thus, access to cheaper non-tradable goods due to MP activity can increase the competitiveness of tradable sectors, thereby improving the welfare of the economy.

Table 5 shows the change in welfare going from a counterfactual scenario, where the barriers to investment in the non-tradable sector are arbitrarily large, to the actual equilibrium. The results in the table show that real wages increase by 4.7 percent,

Table 1.6: Multinational Production and Non-Tradables

	Mean	Median	Std.Dev	Min	Max
	Welfare Change (%)				
Counterfactual Vs Baseline	6.53	4.69	0.05	1.54	12.33
	Tradable Price Index (%)				
Counterfactual Vs Baseline	1.62	1.87	0.04	0.63	2.13

while the reduction in the tradable price index is 1.9 percent.

1.7 Conclusion

This paper shows that by omitting the sectoral heterogeneity of MP sales and therefore its impact on comparative advantage, existing models of trade and MP in uni-sectoral frameworks systematically overstate the gains from trade and understate the gains from MP. A unique industry-level dataset of bilateral foreign affiliate sales for thirty-five countries documents a new empirical regularity: multinational production is disproportionately allocated to industries where local producers exhibit comparative disadvantage.

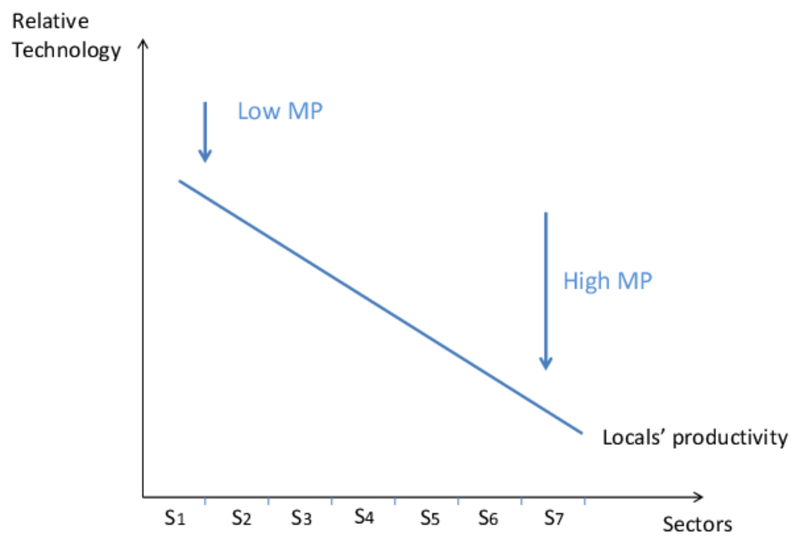
To quantify this phenomenon, the role of differing productivity levels across industries is incorporated into a Ricardian general equilibrium model of trade and multinational production. This paper offers the first set of productivity estimates at the sectoral level for local producers as well as for the entire economy. Compared with previous uni-sectoral models, this paper offers more reliable estimates of fundamental technology, since previous literature does not effectively isolate the technology corresponding to local producers at the sectoral level.

There are three main contributions stemming from this work. First, it shows that comparative advantage plays a crucial role in determining the allocation of multinational production across sectors: foreign affiliate activity is higher on average in sectors where the host economy has comparative disadvantage. The analytical results and quantitative estimations reveal that the effect of multinational production on the state of technology is higher in those sectors in which local producers are relatively less productive, implying that multinational production weakens a country's comparative advantage. Second, it shows that gains from trade are about half of what they would be in the absence of sectoral heterogeneity in multinational activity. In particular, in a counterfactual scenario in which multinational production affects only the average productivity level of the host economy while keeping its comparative advantage unchanged, estimated gains from trade would be twice as large (19.04 percent compared with 10.4 percent). Multinational production not only closes the absolute technology gap across countries, it also reduces the relative technology differences across sectors within a country. Third, it shows that heterogeneity of foreign affiliate sales across sectors is quantitatively important in accounting for welfare gains associated with MP activity.

The results of this study highlight the importance of incorporating a sectoral dimension in the analysis of MP activity. It distinguishes between the absolute and comparative advantage effects of MP, which is essential to improve our understanding of the welfare implications and the mechanism through which an economy responds to multinational production.

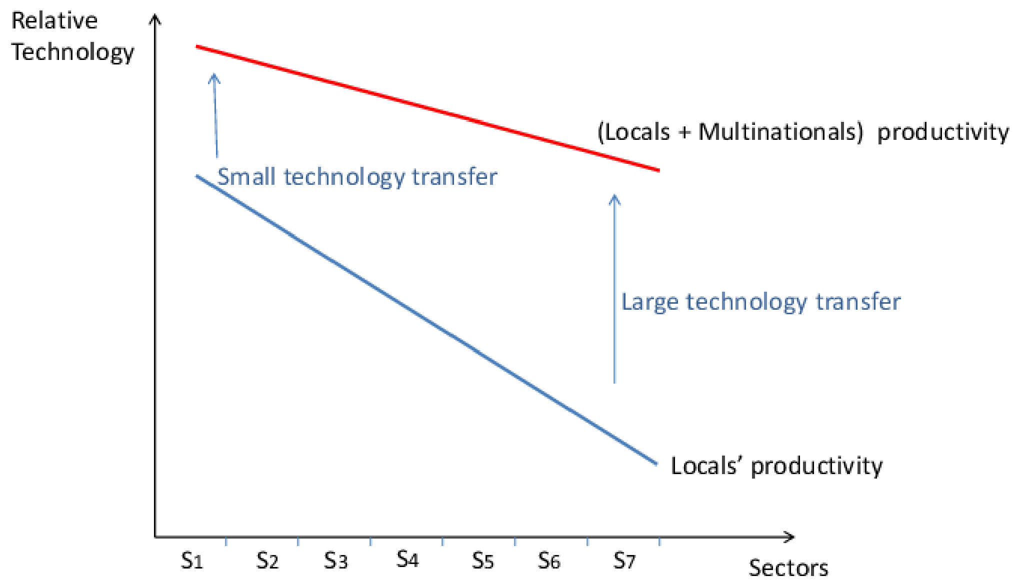
Figures and Tables

Figure 1.7: Effect of Comparative Advantage on MP Allocation



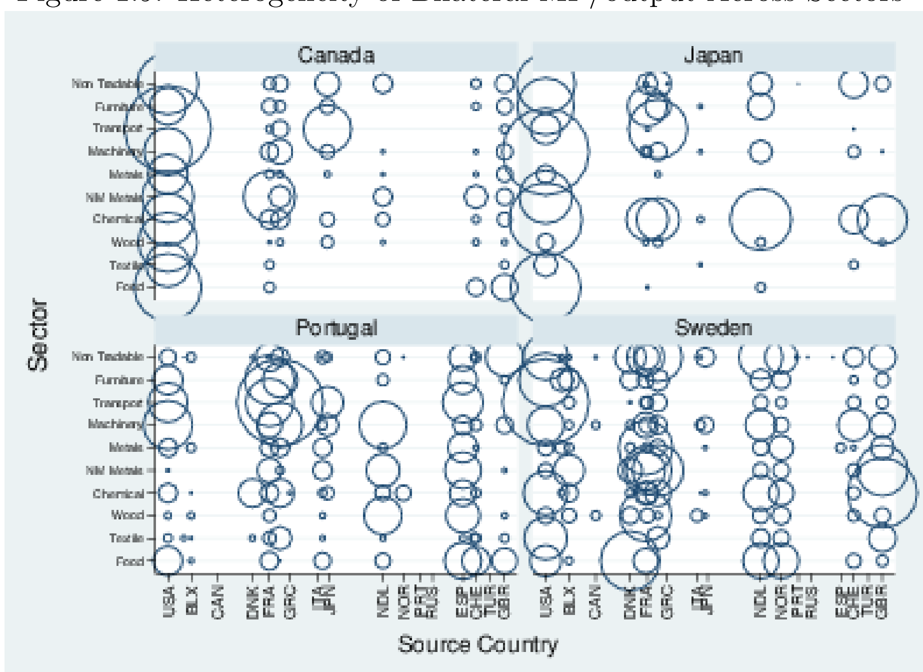
Notes: This figure displays the tradable-sector productivities of local producers, expressed as the ratio to the global frontier productivity for a representative economy. The x-axis labels sectors in descending order of the ratio to the frontier (so that the sectors where local producers are relative more productive are on the left). The Figure shows that the share of MP on the host country's output is higher in sectors where the relative productivity of local producers is low.

Figure 1.8: Effect of MP on Comparative Advantage



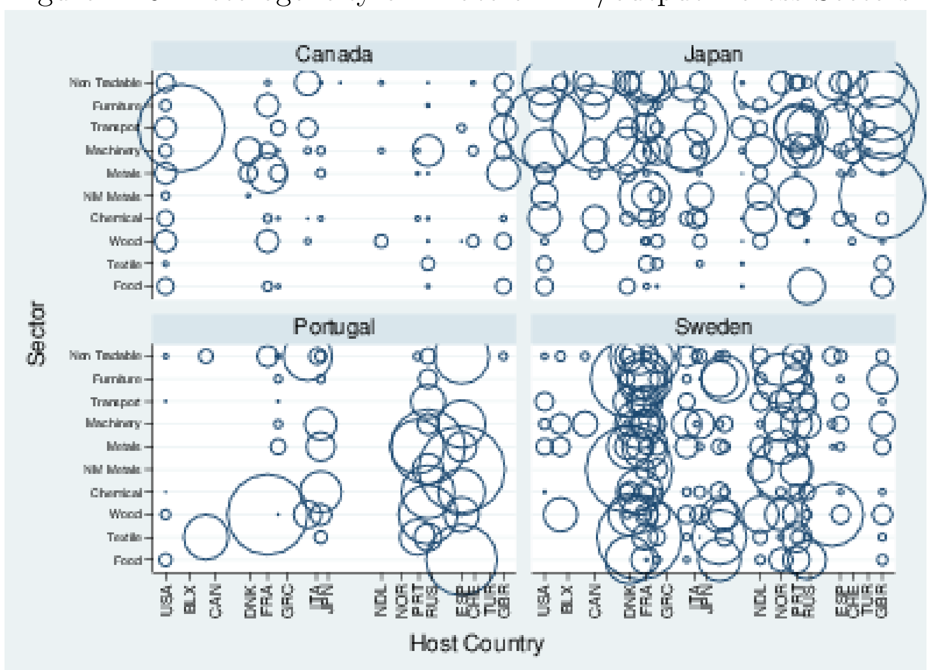
Notes: This figure displays the tradable-sector productivities, expressed as the ratio to the global frontier productivity for the overall economy (red) and for local producers exclusively (blue). The x-axis labels sectors in descending order of the ratio to the frontier of local producers productivity (so that the sectors where local producers are relative more productive are on the left). The Figure shows that the red line is above the blue line for all tradable sector and that the red line is steeper than the blue line; indicating that MP increases the productivity in all sectors but it affects more the productivity of those sectors where local producers are relatively less productive.

Figure 1.9: Heterogeneity of Bilateral MP/output Across Sectors



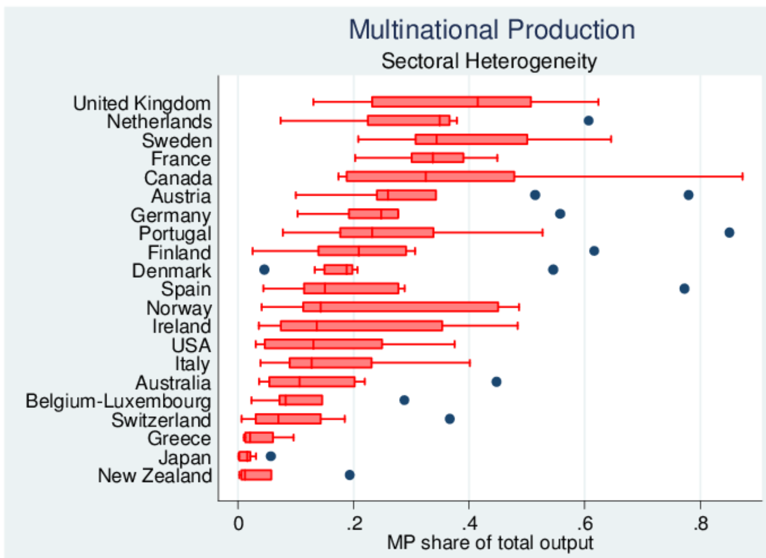
Notes: This figure displays MP/output for nine tradable sectors for four selected host economies (Canada, Japan, Portugal and Sweden). The x-axis represent the source countries; the y-axis represent the sectors; and the bubbles represent the MP shares for each source-host-sector triplet. Source countries with more presence in a host country-sector pair will have bigger bubbles. The selected source countries are: United States, Belgium-Luxembourg, Canada, Denmark, Greece, Italy, Japan, Netherlands, Norway, Portugal, Russia Federation, Spain, Switzerland, Turkey and United Kingdom.

Figure 1.10: Heterogeneity of Bilateral MP/output Across Sectors



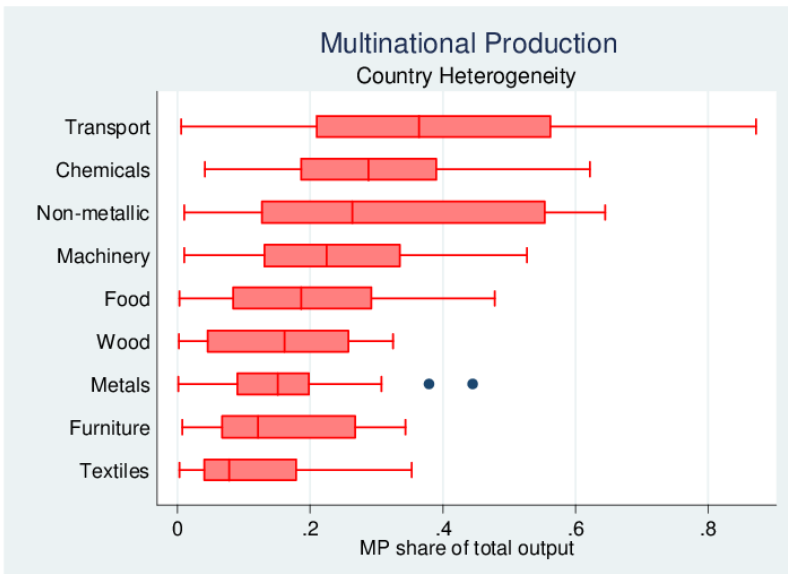
Notes: This figure displays MP/output for nine tradable sectors for four selected source economies (Canada, Japan, Portugal and Sweden). The x-axis represent the source countries; the y-axis represent the sectors; and the bubbles represent the MP shares for each source-host-sector triplet. Source countries with more presence in a host country-sector pair will have bigger bubbles. The selected host countries are: United States, Belgium-Luxembourg, Canada, Denmark, Greece, Italy, Japan, Netherlands, Norway, Portugal, Russia Federation, Spain, Switzerland, Turkey and United Kingdom.

Figure 1.11: Heterogeneity of MP across Sectors within a Country



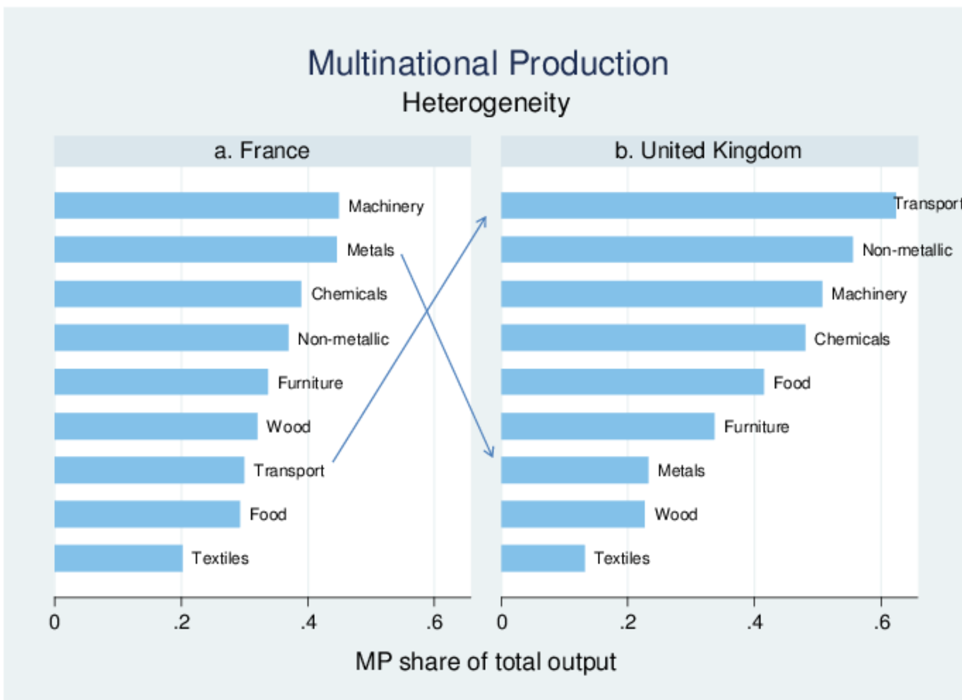
Notes: This figure displays the sum of MP over output across all source countries for each host country-sector pair. The x-axis represents the vale of MP/output in each sector, and the y-axis show the selected host countries. The Box-and-Whisker plot shows the distribution of MP/output across sectors for a give host country. Within the box lies 50 percent of the observations, and the whiskers, are drawn to span all data points within 1.5 interquartile range of the upper and lower quartile. Observations beyond the whiskers are shown by the blue points.

Figure 1.12: Heterogeneity of MP across Countries within a Sector



Notes: This figure displays the sum of MP over output across all source countries for each host country-sector pair. The x-axis represent the vale of MP/output in each host country, and the y-axis show the nine tradable sectors. The Box-and-Whisker plot shows the distribution of MP/output across countries for a give sector. Within the box lies 50 percent of the observations, and the whiskers, are drawn to span all data points within 1.5 interquartile range of the upper and lower quartile. Observations beyond the whiskers are shown by the blue points

Figure 1.13: MP by Sector: France and United Kingdom



Notes: This figure displays the sum of MP over output across all source countries for France and United Kingdom. The x-axis represent the vale of MP/output in each sector, and the y-axis show the nine tradable sectors.

Figure 1.14: Bilateral MP shares and Comparative Advantage

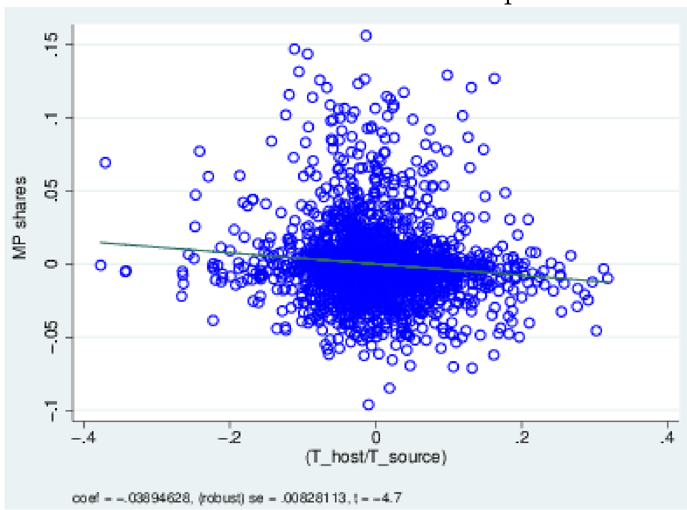
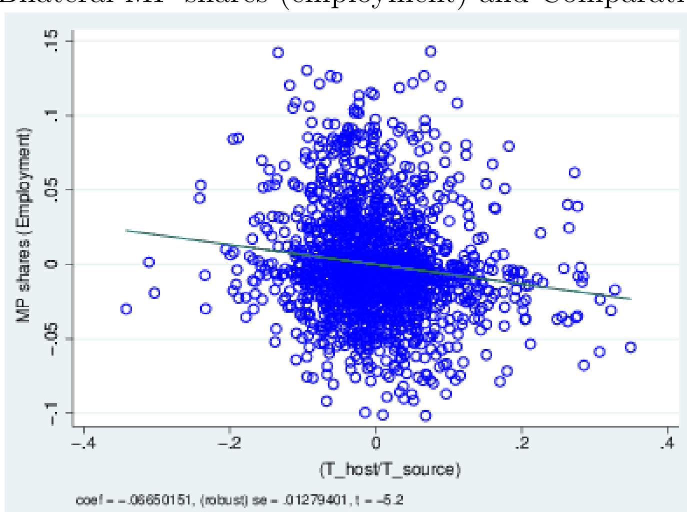


Figure 1.15: Bilateral MP shares (employment) and Comparative Advantage



Notes: The figure in the top panel depicts the partial correlation between the share of MP (sales) for each source-host-sector triplet ($MP\text{share}^{j}_{hs}$) in the y-axis and the ratio of productivities (TFP_{host}/TFP_{source}) in the x-axis. The figure in the bottom panel depicts the partial correlation between the share of MP (employment) for each source-host-sector triplet ($MP\text{share}^{j}_{hs}$) in the y-axis and the ratio of productivities (TFP_{host}/TFP_{source}) in the x-axis. These correlations are conditional to source-host country fixed effects and sector fixed effects.

Figure 1.16: Relationship Between U.S. MP shares and Comparative Advantage

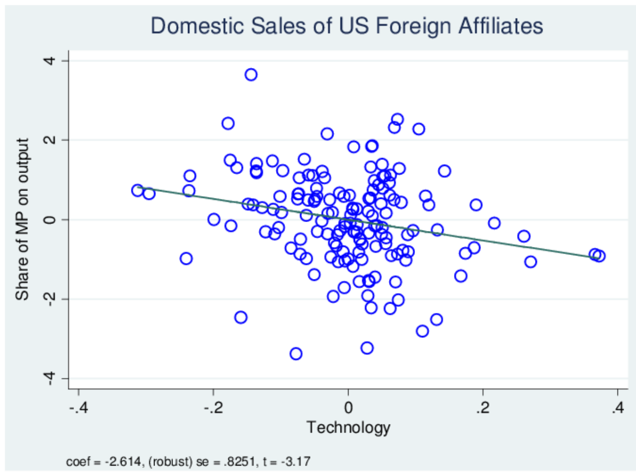
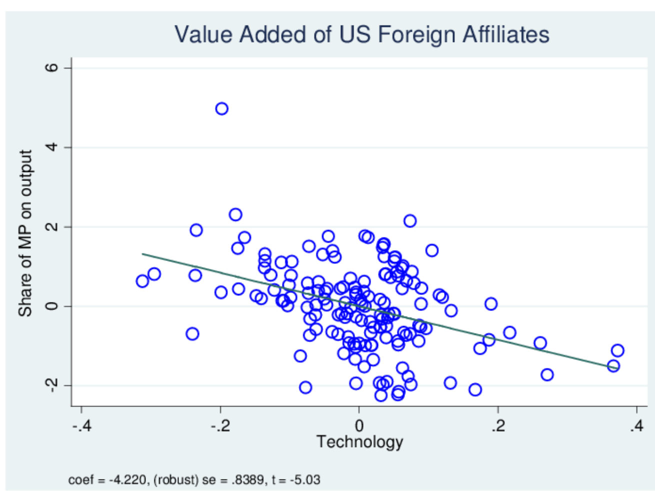
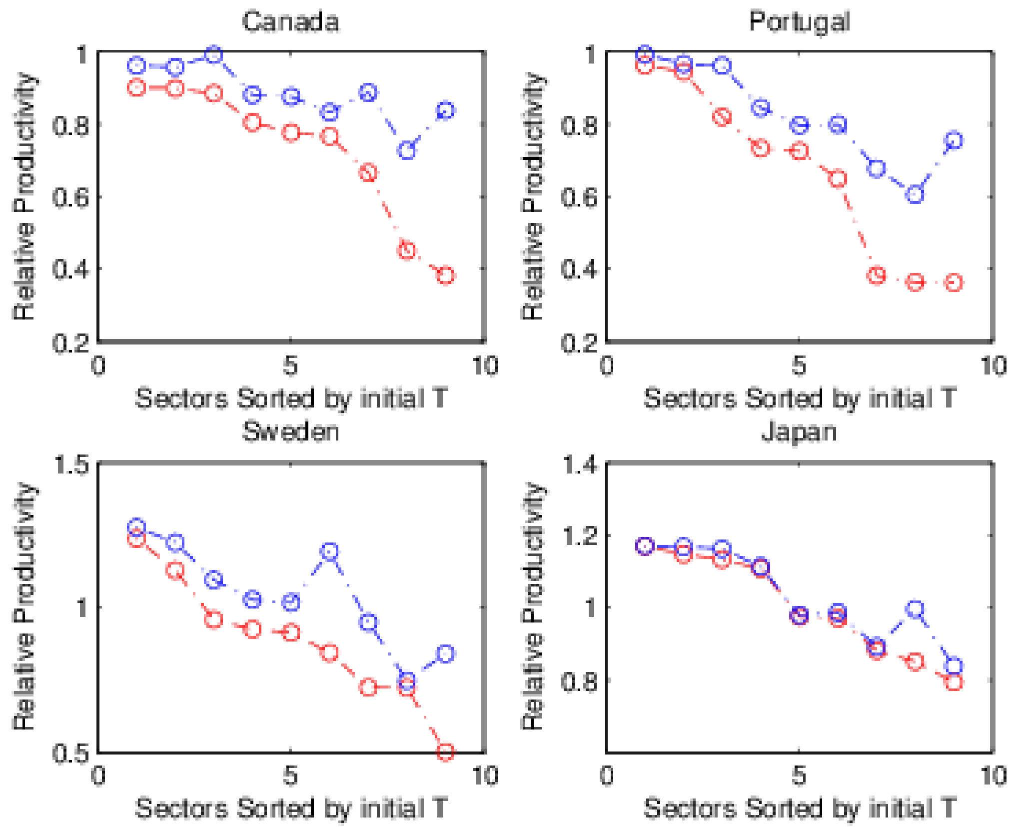


Figure 1.17: Relationship Between U.S. MP shares and Comparative Advantage: Value Added



Notes: This figure depicts the partial correlation between the share of MP of U.S foreign affiliates in each host country-sector pair and the productivity of the host economy in each sector after netting out the country and sector fixed effects.. It considers only the sales of U.S affiliates in the country of operation (host country); that is, excluding all their exports to third countries. The y-axis represent the vale of MP/output in each host country-sector pair, and the x-axis represent the productivity of each host country-sector pair. The source of the data is the Bureau of Economic Analysis (BEA)

Figure 1.18: Relative Productivities



Notes: This figure displays the tradable-sector productivities in selected countries, expressed as the ratio to the U.S productivity for the overall economy (red circles) and for local producers exclusively (blue circles). The x-axis labels sectors in descending order of the ratio to the frontier of local producers productivity (so that the sectors where local producers are relative more productive are on the left).

Table 1.7: List of Countries

Reporting and Partner Countries		
Australia*	Italy*	Spain*
Austria*	Japan*	Sweden*
Belgium-Luxembourg*	Latvia	Switzerland*
Canada*	Lithuania	Turkey*
Czech Republic*	Mexico*	United Kingdom*
Denmark*	Netherlands*	United States*
Estonia	New Zealand*	
Finland*	Norway*	
France*	Poland*	
Germany*	Portugal*	
Greece*	Romania	
Hungary*	Russian Federation	
Ireland*	Slovakia	
Israel	Slovenia	
Partner Countries (only)		
Argentina	India	Malaysia
Bulgaria	Egypt	Philippines
Brazil	Hong Kong	Singapore
Chile	India	South Africa
China	Indonesia	
Croatia	Korea	

Note: The symbol (*) means that the country belongs to the OECD. A reporting country is one that reports or declares the foreign affiliate activity. The other party involved in the transaction is called the partner country. The activity reported by the reporting country could refer either to the sales of affiliates from other countries operating in its territory—or inward MP—or to the sales of locally based multinationals with affiliates operating in foreign markets—or outward MP.

Table 1.8: Summary Statistics (Multinational Production)

	MP/Production		MP/Imports	MP/Absorption
	Non-Tradables	Tradables	Tradables	Tradables
Declaring Economies (35 countries)				
Mean	0.28	0.24	0.73	0.61
Median	0.25	0.23	0.72	0.50
Min	0.01	0.02	0.06	0.02
Max	0.84	0.59	1.86	1.79
All sample (51 countries)				
Mean	0.23	0.21	0.67	0.51
Median	0.14	0.19	0.56	0.38
Min	0.00	0.01	0.04	0.02
Max	1.41	0.59	2.67	1.79

Note: MP refers to the foreign affiliate sales from all source countries in a given host-sector pair. The columns represent MP relative to production, imports, and absorption, where absorption is defined as production minus exports. The table presents basic statistics for the average MP relative to output, imports, and absorption across sectors within a country. The non-tradable sector includes construction; wholesale, retail trade, restaurants and hotels; and transportation, storage, and communication.

Table 1.9: Multinational Production by Country

Country	Number of Source Countries	MP/output (Inward)	Number of Location Countries	MP/output (Outward)
Australia	2	0.15	10	0.27
Austria	22	0.37	19	0.24
Belgium	7	0.10	20	0.26
Bulgaria	26	0.26	3	0.00
Canada	7	0.43	14	0.26
Czech Rep.	25	0.48	14	0.26
Denmark	13	0.18	22	0.29
Estonia	11	0.27	5	0.02
Finland	17	0.18	20	0.34
France	26	0.30	31	0.23
Germany	26	0.27	30	0.23
Greece	1	0.03	23	0.08
Hungary	27	0.64	9	0.00
Ireland	11	0.26	15	0.27
Israel	1	0.02	12	0.22
Italy	25	0.20	20	0.23
Japan	10	0.03	23	0.25
Lithuania	16	0.15	6	0.00

Note: Inward MP refers to foreign affiliate sales from all source countries in a given host-sector pair. Outward MP refers to the sales of foreign affiliates in all host countries for each source-sector pair. The second column represents the number of source countries operating in each country. Similarly, the fourth column represents the number of host countries in which each country has operations. The third and fifth columns represent the weighted average of the shares of inward and outward MP relative to each country's production. Averages are weighted by relative size of the sector in the economy. The table contains statistics for tradable sectors only and thirty-five reporting countries.

Table 1.10: Multinational Production by Country (Cont.)

Country	Number of Source Countries	MP/output (Inward)	Number of Location Countries	MP/output (Outward)
Latvia	11	0.10	2	0.00
Mexico	7	0.26	3	0.15
Netherlands	20	0.32	27	0.21
New Zealand	2	0.02	6	0.16
Norway	14	0.19	19	0.28
Poland	24	0.44	16	0.15
Portugal	17	0.29	12	0.21
Romania	32	0.59	4	0.00
Slovakia	16	0.51	8	0.01
Slovenia	13	0.12	7	0.00
Spain	26	0.27	16	0.25
Sweden	21	0.40	23	0.27
Switzerland	3	0.17	25	0.24
Turkey	8	0.08	6	0.12
United Kingdom	30	0.43	28	0.23
United States	23	0.18	34	0.22

Note: Inward MP refers to foreign affiliate sales from all source countries in a given host-sector pair. Outward MP refers to the sales of foreign affiliates in all host countries for each source-sector pair. The second column represents the number of source countries operating in each country. Similarly, the fourth column represents the number of host countries in which each country has operations. The third and fifth columns represent the weighted average of the shares of inward and outward MP relative to each country's production. Averages are weighted by relative size of the sector in the economy. The table contains statistics for tradable sectors only and thirty-five reporting countries.

Table 1.11: Multinational Production and Comparative Advantage, Selected Countries

Country	Total MP	MP/Production	MP/Absorption	MP/Demand
Canada	-0.569	-0.646*	-0.694*	-0.642*
Denmark	0.223	-0.107	-0.157	-0.2023
France	-0.229	0.352	-0.244	-0.114
Germany	-0.556	-0.370	-0.506	-0.351
Greece	-0.910*	-0.903*	-0.901*	-0.936*
Italy	-0.610*	-0.678*	-0.700*	-0.675*
Japan	-0.551	-0.685*	-0.691*	-0.693*
Mexico	-0.644*	-0.662*	-0.652*	-0.636*
Norway	-0.541	-0.767*	-0.720*	-0.706*
Poland	-0.393	-0.505	-0.592*	-0.521
Spain	-0.759*	-0.759*	-0.756*	-0.729*
Turkey	-0.494	-0.574	-0.598*	-0.601*
United Kingdom	-0.546	-0.355	-0.233	-0.246

Notes: This table presents the correlation between the mean productivity of each host country-sector pair $(T_s^j)^{\frac{1}{\theta}}$ and the importance of multinational production in total output for each country in the sample. The relevance of MP is measured by its value in levels, as well as a fraction of sectoral output, absorption (output minus exports) and demand (output+imports-exports).

Table 1.12: Relationship Between Bilateral MP and Comparative Advantage

Dep. Variable		$MPshare^j_{hs}$	
	(1)	(2)	(3)
$\left(T^j_{host}/T^j_{source}\right)$	–0.0159***	–0.0347**	–0.0389***
	(0.0018)	(0.0049)	(0.0052)
R^2	0.02	0.44	0.47
Host fe × Source fe	No	Yes	Yes
Sector	No	No	Yes
Corr Coef.	–0.109***	–0.09***	–0.11***
Observations	2415	2415	2415

Notes: This table presents the results of the Least Square Regression between the share of MP for each source-host-sector triplet ($MP\text{share}^j_{hs}$) and the ratio of productivities (TFP_{host}/TFP_{source}). Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$.

Table 1.13: **Productivity T_n^j and $\widetilde{T}_n^j$**

Country	Average Change	Relative Change
Australia	0.03	-0.22
Austria	0.24	-0.48
Belgium	0.02	-0.08
Bulgaria	0.14	0.14
Canada	0.17	-0.51
Czech Rep.	0.41	-0.52
Denmark	0.04	-0.07
Estonia	0.19	-0.28
Finland	0.09	-0.22
France	0.07	0.14
Germany	0.11	0.08
Greece	0.01	-0.06
Hungary	0.29	-0.37
Ireland	0.07	-0.27
Israel	0.01	-0.09
Italy	0.14	-0.47
Japan	0.03	-0.14

Note: The first column reports the percentage change in the mean absolute distance to the frontier across all tradable sectors between local producers' productivity $(T_n^j)^{\frac{1}{\theta}}$ and all producers' productivity $(\widetilde{T}_n^j)^{\frac{1}{\theta}}$. The second column reports the percentage change in the coefficient of variation across tradable sectors in the distance to the frontier between local producers' productivity $(T_n^j)^{\frac{1}{\theta}}$ and all producer's productivity $(\widetilde{T}_n^j)^{\frac{1}{\theta}}$. In the baseline, $\theta = 4.0$.

Table 1.14: Productivity T_n^j and $\widetilde{T}_n^j$ (Cont.)

Country	Average Change	Relative Change
Latvia	0.10	0.05
Lithuania	0.30	-0.16
Mexico	0.15	-0.34
Netherlands	0.22	-0.29
New Zealand	0.04	-0.26
Norway	0.04	-0.04
Poland	0.35	-0.53
Portugal	0.22	-0.52
Romania	0.19	-0.27
Russia	0.20	-0.42
Slovakia	0.22	-0.29
Slovenia	0.09	-0.39
Spain	0.13	-0.52
Sweden	0.20	-0.41
Switzerland	0.06	-0.32
Turkey	0.14	-0.43
United Kingdom	0.07	-0.06
Average	0.15	-0.26

Note: The first column reports the percentage change in the mean absolute distance to the frontier across all tradable sectors between local producers' productivity $(T_n^j)^{\frac{1}{\theta}}$ and all producers' productivity $(\widetilde{T}_n^j)^{\frac{1}{\theta}}$. The second column reports the percentage change in the coefficient of variation across tradable sectors in the distance to the frontier between local producers' productivity $(T_n^j)^{\frac{1}{\theta}}$ and all producer's productivity $(\widetilde{T}_n^j)^{\frac{1}{\theta}}$. In the baseline, $\theta = 4.0$.

Table 1.15: **Comparison beteween $\widetilde{T}_{trade}$ and $\widetilde{T}_{mp}$**

	Panel A: Sector by Sector Rank Correlations		
Sector Code	Sector Name	Correlation	Countries
S15-16	Food and Beverages	0.72	35
S17-19	Textiles apparel	0.61	35
S20-22	Wood, paper and printing	0.84	35
S23-25	Chemical products	0.91	35
S26	Non-Metallic Mineral Products	0.65	35
S27-28	Basic and Fabricated Metal Products	0.56	35
S29-33	Computing, Machinery, Communication Equipment	0.81	35
S34-35	Transport Equipment	0.62	35
S36-37	Furniture and Other Manufacturing	0.64	35

Panel B: Fixed Effects Regressions

	(1)	(2)	(3)
Dep. Var: $\log(\widetilde{T}^j_{trade})$			
$\log(\widetilde{T}^j_{mp})$	0.961***	0 .9980***	0.3236***
	(0.0871)	(0.0364)	(0.0760)
Obsevations	315	315	315
R-squared	0.5284	0.4474	0.8657
Partial ρ	0.638	0.642	0.319
Sector FE	no	yes	yes
Country FE	yes	no	yes

Notes: This table reports the results of comparing the overall productivity estimates using the main procedure adopted in the paper$\widetilde{T}^j_{trade}$ (i.e. using the gravity equation) with the overall productivity estimates using the MP gravity equation $\widetilde{T}^j_{mp}$ (i.e.to estimate the locals producers productivity T^j_h and the MP barriers h^j_{hs} in order to calculate the overall productivity. Panel A reports the Spearman rank correlations of the two alternative overlal productivity measures by sector. Panel B reports the results of a fixed effect regression of $\widetilde{T}^j_{trade}$ on $\widetilde{T}^j_{mp}$. In Panel B robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. Partial ρ is the partial correlation between the right-hand side and the left hand side variables, after netting out the fixed effects included in the column.

Table 1.16: The Fit of the Baseline Model with the Data

		Model	Data
Wages			
	Mean	0.761	0.650
	Median	0.790	0.710
	corr(model,data)	0.920	
Imports/GDP			
	Mean	0.364	0.359
	Median	0.342	0.291
	corr(model,data)	0.829	
Inward MP/Production			
	Mean	0.338	0.269
	Median	0.302	0.258
	corr(model,data)	0.758	
Outward MP/Production			
	Mean	0.310	0.205
	Median	0.070	0 .091
	corr(model,data)	0.804	

Note: This table reports the mean and median of wages relative to the United States, return to capital relative to the United States, and imports as a share of GDP, both in the model and in the data. In the data, Imports/GDP are the manufacturing imports as a share of GDP in the 2000s, sourced from the World Bank's World Development Indicators. Wages, production and inward and outward multinational production in the data are calculated as described in Section 1.19.

Figure 1.19: Wages Relative to United States

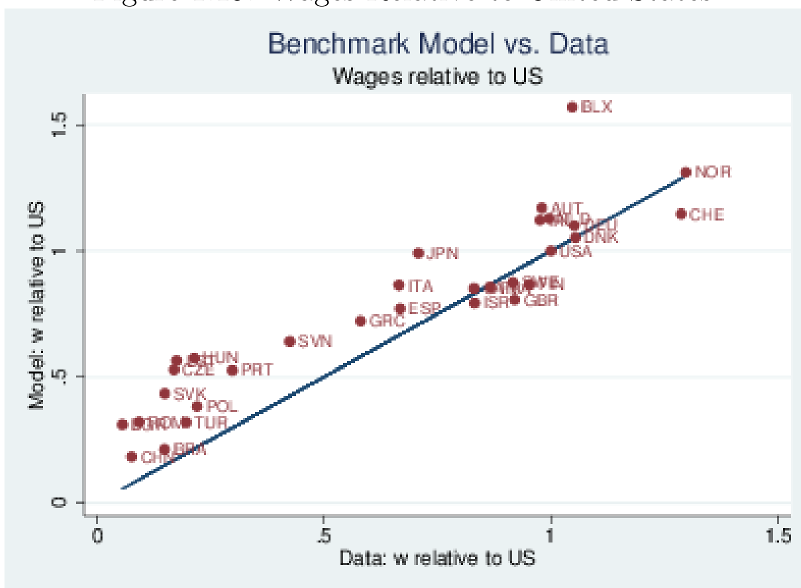
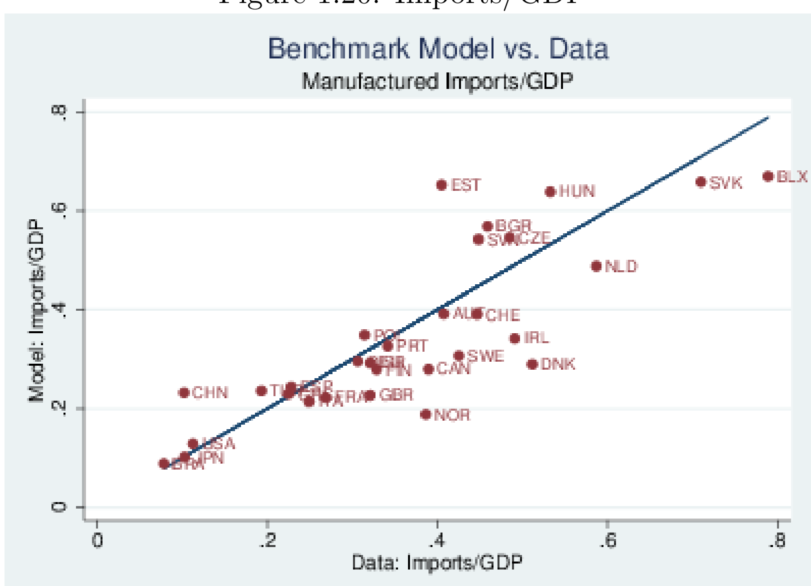


Figure 1.20: Imports/GDP



Note: The Figure in the top represents the scatter-plot of wages in the data (x-axis) against the model's counterpart (y-axis). The bottom panel represents the scatter-plot of Imports/GDP in the data (x-axis) against the model's counterpart (y-axis). In the data, Imports/GDP are the average manufacturing imports as a share of GDP over the period 2003-2007, sourced from the World Bank's World Development Indicators. Wages, in the data are calculated as described in Section 1.19 using UNIDO data. The solid line is the 45-degree line.

Figure 1.21: Inward MP/Production

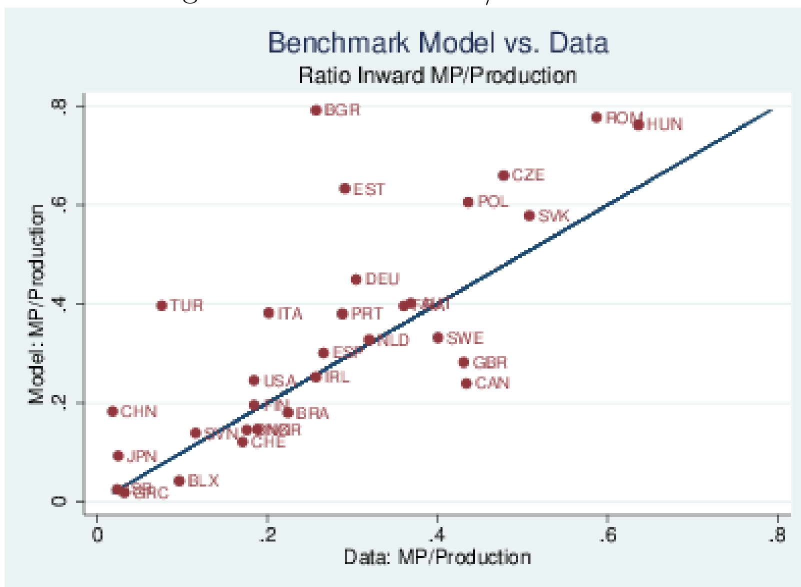
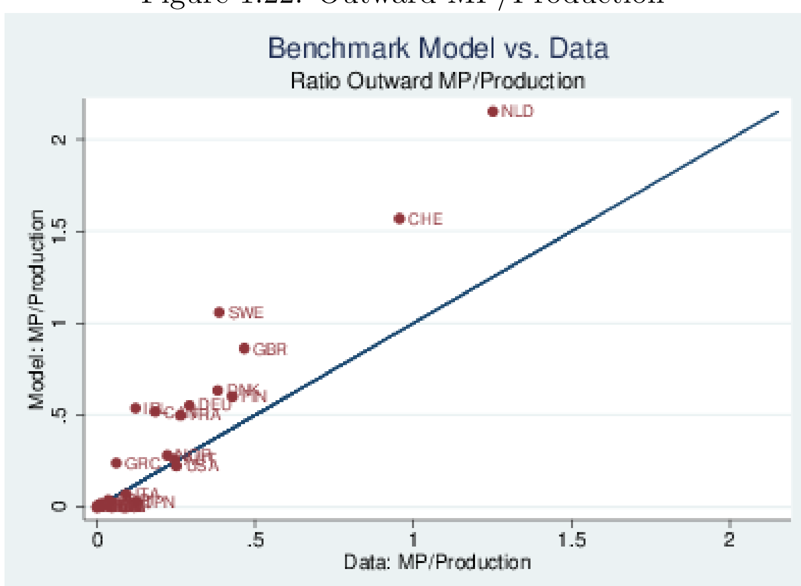


Figure 1.22: Outward MP/Production



Note: The Figure in the top represents the scatter-plot of Inward MP in the data (x-axis) against the model's counterpart (y-axis). The bottom panel represents the scatter-plot of Outward/GDP in the data (x-axis) against the model's counterpart (y-axis). In the data, Inward MP are calculated by summing the foreign affiliate production of all possible sources for each host country-sector pair, and then is normalized by the total output of the hots country in each sector. The solid line is the 45-degree line.

1.8 Appendix A: Data Description

1.8.1 Multinational Production Data

Multinational production data at the bilateral sectoral level was gathered mainly from unpublished OECD data, in particular, International Direct Investment Statistics and the Statistics on Measuring Globalisation. This datasets contain information concerning the economic activities of multinational firms (such as production, employment, number of affiliates, etc.) for thirty reporting countries belonging to the OECD, and the fifty-five partner countries that are host or source of their MP operations. Nominal data is reported in the currency of the reporting country, which is converted to U.S. dollars using the average annual exchange rate provided by the OECD.

The industry classification used is ISIC Revision 3. A total of seventy sectors and sub-sectors are covered in the original data for agriculture, mining, manufacturing, and services. We could potentially get a higher level of sectoral disaggregation, but because of disclosure and confidentiality issues, many observations are available only at a more aggregate level.[42] Therefore, to maximize the accuracy and coverage of the data, we aggregate it to nine tradable and four non-tradable sectors. In order to build a dataset based on primary information for the largest possible set of countries, we aggregate the information at roughly the 1-digit ISIC level, as shown in Table 1.17.

For those countries that do not belong to the OECD, or for which complete information was not available in the OECD data, we draw information from the Foreign Affiliate Statistics database provided by Eurostat. This dataset, reports information for 41 source and 22 host countries at the source-host-sector triplet. A total of 117 sectors and sub-sectors are covered in the original dataset. Eurostat uses NACE Revision 2, for which we develop a concordance to merge it with the ISIC classification used by the OECD database.

In order to ensure that a zero was not mistaken for a missing value in the data, we rely on two additional measures of multinational activity recorded in the dataset (employment and the number of foreign affiliates in a given source-host-sector triplet) as well as information on revenues reported by ORBIS and BEA. Whenever possible, inward flows were chosen, given that it is more likely that multinational sales are better reported by the host country than by the sending country. Moreover, the host country also reports the ultimate sector of investment, which can be different from

[42] For some sector-country pairs, only a few affiliates are operating and therefore the full disclosure of this information could reveal confidential data about a particular firm.

Table 1.17: Sectors

ISIC Code	Name
S15-16	Food, beverages, and tobacco
S17-19	Textiles, wearing apparel, leather, footwear
S20-22	Wood and paper products, publishing, printing
S23-25	All chemical products
S26	Non-metallic mineral products
S27-28	Basic and fabricated metal products
S29-33	Total machinery and equipment; medical and precision instruments
S34-35	Transportation equipment
S36-37	Furniture, recycling, and manufacturing n.e.c.
S40-45	Electricity, gas and water supply, construction
S50-55	Trade, repair, hotels and restaurants
S60-64	Transportation, storage and communications
S65-74	Finance, insurance, real estate, business activities

the parent firm's sector in the source country.

Given the different data sources used in its construction, it is important to assess the quality of the dataset. Because of disclosure and confidentiality issues, the accuracy of reported foreign affiliate sales increases with the aggregation level. This means that we have better information about the total manufacturing sales of Italian multinationals in France, but less accurate information about how much of those sales occur in the chemical and textile sectors. Therefore, we rely on two-dimensional data to assess the quality of this three-dimensional dataset. The first one of the two-dimensional datasets contains information on bilateral MP sales for total manufacturing in a given source-host pair, while the second one aggregates MP sales across all source countries for any given host-sector pair and also across all host countries for any given source-sector pair. Information for total manufacturing is used to assess how well the sectoral disaggregation accounts for total manufacturing flows. These two datasets constitute a benchmark for the aggregate flows, which can be used to check the validity of more disaggregated information coming from other sources. Total manufacturing foreign affiliate sales are calculated by summing them across the nine manufacturing sectors and then comparing them with the total manufacturing sales of foreign affiliates reported directly by OECD, Eurostat, and UNCTAD.

The final database comprises thirty-five countries, nine tradable sectors, and one aggregated non-tradable sector. Each observation is averaged over the period 2003–2007. After all of the quality controls have been applied to of this dataset, we get positive MP values for 2,987 source-host-sector relationships, from a potential of about 11,900.

1.8.2 Trade and Production Data

Production data: gross manufacturing production data at the sectoral level is from the 2012 UNIDO Industrial Statistics Database, which reports output, value added, employment, and wage bills at a 2-digit ISIC Revision 3 level of disaggregation. The data were further aggregated in order to match the classification used in the assembled MP database. Production data at the 2-digit ISIC level was extensively checked for quality. In cases where a country-year-sector observation had missing values, or were production was lower than exports, those values were imputed based on information from previous years as well as information on export patters. The production dataset is also used to calibrate important parameters of the model, such as the share of value added in production (β_j) and the share of labor on total value added (α_j), which are calculated by taking the median of each parameter across countries for each tradable sector. Note, however, that the UNIDO database does not contain information on the non-tradable sector. Therefore, to calculate α_{J+1} and β_{J+1}, we use the 2002 Benchmark Detailed Make and Use Tables for the United States. Table 1.18 lists the sectors along with the key parameters values for each sector: α_j, β_j, and the taste parameter ω. More important, we use the production data to compute the share of output produced by local producers in country h and sector j. This is calculated by subtracting from the output the total production of foreign affiliates, in every country-sector pair.

Trade Shares: Bilateral trade data was drawn from Comtrade (4-digit SITC Revision 2), and aggregated up to the 2-digit ISIC level, using a concordance that we develop. Then we aggregate further to the sectoral aggregation shown in Table 1.18 to merge the trade data with production and MP datasets. Note that imports were use for trade values, which were discounted by a factor of 1.2 because transportation cost is included in the value. To calculate the trade shares $\left(X^j_{mh}/X^j_m\right)$ at a sectoral level, we first compute a country's exports in a given sector, by aggregating bilateral exports across all partners countries. We then divide the value of country m's imports from country h by the demand of the importer for sector j goods (X^j_m); which is gross production minus exports, plus imports in sector j, yielding bilateral trade shares. Also note that imports and exports are calculated using only the countries in the sample.

Bilateral gravity variables: the distance measures used to estimate trade cost, as well as data on common border and common language, are taken from the Centre d'Etudes Prospectives et d'Informations Internationals (CEPII). Information on trade agreements comes from the RTA database maintained by the WTO.

Factor prices: For each country in the sample wages are calculated by dividing the wage bill aggregated across all manufacturing sectors by total employment in manufacturing; wages are then normalized by the U.S. wage. For the few countries for which information on wage bill or employment was not available, the income percapita reported by the Penn World Tables (PWT) was used.

Table 1.18: Model Parameters

ISIC code	Sector Name	α	β	ω	θ
S15-16	Food, beverages, and tobacco	0.351	0.256	0.209	2.84
S17-19	Textiles, wearing apparel, leather, footwear	0.515	0.308	0.103	5.59
S20-22	Wood and paper products, publishing, printing	0.401	0.339	0.025	9.50
S23-25	All chemical products	0.303	0.241	0.114	8.28
S26	Non-metallic mineral products	0.343	0.371	0.071	3.38
S27-28	Basic and fabricated metal products	0.396	0.273	0.014	6.58
S29-33	Total machinery and equipment; medical and precision	0.424	0.276	0.187	10.6
S34-35	Transportation equipment	0.467	0.252	0.175	1.84
S36-37	Furniture, recycling, and manufacturing n.e.c.	0.483	0.253	0.065	5.00
S-NT	Non-Tradables	0.54	0.64		

Note: This table reports the median of the labor share in value added (α_j), the share of value added in total production (β_j), and the taste parameter for tradable sector j. The values of the dispersion parameter θ correspond to estimates of Caliendo and Parro (2011).

To calculate the return of capital, we rely on the market clearing condition of the model $(r_h/w_h = ((1-\alpha) L_h) / (\alpha K_h))$, along with the data on labor and capital.[43] Total labor force in each country (L_n) and capital stock are obtained from the PWT. Total labor force is calculated as the ratio of real GDP (calculated as the product of real GDP per capita and total population) and real GDP per worker. Total capital is calculated using the perpetual inventory method $(K_{h,t} = (1-\delta) K_{h,t-1} + I_{h,t})$, where I_h is the total investment in country h in period t; the depreciation rate δ is assumed to be 6 percent. The initial value of K is equal to $I_{h,0}/(\gamma+\delta)$, where γ is the average growth rate of investment in the first ten years for which data are available.

Intermediate input coefficients: The intermediate input coefficients (γ_{kj}) are obtained from the Direct Requirements Table in the 2002 Benchmark Detailed Make and Use Tables for the United States, which uses the NAICS classification. Specifically, this data report the intermediate input in each row (k) required to produce one dollar of final output in each column (j). Then, we use a concordance to the ISIC Revision 3 classification to build a direct requirement table at the 2-digit ISIC level, and then further aggregate to the ten-sector level classification used in this paper. For a given column j, we can aggregate the rows k using the concordance. In order to further aggregate the columns to the ten-sector level, we compute the weighted average across columns, with the weights given by the relative importance of each sector.

Prices of tradables and non-tradables: The price of non-tradables relative to the United States $\left(p_n^{J+1}/p_{usa}^{J+1}\right)$ and the price of non-tradables relative to tradables in each country $\left(p_h^{J+1}/p_h^{T}\right)$ are calculated using data from the International Comparison of Prices program (ICP).[44]

[43]Where α is the aggregate share of labor in GDP, which is set to 2/3.

[44]The sectors grouped as tradables are: food and non-alcoholic beverages, alcoholic beverages and tobacco, clothing and footwear, furnishings, household equipment, and household maintenance. As non-tradables we group housing; water, electricity, gas, and other fuels; health; transport; communication; recreation and culture; education; restaurants and hotels.

Table 1.19: Intermediate Input Coefficients (γ_{kj})

ISIC	S15-16	S17-19	S20-22	S23-25	S26	S27-28	S29-33	S34-35	S36-37	S-NT
S15-16	0.42698	0.01428	0.00325	0.00299	0.00178	0.00000	0.00000	0.00000	0.00000	0.02200
S17-19	0.00139	0.43133	0.02012	0.00487	0.00492	0.00000	0.00409	0.01526	0.04584	0.00376
S20-22	0.09119	0.01537	0.42683	0.02177	0.05206	0.01314	0.01432	0.01046	0.13538	0.03858
S23-25	0.07866	0.19233	0.09395	0.50759	0.08068	0.04675	0.07382	0.05587	0.13819	0.05982
S26	0.01923	0.00285	0.00719	0.01080	0.26005	0.01002	0.01082	0.01109	0.00709	0.01215
S27-28	0.05982	0.01364	0.02972	0.02629	0.05872	0.47551	0.16597	0.15129	0.15656	0.01885
S29-33	0.01617	0.01586	0.03696	0.02881	0.03558	0.06016	0.30742	0.09851	0.03202	0.03468
S34-35	0.00352	0.00095	0.00379	0.00219	0.00443	0.00356	0.01111	0.36735	0.00212	0.01440
S36-37	0.00013	0.00824	0.00244	0.00157	0.00274	0.00136	0.00604	0.00415	0.08574	0.00772
S-NT	0.29500	0.30511	0.37570	0.39307	0.49900	0.38946	0.40636	0.28600	0.39700	0.78800

Note: This table reports the value of the intermediate input in row k required to produce one dollar of final output in column j (γ_{kj}).

In order to estimate the productivity of each country-sector pair in levels rather than relative to the United States, we need to estimate U.S. productivity in every sector. To do this, we calculate the TFP in each tradable sector using the NBER-CES Manufacturing Industry Database, which reports total output, input usage in production, employment, and capital stock along with sectoral deflators for each. The data are available at the 6-digit NAICS classification and they are converted into the ISIC 2-digit classification using a concordance we have created. Finally, the share of expenditures of traded goods (ξ_h) in each country is sourced from Levchenko and Zhang (2012).

1.9 Appendix B: Estimated Parameters

1. Preferences

a) σ, where $\frac{1}{1-\sigma}$ is the inter-temporal elasticity of substitution

b) η, elasticity of substitution between the tradable sectors

c) ξ_n, Cobb Douglas weight for the tradable sector composite good in country n

d) ω_j, weights of each tradable sector in final consumption

2. Technology

a) ϵ_j, elasticity of substitution in production across goods in sector j

b) α_j, value added based on labor intensity

c) β_j, valued added based on labor intensity

d) γ_{kj}, output industry$j$ requirement from input industry k.

e) θ_j, dispersion of productivity draws in sector j

f) T_n^j, state of technology in country n and sector j

3. Multinational production and Trade barriers

a) d_{ns}^j, iceberg trade cost of exporting from country s to country n in sector j

b) h_{si}^j, iceberg MP cost of produce in country s using technologies from country i in sector j

4. Labor and capital endowment

a) L_n, stock of labor in each country

b) K_n, stock of capital in each country

1.10 Appendix C: Proof of Propositions

1.10.1 Proof of Proposition 1

Proposition 1: *In a two-country, two-sector world economy, the lower the technology of country 1 in sector a (country 1's comparative disadvantage sector) relative to sector b, the higher the probability that firms from country 2 will produce in sector a relative to sector b in country 1.*

Proof. Define the ratio of probabilities that country 2 will produce in country 1 as:

$$\frac{\pi_{112}^{a}}{\pi_{112}^{b}} = \frac{T_2^a}{T_2^b}\left[\frac{T_2^a\left(g^{-\theta}+d^{-\theta}\right)^{-\frac{1}{\theta}}+T_1^b\left[1+(gd)^{-\theta}\right]^{-\frac{1}{\theta}}}{T_2^a\left(g^{-\theta}+d^{-\theta}\right)^{-\frac{1}{\theta}}+T_1^a\left[1+(gd)^{-\theta}\right]^{-\frac{1}{\theta}}}\right]$$

Dividing and multiplying by T_1^a:

$$\frac{\pi_{112}^{a}}{\pi_{112}^{b}} = \frac{T_2^a}{T_2^b}\left[\frac{\frac{T_2^b}{T_1^a}\left(g^{-\theta}+d^{-\theta}\right)^{-\frac{1}{\theta}}+\frac{T_1^b}{T_1^a}\left[1+(gd)^{-\theta}\right]^{-\frac{1}{\theta}}}{\frac{T_1^a}{T_1^b}\left(g^{-\theta}+d^{-\theta}\right)^{-\frac{1}{\theta}}+\left[1+(gd)^{-\theta}\right]^{-\frac{1}{\theta}}}\right]$$

For any set of parameter values T_2^a, T_2^b, and T_1^a consistent with the assumption made, a higher T_1^b increases the comparative disadvantage of country 1 in sector a, increasing the relative probability of hosting multinational production in that sector. In other words, the stronger the comparative advantage of country 1 in sector b, the higher the probability that goods in sector a in country 1 will be produced using the technology of foreign affiliates from country 2. Formally, this means that:

$$\partial\left(\frac{\pi_{112}^{a}}{\pi_{112}^{b}}\right)/\partial T_1^a < 0$$

$$\partial\left(\frac{\pi_{112}^{a}}{\pi_{112}^{b}}\right)/\partial T_2^a > 0$$

$$\partial\left(\frac{\pi_{112}^{a}}{\pi_{112}^{b}}\right)/\partial T_1^a =$$

$$\frac{T_2^b}{T_2^b}\left[T_2^b\left(g^{-\theta}+d^{-\theta}\right)^{-\frac{1}{\theta}}+T_1^b\left[1+(gd)^{-\theta}\right]\right]\left(-\frac{1}{\left(T_1^b\right)^2\left[1+(gd)^{-\theta}\right]}\right) < 0$$

$$\partial\left(\frac{\pi_{112}^{a}}{\pi_{112}^{b}}\right)/\partial T_2^a =$$

$$\frac{\left[T_2^b\left(g^{-\theta}+d^{-\theta}\right)^{-\frac{1}{\theta}}+T_1^b\left[1+(gd)^{-\theta}\right]\right]}{T_2^b}\left(\frac{T_1^a\left[1+(gd)^{-\theta}\right]}{\left(T_2^a\left(g^{-\theta}+d^{-\theta}\right)^{-\frac{1}{\theta}}+T_1^a\left[1+(gd)^{-\theta}\right]\right)^2}\right)>0$$

□

1.10.2 Proof of Proposition 2

Proposition 2: *The more heterogeneous the technology upgrade across sectors toward comparative disadvantage sectors, the lower the dispersion of effective technologies and the lower the gains from trade.*

Proof. Without loss of generality, let us define two welfare scenarios for country 1 (and the same for country 2): First, one in which sectoral productivity increases disproportionately toward comparatively disadvantaged sectors; and a second one in which productivity increases homogeneously in both sectors due to MP.

Scenario 1: To construct the first scenario, we apply a common MP barrier across all sectors ($g^a = g^b = g$). A common g in both sectors causes an uneven technology upgrade across sectors. Using this assumption together with equation (1.14), we can rewrite the expression of technology upgrade in sector j as follows:

$$\frac{\widetilde{T_1^j}}{T_1^j}=\frac{T_1^j+g^{-\theta}T_2^j}{T_1^j}=1+g^{-\theta}\frac{T_2^j}{T_1^j}$$

Replacing this expression in equation (1.25) and using the mirror image assumption ($T_2^a = T_1^b$ and $T_2^b = T_1^a$) yields:

$$GT_{(S1)}=\left[\frac{\left(1+g^{-\theta}\frac{T_1^b}{T_1^a}\right)\left(1+g^{-\theta}\frac{T_1^a}{T_1^b}\right)}{\left((1+(dg)^{-\theta})+\frac{T_1^b}{T_1^a}(g^{-\theta}+d^{-\theta})\right)\left((1+(dg)^{-\theta})+\frac{T_1^a}{T_1^b}(g^{-\theta}+d^{-\theta})\right)}\right]^{-1/2\theta}$$

Scenario 2: To make this scenario comparable to scenario 1, we solve for the set of g^a and g^b such that (1) the productivity upgrade across sectors is the same $\left(\frac{\widetilde{T_h^a}}{T_h^a}=\frac{\widetilde{T_h^b}}{T_h^b}\right)$; and (2) the average effective productivity in country 1 $\left(\frac{\widetilde{T_1^a}+\widetilde{T_1^b}}{2}\right)$ is the same when MP barriers are the same across sectors ($g^a = g^b = g$), as in scenario 1, and also when they are not ($g^a \neq g^b$), as in this scenario.

The first condition implies that:

$$\left(\frac{g^a}{g^b}\right)^{-\theta} = \left(\frac{T_1^a}{T_1^b}\right)^2$$

The second condition implies that:

$$g^{-\theta}\left(T_1^b + T_1^a\right) = g_a^{-\theta} T_1^b + g_b^{-\theta} T_1^a$$

Substituting $g_a^{-\theta} = g_b^{-\theta}\left(\frac{T_1^a}{T_1^b}\right)^2$ from the first equations into the second equation we get expressions for g_a and g_b:

$$g_a^{-\theta} = g^{-\theta}\left(\frac{T_1^a}{T_1^b}\right)$$

and

$$g_b^{-\theta} = g^{-\theta}\left(\frac{T_1^b}{T_1^a}\right)$$

Replacing the expressions for $g_a^{-\theta}$ and $g_b^{-\theta}$ in equation (1.25), we get the gains from trade in Scenario 2 ($GT_{(S2)}$) are equal to:

$$\left[\frac{\left(1+g^{-\theta}\right)^2}{\left(1+\left(dg\frac{T_1^a}{T_1^b}\right)^{-\theta}+\frac{T_1^b}{T_1^a}\left(\left(g\frac{T_1^a}{T_1^b}\right)^{-\theta}+d^{-\theta}\right)\right)\left(1+\left(dg\frac{T_1^b}{T_1^a}\right)^{-\theta}+\frac{T_1^a}{T_1^b}\left(\left(g\frac{T_1^b}{T_1^a}\right)^{-\theta}+d^{-\theta}\right)\right)}\right]^{-1/2\theta}$$

The gains from trade are higher in the counterfactual scenario compared with the actual equilibrium ($GT_{(S2)} > GT_{(S1)}$) if:

$$\frac{\left(1+g^{-\theta}\frac{T_1^b}{T_1^a}\right)\left(1+g^{-\theta}\frac{T_1^a}{T_1^b}\right)}{\left(1+g^{-\theta}\right)^2} > \frac{\left[\left(1+(dg)^{-\theta}\right)+\frac{T_1^b}{T_1^a}\left(g^{-\theta}+d^{-\theta}\right)\right]\left[\left(1+(dg)^{-\theta}\right)+\frac{T_1^a}{T_1^b}\left(g^{-\theta}+d^{-\theta}\right)\right]}{\left[1+\left(dg\frac{T_1^a}{T_1^b}\right)^{-\theta}+\frac{T_1^b}{T_1^a}\left(\left(g\frac{T_1^a}{T_1^b}\right)^{-\theta}+d^{-\theta}\right)\right]\left[1+\left(dg\frac{T_1^b}{T_1^a}\right)^{-\theta}+\frac{T_1^a}{T_1^b}\left(\left(g\frac{T_1^b}{T_1^a}\right)^{-\theta}+d^{-\theta}\right)\right]}$$

or:

$$\frac{\left(1+g^{-\theta}\frac{T_1^b}{T_1^a}\right)\left(1+g^{-\theta}\frac{T_1^a}{T_1^b}\right)}{\left(1+g^{-\theta}\right)^2}\frac{\left[1+\left(dg\frac{T_1^a}{T_1^b}\right)^{-\theta}+\frac{T_1^b}{T_1^a}\left(\left(g\frac{T_1^a}{T_1^b}\right)^{-\theta}+d^{-\theta}\right)\right]}{\left[\left(1+(dg)^{-\theta}\right)+\frac{T_1^b}{T_1^a}\left(g^{-\theta}+d^{-\theta}\right)\right]}\frac{\left[1+\left(dg\frac{T_1^b}{T_1^a}\right)^{-\theta}+\frac{T_1^a}{T_1^b}\left(\left(g\frac{T_1^b}{T_1^a}\right)^{-\theta}+d^{-\theta}\right)\right]}{\left[\left(1+(dg)^{-\theta}\right)+\frac{T_1^a}{T_1^b}\left(g^{-\theta}+d^{-\theta}\right)\right]} > 1$$

The above is true if the following three conditions are satisfied simultaneously:

$$\frac{\left(1+g^{-\theta}\frac{T_1^b}{T_1^a}\right)\left(1+g^{-\theta}\frac{T_1^a}{T_1^b}\right)}{\left(1+g^{-\theta}\right)^2} >= 1$$

$$\frac{\left[1+\left(dg\frac{T_1^a}{T_1^b}\right)^{-\theta}+\frac{T_1^b}{T_1^a}\left(\left(g\frac{T_1^a}{T_1^b}\right)^{-\theta}+d^{-\theta}\right)\right]}{\left[\left(1+(dg)^{-\theta}\right)+\frac{T_1^b}{T_1^a}\left(g^{-\theta}+d^{-\theta}\right)\right]}>=1$$

$$\frac{\left[1+\left(dg\frac{T_1^b}{T_1^a}\right)^{-\theta}+\frac{T_1^a}{T_1^b}\left(\left(g\frac{T_1^b}{T_1^a}\right)^{-\theta}+d^{-\theta}\right)\right]}{\left[\left(1+(dg)^{-\theta}\right)+\frac{T_1^a}{T_1^b}\left(g^{-\theta}+d^{-\theta}\right)\right]}>=1$$

It can be shown that the first condition is true as long as:

$$\frac{T_1^a}{T_1^b}+\frac{T_1^b}{T_1^a}=\left(X+\frac{1}{X}\right)>=2$$

where $X=\frac{T_1^a}{T_1^b}$. This is true for any ratio of productivities $\frac{T_1^a}{T_1^b}$. Note that $\left(X+\frac{1}{X}\right)$ reaches its minimum, which equals 2, when $X=1$. The second and third conditions are always satisfied given that it is always true that $X^{-\theta}>0$ and $\left(X^{-1}\right)^{-\theta}>0$. Therefore, $GT_{(S2)}>GT_{(S1)}$.

□

1.10.3 Proof of Proposition 3

Proposition 3: *The higher the heterogeneity of MP across sectors, the higher the gains from MP. When the share of domestically produced goods is the same across sectors ($y_{hh}^a=y_{hh}^b$), the gains from MP attain a minimum. Therefore, uni-sectoral trade-MP models understate the actual gains from MP as long as $y_{hh}^a\neq y_{hh}^b$*

Proof. The gains from MP are given by:

$$GMP_h=\left[\frac{\left(1+\frac{T_1^a}{T_1^b}d^{-\theta}\right)+\left(1+\frac{T_1^b}{T_1^a}d^{-\theta}\right)}{\left(1+(dg)^{-\theta}\right)+\frac{T_1^a}{T_1^b}\left(g^{-\theta}+d^{-\theta}\right)+\left(1+(dg)^{-\theta}\right)+\frac{T_1^b}{T_1^a}\left(g^{-\theta}+d^{-\theta}\right)}\right]^{-\frac{1}{2\theta}}$$

The first-order condition of this expression is equal to zero when $T_h^a=T_h^b$. At this point, GMP_h attains a minimum given that the second-order condition is higher than zero, as shown below.

$$\frac{\partial GMP_h}{\partial T_1^a/T_1^b} = -\frac{1}{2\theta}\left[Y\right]\left[\left(d^{-\theta}\left(1-X^{-2}\right)\right)\left(2+2\left(dg\right)^{-\theta}+\left(d^{-\theta}+g^{-\theta}\right)\left(X^{-1}+X\right)\right)\right] + \frac{1}{2\theta}\left[Y\right]\left[\left(2+d^{-\theta}\left(X^{-1}+X\right)\right)\left(\left(d^{-\theta}+g^{-\theta}\right)\left(1-X^{-2}\right)\right)\right] \tag{1.52}$$

where $Y = GMP_h^{-\frac{1}{2\theta}-1}$ and $X = T_1^a/T_1^b$. The above equation is equal to zero only when $T_1^a = T_1^b$. As shown below, the second derivative of GMP_h is positive; therefore, we reach a minimum when relative productivities are the same across sectors:

$$\frac{\partial^2 GMP_h}{\partial\left(T_1^a/T_1^b\right)^2} > 0$$

□

1.11 Appendix D: Equilibrium Solution

Given $\left\{L_h, K_h, \left\{T_h^j\right\}_{j=1}^J, \xi_n\right\}_{n=1}^N$, $\left\{\varepsilon, \alpha_j, \theta^j, \beta_j, \{\gamma_{k,j}\}, \left\{g_{hs}^j\right\}_{N\times N}, \left\{d_{hs}^j\right\}_{N\times N}\right\}_{j=1}^{J+1}$, and η, we compute the competitive equilibrium of the model as follows.

1. Guess $\{w_h, r_h\}_{n=1}^N$

a) Compute the prices from the following equations:

$$c_h^j = \left[(w_h)^{\alpha_j}(r_h)^{1-\alpha_j}\right]^{\beta_j}\left[\prod_{k=1}^{J+1}\left(p_h^k\right)^{\gamma_{kj}}\right]^{1-\beta_j}$$

$$\delta_{mhs}^j = c_h g_{hs} d_{mh}$$

$$\Delta_{ms}^j = \left[\sum_h \left(\delta_{mhs}^j\right)^{-\theta_j}\right]^{-\frac{1}{\theta_j}}$$

$$\widetilde{\Delta}_m^j = \sum_s T_s^j\left(\Delta_{ms}^j\right)^{-\theta_j}$$

$$\widetilde{\Delta}_m^{J+1} = \sum_s T_s^{J+1}\left(c_m^{J+1} g_{hs}^{J+1}\right)^{-\theta_j}$$

$$p_m^j = \Gamma_j\left(\widetilde{\Delta}_m^j\right)^{-\frac{1}{\theta_j}}$$

$$P_m = B_m\left(\sum_{j=1}^J \omega_j (p_m)^{1-\eta}\right)^{\frac{1}{1-\eta}\xi_m}\left(p_m^{J+1}\right)^{1-\xi_n}$$

b) Compute the final demand as follows: for any country n:

$$Y_m^j = \xi_n \frac{w_m L_m + r_m K_m}{p_m^j}\frac{\omega_j\left(p_m^j\right)^{1-\eta}}{\sum_{k=1}^J \omega_k\left(p_m^k\right)^{1-\eta}} \quad \forall j \in \{1, ..., J\}$$

$$Y_m^{J+1} = (1-\xi_m)\frac{w_m L_m + r_m K_m}{p_m^{J+1}}$$

c) Compute the probabilities π_{mhs}^j as follows:

$$\pi_{mhs}^j = \frac{T_s^j\left(h_{hs}^j\right)^{-\theta_j}\left(c_h^j d_{mh}^j\right)^{-\theta_j}}{\sum_h\sum_s T_s^j\left(g_{hs}^j\right)^{-\theta}\left(c_h^j d_{mh}^j\right)^{-\theta_j}}$$

d) Total Demand. In this section we are looking for the Q_h^k that satisfies the following equation:

$$p_h^j Q_h^j = p_h^j Y_h^j + \sum_{k=1}^{J} (1-\beta_k)\,\gamma_{j,k} \left(\sum_{m=1}^{N} \sum_{s=1}^{N} \pi_{mhs}^k p_m^k Q_m^k \right) + (1-\beta_{J+1})\,\gamma_{j,J+1} \sum_{s=1}^{N} \pi_{hhs}^{J+1} p_h^{J+1} Q_h^{J+1}$$

e) Compute the factor allocations across sectors as follows: for any country n

$$\sum_{m=1}^{N} \sum_{s=1}^{N} \pi_{mhs}^j p_m^j Q_m^j = \frac{w_h L_h^j}{\alpha_j \beta_j} = \frac{r_h K_h^j}{(1-\alpha_j)\,\beta_j}$$

$$\sum_{s=1}^{N} \pi_{hhs}^{J+1} p_m^{J+1} Q_m^{J+1} = \frac{w_h L_h^{J+1}}{\alpha_{J+1} \beta_{J+1}} = \frac{r_h K_h^{J+1}}{(1-\alpha_{J+1})\,\beta_{J+1}}$$

f) Update $\{w_h', r_h'\}_{n=1}^N$ with the feasibility conditions for factors: for any n

$$\sum_{j=1}^{J+1} L_h^j = L_h, \ \sum_{j=1}^{J+1} K_h^j = K_h$$

2. Repeat the above procedures until $\{w_h', r_h'\}_{n=1}^N$ is close enough to $\{w_h, r_h\}_{n=1}^N$.

1.12 Appendix E: Estimation

1.12.1 Effective technology: two-step procedure

The importer fixed effect recovered from the gravity equation is given by:

$$S_n^j = \frac{\widetilde{T}_n^j}{\widetilde{T}_{us}^j}\left(\frac{c_n^j}{c_{us}^j}\right)^{-\theta}$$

The share of spending on home-produced goods is given by:

$$\frac{X_{nn}^j}{X_n^j} = \widetilde{T}_n^j\left(\frac{c_n^j}{p_n^j}\right)^{-\theta}$$

Dividing it by US, we have:

$$\frac{X_{nn}^j/X_n^j}{X_{us,us}^j/X_{us}^j} = \frac{\widetilde{T}_n^j}{\widetilde{T}_{us}^j}\left(\frac{c_n^j}{c_{us}^j}\right)^{-\theta}\left(\frac{p_n^j}{p_{us}^j}\right)^{-\theta} = S_n^j\left(\frac{p_{us}^j}{p_n^j}\right)^{-\theta}$$

The ratio of price levels in sector j relative to US becomes

$$\frac{p_n^j}{p_{us}^j} = \left(\frac{X_{nn}^j/X_n^j}{X_{us,us}^j/X_{us}^j}\frac{1}{S_n^j}\right)^{\frac{1}{\theta}}$$

Then, cost of the input bundles relative to the U.S can be written as:

$$\frac{c_n^j}{c_{us}^j} = \left(\frac{w_n^j}{w_{us}^j}\right)^{\alpha_j\beta_j}\left(\frac{r_n^j}{r_{us}^j}\right)^{(1-\alpha_j)\beta_j}\left(\prod_{k=1}^{J+1}\left(\frac{p_n^k}{p_{us}^k}\right)^{\gamma_{k,j}}\right)^{1-\beta_j}$$

CHAPTER II

Multinational Production and Intra-firm Trade

2.1 Introduction

The proximity-concentration tradeoff constitutes the basis of one of the most important theories of multinational production. 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; Irarrazabal et al., 2013). That is, rather than avoid the transportation costs associated with exports, multinational sales also decrease with 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 use of intermediate inputs produced by the parent introduces a source of complementarities between trade and multinational production if in order to produce overseas, foreign affiliates have to import intermediate inputs from their home market.

Intra-firm trade is an important component of U.S. international trade. In particular, exports of manufactured goods from U.S. parents to their cross-border network of affiliates account for 20 percent of U.S. exports; and intra-firm imports by foreign-controlled U.S. affiliates from their foreign parent groups have generally accounted for 20-25 percent of total U.S. imports [1]. Thus, to reconcile the theory of horizontal

[1] Bureau of economic Analysis.

multinational activity with the new empirical facts, new models have incorporated intra-firm transactions in the workhorse framework of trade and foreign direct investment (FDI) (Helpman et al., 2004. HMY, henceforth).

A striking feature of intra-firm trade is its pronounced heterogeneity across firms; not only at the aggregate level, but also at the sector-destination country level. In particular, using detailed data from the Bureau of Economic Analysis, Ramondo et al. (2014) have documented that intra-firm trade is concentrated among a small number of large affiliates and it represents only a very small fraction of their input and their total sales. For example, in 2004, the median manufacturing affiliate, measured by sales, received none of its inputs from its parent firm,[2] and sold 91 percent of its production to unrelated parties, mostly in the host country. The skewness of intra-firm flows toward large corporations, and the bias of multinational sales to local unrelated parties are robust to both the country of destination and the industry of operations.

These findings pose new challenges to the theory. First, existent models take it for granted that all affiliates import from their parents and therefore are silent about the selection and the skewness observed in intra-firm flows. Second, if intra-firm trade is what causes affiliate sales to decline with increases in trade frictions, then gravity forces will affect only those firms in the upper tail of the firm size distribution but not the relatively small firms.[3] Using the ORBIS dataset, we present evidence showing that the gravity of foreign sales could not be explained solely by intra-firm trade. In fact, we show that even firms that likely do not engage in intra-firm trade exhibit a significant resistance to geographical barriers. In particular, we divide the sample of firms by the likelihood of engaging in intra-firm transaction and show that the standard gravity variables (i.e., distance, common border, common language, and regional trade agreements) play a significant role in diminishing the observed foreign

[2]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 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.

[3]The fact that foreign affiliate sales decline with increases in trade frictions (gravity of multinational activity) also poses important challenges to the theory of multinational production based on vertical integration. In contrast with horizontal intra-firm FDI models in which firms may or may not engage in intra-firm trade, in models of vertical multinational production, intra-firm transactions are a necessary condition for the existence of foreign affiliates, whose main role is to provide cheaper 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 firm within a corporation that sell the majority of their output to unrelated parties in the host market.

affiliate sales of all firms, regardless of their size. As expected, gravity forces diminish the sales of large affiliates which often engage in intra-firm trade. But the gravity frictions also negatively and significantly affect the sales of the relatively small foreign affiliates, which often do not trade with their parents and sell the vast majority of their output to unrelated parties in the host market.[4]

The previous finding it is at odds with the predictions of new FDI intra-firm models, where the gravity of multinational production relies on the existence of intra-firm flows. Therefore, to capture the former stylized fact and to account for the extensive margin of intra-firm trade, this paper develops a multi-country model of heterogeneous firms, in which parents decide whether or not to supply foreign affiliates with intermediate inputs and if so, optimally decide the fraction that will be imported from the parent company. The proposed theoretical framework matches the distribution of multinational sales as well as the intra-firm trade patterns observed in the data: the less productive firms do not import intermediate inputs from their parent, whereas the most productive ones engage in intra-firm trade. In the model, the selection is explained by the irreversible investment that a multinational corporation has to make in order to establish an adequate platform to carry on cross-border transactions within the boundaries of the firm on a regular basis. The high cost associated with these important coordination efforts is a fact well explored in the international management literature (Seuring and Goldbach, 2002).

This paper contributes to previous efforts to rationalize intra-firm trade patterns. Irarrazabal et al. (2013) propose an HMY model of horizontal multinational production with intra-firm trade from parents to affiliates. Their model assumes that the final good produced by affiliates is assembled in a Cobb Douglas fashion using local labor and intermediate inputs produced and shipped by the parent. As a consequence, all firms engage in intra-firm trade and imported intermediate inputs from the parent as a share of total cost are the same for all firms regardless of their productivity level. Similarly, Ramondo and Rodriguez-Clare (2013b) develop a general equilibrium model of trade and multinational production under perfect competition in which foreign affiliates use an international input bundle in production, where some fraction is obtained in the local market and the rest comes from the parent firm. This paper differs from these approaches in that it endogenizes the existence of intra-firm trade as well as the degree to which it occurs.

[4] The results are robust to whether the sample of firms is divided above and below the fiftieth percentile or instead it is divided above the seventy-fifth percentile and below the twenty-fifth percentile. The results of the impact of gravity on multinational activity are also robust to different econometric specifications.

Following Keller and Yeaple (2013), we assume that there are two ways in which a foreign affiliate can absorb the productivity level of its parent company. Either the affiliate establishes communication with its headquarters to receive the necessary instructions (direct knowledge transfer) or alternatively, the parent can transfer knowledge across borders by exporting intermediate inputs embodying technology to its affiliates (indirect knowledge transfer). In the first case the affiliate incurs the cost of transferring knowledge across countries; but it saves the transportation cost associated with importing intermediate inputs from its parent. Therefore, under this framework, multinational sales of more knowledge-intensive firms will suffer more strongly from gravity, precisely because these companies face relatively high costs of direct knowledge transfer, reducing the elasticity of intra-firm trade to changes in transportation cost. In Keller and Yeaple (2013) model, although affiliates differ in their share of imported intermediate inputs from the parent, all affiliates buy some inputs from their headquarters. However, in the data, only a small fraction of firms, often relatively large, import from their parent while a vast majority of them report zero intra-firm flows.[5]

Our paper improves upon the previous theoretical framework in several dimensions in order to reproduce several of the recently uncovered stylized facts of intra-firm trade. First, in the model presented in this paper knowledge intensity is firm-specific rather than sector-specific. This is based of the fact that the knowledge intensity is more heterogeneous across firms within an industry than it is across industries. Second, knowledge intensity affects not only the composition or degree of in-house production versus imported intermediate inputs, but also the existence of intra-firm trade itself. Therefore, firms could optimally decide not to engage in intra-firm trade given that developing an international distribution channel within the firm entails a fixed cost.[6] Third, the share of imported intermediate inputs increases with firms

[5]In their appendix, Keller and Yeaple sketch an extension of the original model in which firms have the option of paying a fixed cost for investing in information and communication technology in order to lower the efficiency cost of knowledge transfer by reducing the efficiency loss of remote production. An implication of this extension is that only the most productive firms produce a larger fraction of their intermediate input in the host market, given that only these affiliates are able to afford the fixed cost. However, this prediction is contrary to the patterns observed in the data in which only the most productive firms engage in intra-firm trade. Instead, our model proposes a very different type of fixed cost, which allows it to generate the observed selection. In our model, in order to engage in intra-firm trade the corporation has to build a complex distribution network that allows frequent trade between related affiliates operating in different countries.

[6]It might seem that the affiliate's need for instructions from the parent firm would decrease with time, as the affiliate moves along the learning curve. However, multinational firms develop innovation at a high rate and new techniques will constantly be passed to the affiliates in the form of direct technology transfer.

productivity. Fourth, communication costs are higher, the higher the knowledge intensity of the intermediate inputs and the larger the distance between the parent and the foreign affiliate.[7]

From an empirical perspective, it has been a challenge to unveil the determinants of multinational production and intra-firm trade. One of the reasons is the limited data available to distinguish vertical and horizontal FDI. In fact, very often the existence of intra-firm trade has been interpreted as evidence of vertical MP. This is because under vertical integration foreign production will always result in intra-firm flows from affiliates to parents or to other affiliates within the corporation.[8] Nevertheless, horizontal MP can also rationalize intra-firm transactions from parents to affiliates when the latter imports knowledge embedded in intermediate inputs. The magnitude and direction of intra-firm flows could shed light on the relative importance of these two alternative theories, given that horizontal MP will be compatible with intra-firm transactions from the parent to the affiliate, while vertical MP will be compatible with transactions in both directions, but more strongly from affiliates to parent firms.[9] Even though we recognize the richness of intra-firm transactions, which also include sales from affiliates to parents as well as from affiliates to affiliates, the model developed in this paper focuses on intra-firm trade from the parent to its network of foreign affiliates, which is quantitatively important and consistent with a model of horizontal multinational production.[10]

[7] For example, communications tend to be more cumbersome when firms are located in different time zones, or in countries with different languages.

[8] Vertically integrated firms often set operations abroad to produce cheaper intermediate inputs within the boundaries of the firm in order to internalize any product contractibility issue and potential spillovers of proprietary knowledge that could emerge from outsourcing.

[9] For the United States there are two main sources of information. One of them is the U.S. Census Bureau, which administrates the information contained in the custom declaration that includes information on ownership ties between the foreign and domestic parties involved in any transactions. The other main source is the U.S. Commerce Department's Bureau of Economic Analysis, which conducts extensive surveys of multinational firms that include questions on the value of specific trade flows between foreign and domestic units of the firm. The Census data provides comprehensive detail on the goods traded between U.S. parents and affiliates overseas and also between foreign parents and their affiliates operating in the United States. With these data it is possible to identify not only the type of relationship between the parties involved in the international transaction, but also the nationality of the parties. Unfortunately, the Census Bureau does not collect further information on the activity of the foreign party in the transaction. On the other hand, the BEA data offer in-depth information about affiliates' operations, including total assets, sales, net income, employment, and $R\&D$. The BEA data also have information about international transactions between the affiliate and related or unrelated parties, including the parent company, either in the host market or in third markets. Unfortunately, foreign affiliates report related parties' sales to third markets only in total, not by country. For this reason, even when it is possible to track intra-firm transactions between parents and affiliates, it is not possible to track the trade among foreign affiliates within the same company.

[10] Zeile (2003), using detailed data from the Census Bureau, finds that U.S. intra-firm exports

The reminder of the paper is organized as follows. Section 2 discusses the main source of data in our analysis and it also describes the main characteristics of multinational sales at the firm level. Section 3 presents the stylized facts that support the main assumption in our model. Section 4 lays out the theoretical framework and derives the analytical implications for intra-firm flows and multinational sales. Section 5 discusses the parametrization, the functional forms, and the estimation strategy of some of the model's key parameters. Section 6 presents the general equilibrium and the gravity equations of affiliate sales for firms that do engage in intra-firm trade and those that do not. Section 7 concludes.

2.2 Data

The primary source of data is ORBIS, which contains information at the level of the firm for a wide range of countries. In particular, it contains detailed information about the ownership structure of the firm, including the company's degree of independence, and its ultimate owner.[11] Unlike the Census Bureau, ORBIS does not keep records of the transactions between parents and their affiliate firms. Instead it offers information about foreign affiliates' operations, such as sales, employment, assets, and capital, among others.[12]

For the purpose of this analysis we have constructed two samples. The first sample comprises U.S. affiliate firms operating outside the United States, but whose ultimate owners—or parents—are located in the United States. The second sample groups affiliates operating in the United States, but whose parents are located overseas. In both samples, we only consider foreign affiliates that are majority owned (or wholly owned) and which operating revenue is known for at least one of the years in the period (2004-2012).[13]

mainly consist of shipments from U.S. parent companies to their foreign affiliates, and U.S. intra-firm imports mainly consist of shipments from foreign parent groups to U.S. affiliates.

[11] Alfaro and Chen (2012) assess the extent and coverage of this dataset using more aggregate information from alternative sources. Because the focus here is on affiliates owned by U.S. parent firms, as well as U.S. affiliates owned by foreign parents, we have used the aggregate values in the BEA data to evaluate the accuracy of the information provided by Orbis.

[12] The best characterization of the intra-firm trade can be obtained from the Census Bureau, but it lacks information about the activity of affiliates, including the type and destination of their exports, which is contained in the BEA data.

[13] Therefore we only consider firms with a Global Ultimate Owner (GUO), a firm that exercises the highest control over the affiliate and that owns at least fifty percent of the shares. We also consider a company to be an ultimate owner if it has no identified shareholders or if its shareholders' percentages are not known. The definition of global ultimate owner adopted in this paper, with a minimum of 50 percent ownership, is also the one followed by international agencies and by the U.S.

Our sample only contains firms in the manufacturing sectors and it covers more than 9,000 U.S.-owned affiliates operating in thirty-four developed countries (see Table 2.1). 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 fifteen employees. Furthermore, to alleviate the problem of potential outliers, we eliminate firms below the first percentile and above the 99th 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 (2004-2012).

2.3 Stylized Facts

In this section we introduce some key regularities about affiliate sales and the location patterns of U.S. multinational firms. First, we show that the knowledge intensity of U.S. parents is very heterogeneous across firms, even within very narrowly defined sectors. Second, we show that the vast majority of U.S. parents operate in only one foreign market regardless of the manufacturing industry; and for any given market-sector pair, the market share of U.S. foreign production is concentrated in a very small set of affiliates. Third, we present empirical evidence that intra-firm trade alone is not enough to explain the observed strong dampening effect of distance on multinational production. Overall, this section describes the motivation for this study and provides support for the building blocks of the model proposed in section 4.

Fact 1: *Research and development intensity is highly heterogeneous across multinational firms within a narrowly defined industry.* The average research intensity varies significantly across parent firms, even in very narrowly defined industries. Figure 2.2 shows the distribution of R&D shares for the pool of U.S. parents in the sample, regardless of industry classification. As can be observed, the expenditure on 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 few very large firms. Figure 2.3 shows the distribution of parents' R&D share for four selected 3-digit NACE sectors: (1) manufactured of parts and accessories for motor vehicles—NACE 293 (top-left panel), (2) manufacture of other special-purpose machinery—NACE 289 (top-right panel), (3) manufacture of basic pharmaceutical products—NACE 211 (bottom-left panel), and (4) manufacture of

Bureau of Economic Analysis.

air and spacecraft and related machinery—NACE 303 (bottom-right panel). Firm productivity is measured by the value of output per worker of the U.S. parent, and the share of R&D is calculated as the fraction 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.

However, ORBIS provides information on R&D expenditures for only one-third of U.S. ultimate owners with at least one foreign affiliate. In order to assess how this could bias our previous results, Figure 2.4 shows the distribution of productivity for two groups of parent firms: those for which the ORBIS dataset contain information regarding expenditures on research and development activities; and those for which this variable is missing. Figure 2.4 highlights that those firms for which ORBIS does not record information about R&D expenditures are on average less productive than firms for which it does. Therefore, it appears from this evidence that even when multinationals are responsible for the majority of the private R&D activities, the largest share of the R&D expenditures in any given industry is mainly carried on by a few very productive U.S. parent firms.

Fact 2: *The distribution of foreign affiliate sales is fat-tailed, for each country-sector pair.*

A well documented fact is that firm sales follow a Zipf Law distribution (Gabaix, 2009 and 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 section, 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 fat-tailed. This is the case not only overall, within an industry, or within a country, but also for a given country-sector pair.

Figure 2.5 evaluates the participation of U.S. parents in foreign markets. Each parent produces on average in two foreign economies, but fifty percent of the parents only produce in one market besides United States. Strikingly, the mean coincide with the number of markets penetrated by a firm in the 75 percentile of the distribution. Ten percent of the parent firms produce in more than four markets and only five percent of all firms set operations in seven or more foreign countries.

Fact 3: *Intra-firm trade alone cannot explain the observed gravity of multinational sales.*

Intra-firm trade from the parent to the cross-border network of foreign affiliates has been the approach used in the literature to rationalize the gravity of multinational production, meaning that aggregate foreign affiliate sales fall with geographical barriers. Nevertheless, only the most productive foreign affiliates buy intermediate inputs from their parent firms in the United States, a fact that is robust across countries and also across industries (Ramondo et al., 2014). From the perspective of the existing models, this implies that only sales of foreign affiliates located at the upper-tail of the size distribution should suffer from gravity. Conversely, in this subsection we present some evidence showing that the gravity of foreign sales could not solely be explained by intra-firm trade. In fact, we show that even firms that likely do not engage in intra-firm trade exhibit a significant resistance to geographical barriers.[14]

Ideally, we would like to test the existence of gravity for two groups of firms: those that participate in intra-firm trade transactions and those that do not. Unfortunately, for this paper we do not have access to intra-firm trade data at the firm level.[15] Instead, we divide U.S. affiliates by size into two groups for any given host country-sector pair. First, we split the whole sample of firms into two subsamples at the 50th percentile of the size distribution. This criterion is based on Ramondo et al. (2014) who found that none of the affiliates below the median import intermediate inputs from their parent firms.[16,17] Second, we divide the sample of firms by those that belong to the lower-tail (below 25th percentile) and the upper-tail (above 75th percentile) of the firm size distribution, in each country-sector pair. Taking only the extremes of the firm size distribution reduces the likelihood that relatively small firms will engage in intra-firm trade, and increases the likelihood that the very large firms

[14]Most models of horizontal multinational production fail to account for the observed selection of intra-firm trade, assuming instead that all firms will require some fraction of the intermediate inputs from the parents. In section 2.4 we propose a model to account for the intensive and extensive margins of intra-firm trade.

[15]To overcome this limitation we are working in a project to merge ORBIS firm-level data with the Census Bureau data, to get a perspective of the transactions between U.S. multinationals and their foreign affiliates as well as of the economic activity of U.S. affiliates overseas.

[16]Our criterion differs from Ramondo et al. (2014) in that their finding is established for the median firm in a given industry and in a given region. Instead, we split the sample based on the median firm in each country-sector pair.

[17]As discussed in the introduction to this paper, the fact that firms do not import intermediate inputs from the parent firm does not mean they are not engaged in intra-firm trade with other affiliates within the same corporation. Ramondo et al. (2014) find that regardless of firm size, the majority of affiliates sell their output to unrelated parties in the host country. Unfortunately, intra-firm imports from affiliates other than the U.S. parents are not captured by any of the available data sources.

will.

Below we present the results of the gravity equation that comes from different specifications and samples. Table 2.2 presents the results of the regression for the intensive and extensive margin of multinational activity (columns 1 and 2) as well as for the extensive margin only (columns 3 and 4). It includes all U.S. multinational firms in our sample, and the data have been aggregated up to the country-sector level. As a proxy for geographical barriers, we have included the log of physical distance ($ln\,(dist_{i,us})$), a set of dummy variables indicating whether countries share a common border ($Border_{i,us}$), have a common language ($Language_{i,us}$), belong to a regional trade agreement ($RTA_{i,us}$), and whether they have had a colony relationship ($Colony_{i,us}$). In columns 1 and 3 we also control for some key characteristics of the host country that could determine the scale of foreign operations and so directly affect the volume of local sales and intra-firm trade. These controls include the capital endowment relative to the United States, a measure of the size of the market (GDP per capita), and a proxy for institutional quality measured by the Rule of Law variable from the Worldwide Governance Indicators database of the World Bank. In order to account for other country characteristics that are potential determinants of FDI and that are not included in our regression, such as relative technology differences and skill endowments, in columns 2 and 4 we include instead country fixed effects to control for any country-specific characteristic that could affect the gravity of multinational production. Notice that in both specifications sector fixed effects are included to control for the observed sectoral heterogeneity of multinational production, which can affect the impact of gravity variables on MP sales as well as on the number of firms that produce overseas.

Consistent with previous studies, both the total affiliate sales and the number of U.S. parents decrease with trade barriers, and in particular, they decline with distance from the United States in both specifications. Having a common language positively affects both margins of MP; nevertheless, it loses statistical significance once we control for country fixed effect. The existence of a trade agreement between the United States and the host economy significantly increases the affiliates' sales but negatively affects the number of firms that engage in foreign production. A potential explanation is that trade agreements increase the sales of U.S. firms in the foreign market by facilitating intra-firm transactions with the parent firm, but reduce the number of firms that find it profitable to engage in multinational production given that exporting becomes more attractive. Of the host country-specific variables, the size of the host market (GDP) and the level of capital show the expected size and are significant. On the other hand, foreign affiliate sales fall in host country institutional quality.[18]

To further explore whether the negative effect of geographical barriers on MP is not driven only by those firms that engage in intra-firm trade, Table 2.3 and Table 2.4 present the results of gravity on number of firms and MP sales, respectively, but this time dividing the sample into firms below and above the median of the firm size distribution in each country-sector pair. Columns 1 and 2 show that, for both groups, the number of firms and the MP sales decrease with distance, showing a negative and statistically significant coefficient for firms below and above the median. Notice that the coefficients on the distance variable in Table 2.4 are very similar when country fixed effects are included.

Given that we are relying on the size of the firm as a proxy of its participation in intra-firm trade, we reproduce the above exercise but this time we only consider firms under the 25th percentile, which most likely do not engage in intra-firm trade, as well as firms above the 75th percentile of the distribution, which most likely do conduct intra-firm transactions.[19] Tables 2.5 and 2.6 reproduce the gravity regression for the group of firms in the tails of the firm size distribution. Consistent with previous results for both groups of firms, foreign sales and number of firms are significantly lower in countries far from the United States.

So far, the evidence shows that regardless of firm size, multinational sales are significantly affected by gravity forces. Therefore, the data reject a model in which the only source of MP gravity comes from intra-firm trade. The model presented in the next section addresses two important issues. First, the observed selection in intra-firm trade: only very a few large firms conduct intra-firm transactions across borders within the firm. Second, the model proposes another source of gravity to capture the fact that multinational firms that do not trade with their affiliates are nonetheless significantly affected by gravity.

[18]At first glance, this seems a very surprising result, but it is possible that it is driven by the fact that United States has less room to exploit its institutional comparative advantage in countries with a high level of law enforcement. In light of the theory of the boundaries of the firm, this finding could go with both of the leading theories in this vein: transaction costs theory and property rights theory. According to transaction costs theory, better institutional setting reduces the need for vertical integration, reducing the number of majority-owned affiliates. Incorporating this finding with the property rights theory is more subtle: if contractibility is a more important element of the investments carried out by the headquarters, then the result is consistent with the property rights theory; as institutions advance, the need to provide more incentives to headquarters declines, leading to less vertical integration.

[19]The fact that the firm size follows a Zipf law distribution, and also that the distribution of foreign sales is fat-tailed, suggests that some firms above the median are not large enough to trade within the firm.

2.4 The Model

Our model is based on Helpman et al. (2004). Firms are heterogeneous in terms of their productivity and goods are horizontally differentiated with each variety produced by a firm that acts as a monopolist competitor. A firm can enter the foreign market either by exporting or by opening a foreign affiliate in the destination market (FDI). In choosing between the two modes of entry, a firm faces a proximity-concentration trade-off: establishing a foreign affiliate allows the firm to save the transportation cost of exporting, but the saving is offset by the fixed cost of operating overseas. The model predicts a definitive hierarchy of firms: least productive firms do not produce, low productive firms sell only to the domestic market, medium productive firms export, and most productive firms turn into multinational corporations. Furthermore, similar to Irarrazabal 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 several ways. First, in order to be consistent with the fact that intra-firm trade is concentrated among the most productive multinational corporations with the majority of affiliates reporting zero intra-firm trade, we introduce a fixed cost of intra-firm trade. Second, in contrast to Irarrazabal et al. (2013), the share of imported intermediate inputs in total intermediate input cost is not constant and varies with firm size. Unlike Keller and Yeaple (2013) and consistent with the empirical fact that the share of intermediate inputs in total input costs also increases with firm size, we tie firm productivity to firm knowledge intensity (R&D). Finally, we show that FDI-gravity forces are present in the model even for affiliates that do not import from their parents.

2.4.1 Consumer Demand

The world economy consists of N countries (indexed by i, n). Each country is populated by L_n utility-maximizing 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. A consumer's preferences between the homogenous good and the differentiated goods sector are represented by a Cobb-Douglas utility function with an income fraction μ

spent on the differentiated goods

$$U_n = Q_0^{1-\mu} Q_n^{\mu}, \quad \mu \in (0,1) \tag{2.1}$$

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

$$.Q_n = \left[\int\limits_{\omega \in \Omega_n} q^d(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}}. \tag{2.2}$$

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, and A_n is an index of market size in country n.[20]

2.4.2 Production and Market Structure

The market for the homogeneous good is perfectly competitive, and it is freely traded in the world economy. The production technology of the homogeneous product is linear in labor: one unit of labor are required to produce one unit in country n.[21] The price of the homogeneous good is normalized to one; in effect, the wage in country n is pinned down by the numeraire and is equal to w_n.[22]

Each country n is endowed with an exogenously determined 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 firm-specific, and it 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 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 by the firm from a CES aggregation of a continuum

[20] $A_n \equiv \mu \frac{X_n}{P_n^{1-\sigma}}$. The aggregate price level of the differentiated goods sector in country n is denoted by P_n, and X_n represents the total expenditures in country n.

[21] As long as $1-\mu$, L_n, and the variable trade costs are large enough, the production of the homogeneous good Q_0 in country $n \in \{1, 2, \ldots N\}$ is strictly positive.

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

of intermediate inputs with elasticity of substitution $\eta \geq 1$:[23]

$$M_{\varphi} = \left(\int_{0}^{\infty} \beta(z|\varphi)^{\frac{1}{\eta}} m(z)^{\frac{\eta-1}{\eta}} dz \right)^{\frac{\eta}{\eta-1}}. \tag{2.3}$$

Four notes warrant attention here: (i) $m(z)$ is the quantity of an intermediate input of knowledge intensity z, with higher z indicating higher knowledge intensity; (ii) $\beta(z|\varphi)$ is the cost share of intermediate input z in the total cost of the intermediate input bundle specific to the φ-firm, and $\int_0^\infty \beta(z|\varphi)dz = 1$ for any φ; (iii) $\beta(z|\varphi)$ 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 in 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 $\varphi^1 > \varphi^2$, $\beta(z^{'}|\varphi^1)\beta(z^{''}|\varphi^2) > \beta(z^{'}|\varphi^2)\beta(z^{''}|\varphi^1)$. In other words, firm φ^1 is more knowledge-intensive because it requires relatively more knowledge-intensive intermediate inputs relative to the low-productivity firm φ^2;[24] and (iv) production technology of producing intermediate inputs is common across all firms: one unit of labor is needed to produce one unit of intermediate input z.

2.4.3 Mode of Entry

To gain access to the domestic market in country n, a domestic firm in country n incurs a fixed cost of production of f_{nn} units of labor. Exports from country i to country n are subject to fixed cost f_{ni} (measured in units of labor in country i),[25] and iceberg-type variable trade costs, $\tau_{ni} > 1$. Firms from country i can also serve country n via FDI by paying a fixed cost, f_{ni}^{fdi} (measured in units of labor in country n). In so doing, a firm avoids the transportation costs associated with shipping the final good, but incurs an additional fixed cost of operating an affiliate in country n. Conditional on establishing a foreign affiliate in country n, a parent firm in country i could let its affiliate produce the composite intermediate inputs M (standard HMY setting), or the parent could choose to ship intermediate inputs to its affiliate, where

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

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

[25]In f_{ni} the first subscript refers to the destination market and the second one to the origin country.

the fraction of inputs offshored and the volume of intra-firm trade are endogenous.[26] A parent incurs a fixed cost, f_{ni}^{int} (measured in units of labor in country i), to initiate intra-firm trade and it also incurs the standard iceberg-type trade costs τ_{ni}, for the shipped intermediate inputs.

2.4.3.1 Intra-firm Trade and Knowledge Transfer

There are two ways in which parents can transfer knowledge to their foreign affiliates. (i) *Embodied knowledge transfer*: simply, a parent produces intermediate input z and ships it to the affiliate in country n. (ii) *Disembodied knowledge transfer*: parent firms directly transfer knowledge to their affiliates through remotely communication. Nonetheless, transferring the knowledge required to produce intermediate input z entail communication cost, and the possibility for mis-implementation and mis-interpretation. Differently put, knowledge is not perfectly codified and therefore any knowledge transfer between a parent and its affiliate is subject to error. Intuitively, the higher the knowledge intensity of the intermediate input z, the higher the costs of transferring knowledge from a parent to the affiliate. As mentioned above the knowledge transfer costs are denoted by $t(z)$. To capture the idea that the cost of moving knowledge over space increases with knowledge intensity z, we assume that $t(0) = 0$, $\lim_{z\to\infty} t(z) > \tau_{ni}$ and $t'(z) > 0$.[27]

Finally, the production technology of the final good is invariant to the location of the producer: 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 decision to export, to open an affiliate, or to outsource intermediate inputs affects production of the final good only insofar as it affects production of the composite intermediate input M_φ.

2.4.4 Partial Equilibrium

First, we characterize the geography of input sourcing. The decision whether to outsource the production of intermediate input z is simply pinned down by com-

[26]If a parent in country i does not trade with its affiliate in country n, it has to transfer knowledge by establishing direct communications with the affiliate's manager. Here we assume an affiliate suffers some productivity losses when it receives instructions remotely from its parent in order to produce intermediate inputs by itself. Therefore, an affiliate needs $t_{ni}(z) > 1$ units of labor to produce one unit of intermediate input z. A crucial assumption in our model is that $t_{ni}(\varphi)$ is a function of trade frictions τ_{ni}. Nevertheless, the impact of distance, language, time zone differences, and border on trade frictions, τ_{ni}, is stronger on physical shipping compared with their effect on the cost of knowledge transfer. Formally, $0 < \frac{\partial t_{ni}}{\partial \tau} < 1$.

[27]Notice that the cost of knowledge transfer is not firm-specific; however, the aggregate cost of disembodied knowledge transfer for a given fraction of the intermediate inputs varies across firms.

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

$$C^M_{ni}(\tau_{ni}, \mathcal{I}(\varphi), \varphi, \varpi) =$$

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

where $\bar{t} \equiv \int_0^\infty \beta(z|\varphi)t(z)^{1-\eta}dz$.[28]

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 a firm's productivity draw φ. Indeed, $C^M_{ni}(\tau_{ni}, \mathcal{I}(\varphi) = 1, \varphi) < C^M_{ni}(\tau_{ni}, \mathcal{I}(\varphi) = 0, \varphi)$.[29]

The elasticity of $C^M_{ni}(\tau_{ni}, \mathcal{I}(\varphi) = 1, \varphi, \varpi)$ with respect to trade costs τ_{ni}, $\varepsilon^{MC}(\tau_{ni}, \varphi, \varpi)$ is given by:

$$\varepsilon^{MC}(\tau_{ni}, \varphi, \varpi) = \frac{(w_i\tau_{ni})^{1-\eta}\int_{\tilde{z}(\tau_{ni},\varpi)}^{\infty}\beta(z|\varphi)dz}{\int_0^{\tilde{z}(\tau_{ni},\varpi)} \beta(z|\varphi)(t(z)w_n)^{1-\eta}dz + (\tau_{ni}w_i)^{1-\eta}\int_{\tilde{z}(\tau_{ni},\varpi)}^{\infty}\beta(z|\varphi)dz}. \quad (2.4)$$

In order to show that among 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 their affiliates, we introduce the following lemmas.

Lemma II.1. *The elasticity of marginal cost of intermediate inputs with respect to trade costs τ_{ni} increases with firm productivity φ. For $\varphi^1 > \varphi^2$, $\varepsilon^{MC}(\tau_{ni}, \varpi, \varphi^1) > \varepsilon^{MC}(\tau_{ni}, \varpi, \varphi^2) > 0$.*

Lemma II.2. *Let $\theta(\tau_{ni}, \varphi, \varpi)$ be the share of imported inputs, $M(\tau_{ni}, \varphi, \varpi)$, in total intermediate input costs $TC(\tau_{ni}, \varphi, \varpi)$: $\theta(\tau_{ni}, \varphi, \varpi) = \frac{M(\tau_{ni},\varphi,\varpi)}{TC(\tau_{ni},\varphi,\varpi)} = \varepsilon^{MC}(\tau_{ni}, \varphi, \varpi)$.*

[28] It is assumed that $w_n\bar{t} < w_i\tau_{ni}$ for some φ; otherwise no firm chooses FDI without intra-firm over exporting.

[29] The results emanate from firm optimization and the definition of $\tilde{z}(\tau, \varpi)$.

Then, (i) θ increases with φ, (ii) θ declines with trade costs for all firms, and (iii) the rate of decline in θ is slower in the more knowledge intensive firms.

Despite the fact that all firms that engage in intra-firm trade choose to import the same range of intermediate inputs (notice that $t(z)$ and τ_{ni} are not firm-specific), the share of imported intermediate inputs in total intermediate input costs varies across firms in a way consistent with the log-supermodularity assumption. Accordingly, all the variations in the share of imported intermediate inputs to total costs are on the intensive margin, not the extensive margin.[30] Lemma II.1 is of great importance in the current setting: more knowledge-intensive firms are more vulnerable to trade costs because they are more dependent on imported intermediate inputs from their parents (Lemma II.2). Reframing, the firm-level gains from trade liberalization (savings in marginal cost) are positively related to firms knowledge intensity (i.e. productivity).

To sum up, the two lemmas above highlight the role of firm knowledge-intensity, trade frictions, and the interaction between the two in shaping intra-firm trade at the firm level. More knowledge-intensive firms require more knowledge-intensive intermediate inputs; therefore, a more knowledge-intensive affiliate imports a higher share of its intermediate inputs from its parent. This is precisely because the more knowledge intensive the intermediate inputs are, the higher is the cost of transferring knowledge through direct communication between parents and affiliates.

Consequently, an increase in trade costs raises the marginal cost for more knowledge-intensive affiliates disproportionately more than for less knowledge-intensive firms. Similar to Keller and Yeaple (2013), changes in trade costs impact a firm's decision regarding embodied and disembodied knowledge transfer, yet the degree of substitution between them is significantly less for more knowledge-intensive firms. For more knowledge-intensive affiliates an increase in trade costs leads to less decrease in the share of imported inputs in total intermediate input costs. The reason for this is that 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.

Embodied vs. Disembodied Knowledge Transfer: Given the isoelastic demand faced by all firms, profits for an affiliate in country n which parent is in country

[30]If we let $t(z)$ be dependent on firm productivity, both the extensive and the intensive margin of imported inputs will vary across firms, and all the results presented in the paper will be reinforced.

i can be written as:

$$\pi_{ni}^{aff} = \varphi^{\sigma-1} B_n C_{ni}^M(\tau_{ni}, \mathcal{I}(\varphi), \varphi, \varpi)^{1-\sigma} - w_i(f_{ni}^{fdi} + \mathcal{I}(\varphi) f_{ni}^{int}), \tag{2.5}$$

where $B_n \equiv \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} A_n$.[31]

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

$$\varphi^{\sigma-1} B_n \left[\Delta C_{ni}^M(\tau_{ni}, \mathcal{I}(\varphi), \varphi, \varpi)\right] \geq w_i f_{ni}^{int}, \tag{2.6}$$

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 intermediate input once an affiliate starts trading with its parent. In the Appendix, we show that the left-hand side of equation (2.6) is continuous and strictly increasing with φ. As a result, there exists a productivity cutoff φ_{ni}^{int} such that all affiliates with productivity above the cutoff choose to import a fraction of their intermediate inputs from their parents, whereas, conditional on FDI, firms with productivity below the cutoff point do not import from parents.

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

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

That is, only the most productive foreign affiliates in country n engage in intra-firm trade with their parents.

The productivity cutoff φ_{ni}^{int} is simply pinned down by equation (2.6):

$$(\varphi_{ni}^{int})^{\sigma-1} B_n \left[\Delta C_{ni}^M(\tau_{ni}, \mathcal{I}(\varphi), \varphi_{ni}^{int}, \varpi)\right] = w_i f_{ni}^{int}. \tag{2.7}$$

As usual, the FDI cutoff $\varphi_{ni}^{fdi} < \varphi_{ni}^{int}$ is found by equating export profits $\pi_{ni}(\varphi)$ with

[31] Notice that the marginal cost of producing the final good is given by $\frac{C_{ni}^M(\varphi,\cdot)}{\varphi}$, which we require to be strictly decreasing with φ. This can be done by imposing a specific functional form on $C_{ni}^M(\varphi,\cdot)$ such that the marginal cost of the final good is decreasing with φ or, equivalently, we assume that a 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 decreases with φ.

FDI profits without intra-firm trade π_{ni}^{fdi}

$$(\varphi_{ni}^{fdi})^{\sigma-1}B_n\left[C_{ni}^M(\tau_{ni},\mathcal{I}(\varphi)=0,\varphi_{ni}^{fdi},\varpi)^{1-\sigma}-(w_i\tau_{ni})^{1-\sigma}\right]=w_i(f_{ni}^{fdi}-f_{ni}). \quad (2.8)$$

The exporting cutoff to country n is given by:

$$\varphi_{ni}^{\sigma-1}B_n(w_i\tau_{ni})^{1-\sigma}-w_if_{ni}=0 \quad (2.9)$$

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

$$\varphi_{nn}^{\sigma-1}B_nw_n^{1-\sigma}-w_nf_{nn}=0 \quad (2.10)$$

Parameter Restrictions and Firm Hierarchy: Consistent with the literature, we impose the following restrictions on the model's parameters to sustain a firm hierarchy as in HMY.

- Exporters are more productive than nonexporters: $\varphi_{ii}<\varphi_{ni}$; 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 $\bar{t}<\varpi\tau_{ni}$.
- Multinational firms with nonzero intra-firm trade are more productive than multinationals with zero intra-firm: $\varphi_{ni}^{int}>\varphi_{ni}^{fdi}$; if $f_{ni}^{int}>f_{ni}^{fdi}-f_{ni}$.

The geography of foreign affiliate sales: Country i foreign affiliate sales in country n, $r_{ni}^{aff}(\varphi)$, are given by

$$r_{ni}^{aff}(\varphi)=\sigma\varphi^{\sigma-1}B_n\left[C_{ni}^M(\tau_{ni},\mathcal{I}(\varphi),\varphi,\varpi)\right]^{1-\sigma} \quad (2.11)$$

Proposition 2. **(Gravity)**: Country i foreign affiliate sales in country n, $r_{ni}^{aff}(\varphi)$, decrease with 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 $\varepsilon_{ni}^r(\varphi,\tau_{ni})$ increases with φ. In other words, the sales of more knowledge-intensive firms (affiliates) are more sensitive to trade costs. That is, **FDI-Gravity** is more pronounced for more knowledge-intensive firms.

2.5 Parameterization, Functional Forms, and Estimation

In this section we provide functional forms for the log-supermodular function $\beta(z|\varphi)$, the cost of disembodied knowledge transfer, and the distribution of productivity draws. Before proceeding further, we set $\eta = 1$, and therefore M_φ is a Cobb-Douglas composite intermediate input: $M_\varphi = \mathcal{C}.exp\left\{\int_0^\infty \beta(z|\varphi)\ln m(z)dz\right\}$.[32] Assuming $w_i = 1$ for $i \in \{1, 2, \ldots, N\}$, domestic producers' composite intermediate input cost is given by $C_{nn}^M = 1$, while

$$C_{ni}^M(\tau_{ni}, \varphi, \mathcal{I}) = \begin{cases} \bar{t} & \text{if} \quad \mathcal{I} = 0, \\ \exp\left\{\int_0^{\tilde{z}} \beta(z|\varphi)\ln t(z)dz + \int_{\tilde{z}}^\infty \beta(z|\varphi)\ln \tau_{ni}dz\right\} & \text{if} \quad \mathcal{I} = 1 \end{cases}$$

Following Keller and Yeaple (2013), we set the knowledge transfer function $t(z) = \exp\{z\}$. Let $\phi(\varphi)$ denote φ-firm's knowledge intensity where $\phi(\varphi)$ weakly increases with 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 connect the well documented relationship between firm size 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 knowledge intensity. We are still able to use this simple functional form to compare intra-firm trade across firms with different knowledge intensities. 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 $\frac{1}{\phi}$.[33]

We additionally assume that the costs of disembodied technology transfer also vary with destination-origin 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. Hence $t_{ni}(z) = g_{ni}t(z)$, where $g_{ni} = \tau_{ni}^\alpha$, and $\alpha \in (0, 1)$.[34] Also $\bar{t}_{ni} = g_{ni}\exp\left\{\int_0^\infty \beta(z|\phi)\ln t(z)dz\right\}$. 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:

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

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

[34] $1 < g_{ni} < \tau_{ni}$. Akin to τ_{ni}, g_{ni} denotes the costs of disembodied knowledge transfer as a function of distance, common border and language, time zone differences, colonial origins, etc.

$$C^M_{ni}(\tau_{ni}, \mathcal{I}, \phi) = \begin{cases} \bar{t} = \tau^{\alpha}_{ni}\exp\{\phi\} & \text{if} \quad \mathcal{I} = 0, \\ \exp\left\{\phi\left(1 - \tau_{ni}^{\frac{\alpha-1}{\phi}}\right) + \alpha\ln\tau_{ni}\right\} & \text{if} \quad \mathcal{I} = 1 \end{cases} \tag{2.12}$$

provided that $\tau_{ni} > g_{ni}\exp\{\phi^l\}$.[35]

2.5.1 Foreign Affiliate Sales: Firm-Level Gravity

Foreign affiliate sales are given by equation (2.11). Given the functional forms provided in this section, we have:

$$r^{fdi}_{ni} = \sigma\varphi^{\sigma-1}B_n\left(\tau^{\alpha}_{ni}exp(\phi)\right)^{1-\sigma}, \tag{2.13}$$

and

$$r^{int}_{ni} = \sigma\varphi^{\sigma-1}B_n\left(exp\left\{\phi(1 - \tau_{ni}^{\frac{\alpha-1}{\phi}}) + \alpha\ln\tau_{ni}\right\}\right)^{1-\sigma}. \tag{2.14}$$

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

$$\varepsilon^r_{ni}(\phi, \tau_{ni}, \mathcal{I}) = \begin{cases} (1-\sigma)\alpha < 0, & \text{if} \quad \mathcal{I} = 0, \\ (1-\sigma)\left((1-\alpha)\tau_{ni}^{\frac{\alpha-1}{\phi}} + \alpha\right) < 0, & \text{if} \quad \mathcal{I} = 1 \end{cases} \tag{2.15}$$

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

2.6 General Equilibrium

To solve the model we assume that firm's productivity is distributed Pareto with shape parameter κ:[36]

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

[36] The assumption that $\kappa > \sigma - 1$ ensures that the distribution of firm size has a finite mean. In general, $G(\varphi) = 1 - \left(\frac{\varphi_{min}}{\varphi}\right)^{\kappa}$, $\kappa > 2$, and $\varphi_{min} = 1$. In this section we assume that all firms in

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

The relevant cutoffs for country-pair (n, i) are given by:

$$\text{Zero profit cutoff ZPC} : \varphi_{nn}^{\sigma-1} = \frac{f_{nn}}{B_n}$$
$$\text{Export cuttoff} : \varphi_{ni}^{\sigma-1} = \frac{f_{ni}}{B_n}\tau_{ni}^{\sigma-1}$$
$$\text{FDI cutoff} : (\varphi_{ni}^{fdi})^{\sigma-1} = \frac{f_{ni}^{fdi} - f_{ni}}{B_n C_{1ni}}$$
$$\text{Intra-firm cutoff} : (\varphi_{ni}^{int})^{\sigma-1} = \frac{f_{ni}^{int}}{B_n C_{2ni}}$$

where:

$$C_{1ni} \equiv \tau_{ni}^{\alpha(1-\sigma)} \exp\{\phi(1-\sigma)\} - \tau_{ni}^{1-\sigma} > 0$$

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

As shown in Figure 2.1, the proximity-concentration trade-off of the standard HMY model is strongly present in our framework.[37] However, we have an additional line representing the profits for affiliates who import from their parents, π_{int}, and also the line denoted by π_{fdi} is not parallel anymore to the domestic profit line. Also notice that in most models of FDI and intra-firm trade, the line representing the profits for affiliates who do not import from parents π_{fdi} is missing since by default all affiliates import from their parents.

a given sector share the same knowledge intensity given by the mean of knowledge intensity of all firms operating in that particular sector. In this case, our model becomes very similar to Keller and Yeaple (2013) with the exception of affiliates' endogenous selection into intra-firm trade.

[37]In the figure, proximity is represented by the slope of each profit line, while concentration is represented by the y-axis intersection.

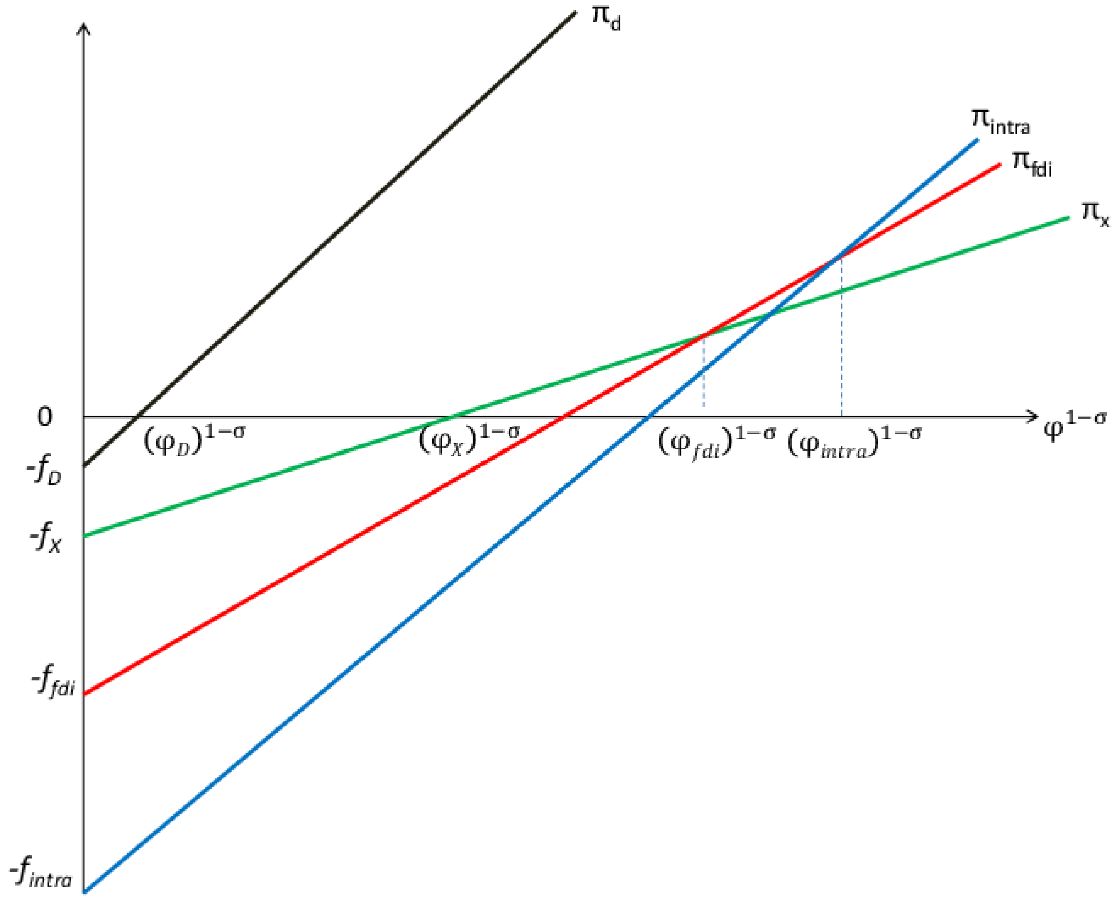


Figure 2.1: Profit from domestic sales, exports, FDI and intra-firm trade

Notes: This figure shows the different productivity cutoffs 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.

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

$$P_n^{1-\sigma} = J_n \int_{\varphi_{nn}}^{\infty} p_{nn}(\varphi)^{1-\sigma} dG(\varphi) + \sum_{i \neq n}^{N} J_i \int_{\varphi_{ni}}^{\infty} p_{ni}(\varphi)^{1-\sigma} dG(\varphi), \qquad (2.16)$$

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

Evaluating the integration and using the Pareto distribution assumption:

$$P_n^{-\kappa} = \frac{\kappa}{\kappa-(\sigma-1)} \left(\frac{\sigma}{\sigma-1}\right)^{-\kappa} \left(\frac{\mu X_n}{\sigma}\right)^{\frac{\kappa-(\sigma-1)}{\sigma-1}} \Xi_n \qquad (2.17)$$

where:

$$\Xi_n \equiv \sum_{i=1}^{N} J_i \left(\tau_{ni}^{-\kappa} f_{ni}^{\frac{\sigma-1-\kappa}{\sigma-1}} + \mathcal{I}_{i\neq n} \left\{ (f_{ni}^{fdi} - f_{ni})^{\frac{\sigma-1-\kappa}{\sigma-1}} C_{1ni}^{\frac{\kappa}{\sigma-1}} + (f_{ni}^{int})^{\frac{\sigma-1-\kappa}{\sigma-1}} C_{2ni}^{\frac{\kappa}{\sigma-1}} \right\} \right).[38]$$

Since the mass of firms is exogenously given, the aggregate profits of country n firms, including affiliates' profits, are strictly positive. Accordingly, total income 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 (2002b) and Chaney (2008), J_i is proportional to the size of the 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: $s = \frac{\sigma-1}{\sigma(\kappa-1)+1}$.

The aggregate equilibrium price level in country n is the solution of equation (2.17) 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.

2.6.1 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

[38] The indicator function $\mathcal{I}_{i\neq n} = 1$ if $i \neq n$ and zero otherwise.

trade between parents and affiliates, X_{ni}^{fdi}, and (iii) country i foreign affiliate sales in country n, for affiliates that import from parents; X_{ni}^{int}.

$$X_{ni} = \frac{\mu X_n X_i \tau_{ni}^{-\kappa} \delta_{ni}}{\Xi_n} \tag{2.18}$$

$$X_{ni}^{fdi} = \frac{\mu X_n X_i \left\{\tau_{ni}^{\alpha} exp(\phi)\right\}^{-\kappa} \lambda_{ni}}{\Xi_n} \tag{2.19}$$

$$X_{ni}^{int} = \frac{\mu X_n X_i exp \left\{\phi \left(1 - \tau_{ni}^{\frac{\alpha-1}{\phi}}\right) + \alpha(\ln \tau_{ni})\right\}^{-\kappa} \vartheta_{ni}}{\Xi_n} \tag{2.20}$$

where:

$$\delta_{ni} \equiv f_{ni}^{\frac{\sigma-1-\kappa}{\sigma-1}} - \left[\frac{f_{ni}^{fdi} - f_{ni}}{\tau_{ni}^{(1-\sigma)(\alpha-1)} exp(\phi(1-\sigma)) - 1}\right]^{\frac{\sigma-1-\kappa}{\sigma-1}},$$

$$\lambda_{ni} \equiv \left[\frac{f_{ni}^{fdi} - f_{ni}}{1 - \tau_{ni}^{(1-\sigma)(1-\alpha)} exp(\phi(\sigma-1))}\right]^{\frac{\sigma-1-\kappa}{\sigma-1}} - \left[\frac{f_{ni}^{int}}{(\tau_{ni}^{\alpha} exp(\phi))^{\sigma-1} C_{2ni}}\right]^{\frac{\sigma-1-\kappa}{\sigma-1}}$$

$$\vartheta_{ni} \equiv \left[\frac{f_{ni}^{int}}{\left(\exp((\phi(1-\tau_{ni}^{\frac{\alpha-1}{\phi}}) + \alpha \ln \tau_{ni})\right)^{\sigma-1} C_{2ni}}\right]^{\frac{\sigma-1-\kappa}{\sigma-1}}$$

Notice that Ξ_n is reminiscent of the multilateral resistance term in Eaton and Kortum (2002b).[39] Ξ_n is a measure of country n remoteness relative to all trading countries; whereas, the bilateral terms δ_{ni}, λ_{ni}, and ϑ_{ni} depend only on country i and country n parameters.[40] Relative to the standard gravity equation (e.g., from a Melitz style model with no FDI), the impact of trade frictions on exports is more involved. In an model without FDI, aggregate exports from country i to country n can be decomposed into the intensive and extensive margins, with the average exporter's

[39]With a slight abuse of notation, we redefine Ξ_n to be:

$$\Xi_n \equiv \sum_{i=1}^{N} L_i(1+s) \left(\tau_{ni}^{-\kappa} f_{ni}^{\frac{\sigma-1-\kappa}{\sigma-1}} + \mathcal{I}_{i \neq n} \left\{(f_{ni}^{fdi} - f_{ni})^{\frac{\sigma-1-\kappa}{\sigma-1}} C_{1ni}^{\frac{\kappa}{\sigma-1}} + (f_{ni}^{int})^{\frac{\sigma-1-\kappa}{\sigma-1}} C_{2ni}^{\frac{\kappa}{\sigma-1}}\right\}\right)$$

[40]Our assumptions about firm 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 $f_{ni}^{int} > (f_{ni}^{fdi} - f_{ni}) \frac{C_{2ni}}{C_{1ni}}$.

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

$$\xi_{X,\tau} = -\kappa - |\xi_{\delta,\tau}| < 0, \tag{2.21}$$

where:

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

Likewise, the elasticity of aggregate foreign affiliate sales with respect to trade costs, for affiliates that do not import from their parents and those that do, are respectively given by:[41]

$$\xi_{X^{fdi},\tau} = -\alpha\kappa + \xi_{\lambda,\tau} < 0 \tag{2.22}$$

$$\xi_{X^{int},\tau} = -\left[\tau_{ni}^{\frac{\alpha-1}{\phi}} (1-\alpha) + \alpha \right] \kappa + \xi_{\vartheta,\tau} < 0 \tag{2.23}$$

where

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

Aggregate affiliate sales (for importer affiliates) decrease as trade costs increase. It is straightforward to show this since the second term of equation (2.23) is negative for any $\alpha \in (0, 1)$. The finding that foreign affiliate sales are negatively correlated with trade costs for the affiliates who import from their parents is not surprising and consistent with models of multinational production and intra-firm trade. We are mainly interested in the gravity equation for affiliates who report zero intra-firm trade with their parents. The intra-firm trade mechanism that puts gravity forces in play ceases in the case of small affiliates who never import from parents. Nonetheless, as we

[41] Deriving the sign of $\xi_{\lambda,\tau}$ is not trivial. In general, $\xi_{\lambda,\tau}$ is negative if α and f_{ni}^{int} are large enough (see the Appendix for details). Nonetheless, $\xi_{X^{fdi},\tau}$ is negative as long as α is not very close to zero.

show in equation (2.22), sales of non-importer affiliates are still suffering from gravity forces,[42] since affiliates sales are negatively affected by the distance from headquarters and other common trade frictions.

In order to comment on the role of intensive and extensive margins in the gravity equations above, in line with Chaney (2008), we formally introduce the impact of changing variable trade costs on the intensive margin (sales of existing firms) and the extensive margin (sales of new entrants). By differentiating aggregate exports from country i to country n, $X_{ni} = J_i \int_{\varphi_{ni}}^{\varphi_{ni}^{fdi}} r_{ni}(\varphi) dG(\varphi)$, we obtain the following expression for the elasticity of X_{ni} with respect to τ_{ni}:[43]

$$\xi_{X,\tau} = \overbrace{(1-\sigma)}^{\text{Intensive margin}} + \overbrace{\frac{\kappa-(\sigma-1)}{\varphi_{ni}^{\sigma-1-\kappa} - (\varphi_{ni}^{fdi})^{\sigma-1-\kappa}} \left[\xi_{\varphi^{fdi},\tau} (\varphi_{ni}^{fdi})^{\sigma-1-\kappa} - \varphi_{ni}^{\sigma-1-\kappa} \right]}^{\text{Extensive margin}}, \quad (2.24)$$

where $\xi_{\varphi^{fdi},\tau}$ denotes the elasticity of FDI cutoff with respect to variable trade costs. If $\xi_{\varphi^{fdi},\tau}$ is negative then both the sales of existing exporters and the sales of new exporters decrease with trade costs. In fact, $\xi_{\varphi^{fdi},\tau} < 1$ for any value of $\alpha \in (0,1)$.[44] Moreover, consistent with our finding that the number of foreign affiliates in the lower tail of firm size distribution decreases as the distance from headquarters increases, the elasticity of FDI cutoff with respect to trade costs is positive, $0 < \xi_{\varphi^{fdi},\tau} < 1$.[45] Interestingly, even when the FDI cutoff increases with τ, as in HMY, the ratio of the number of multinational firms to the number of exporters increases as trade costs increase.[46]

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

$$\xi_{X^{fdi},\tau} = \overbrace{\alpha(1-\sigma)}^{\text{Intensive margin}} + \overbrace{\frac{\kappa-(\sigma-1)}{(\varphi_{ni}^{fdi})^{\sigma-1-\kappa} - (\varphi_{ni}^{int})^{\sigma-1-\kappa}} \left[\xi_{\varphi^{int},\tau} (\varphi_{ni}^{int})^{\sigma-1-\kappa} - \xi_{\varphi^{fdi},\tau} (\varphi_{ni}^{fdi})^{\sigma-1-\kappa} \right]}^{\text{Extensive margin}} \quad (2.25)$$

The elasticity of intra-firm cutoff with respect to variable trade costs is denoted by $\xi_{\varphi^{int},\tau}$.[47] In the Appendix we show that if the fixed cost of intra-firm trade is sufficiently high, the impact of trade costs on the extensive margin is negative as

[42] See the Appendix for formal derivations and the conditions for FDI gravity to hold.
[43] We use Leibniz's integral rule to differentiate the aggregate exports expression.
[44] Specifically, $\xi_{\varphi^{fdi},\tau} = \frac{\alpha exp(\phi(1-\sigma)) - \tau_{ni}^{(1-\sigma)(1-\alpha)}}{exp(\phi(1-\sigma)) - \tau_{ni}^{(1-\sigma)(1-\alpha)}} < 1$.
[45] For large enough values of α.
[46] Notice that if the FDI cutoff is ∞, the model collapses to Chaney's model and $\xi_{X,\tau} = -\kappa$.
[47] $\xi_{\varphi^{int},\tau} = \frac{1}{1-\sigma} \frac{\partial \ln C_{2ni}}{\partial \ln \tau} > 0$.

well.[48]

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

$$\xi_{X^{int},\tau} = \overbrace{(1-\sigma)\left[(1-\alpha)\tau_{ni}^{\frac{\alpha-1}{\phi}} + \alpha\right]}^{\text{Intensive margin}} - \overbrace{(\kappa - (\sigma - 1))\xi_{\varphi^{int},\tau}}^{\text{Extensive margin}}. \qquad (2.26)$$

Both sales per existing affiliates and the sales of new importer affiliates decline as trade costs increase. An intriguing result here is that although the impact of trade costs on the intensive margin is unambiguously larger for importer affiliates than for non-importer affiliates, the relative impact on the extensive margin for non-importer affiliates relative to importer affiliates is ambiguous: the sales of new entrants/existing non-importer affiliates might decline more than their counterparts for importer affiliates as trade costs increase. In effect, the overall impact of trade costs on the aggregate sales of non-importer affiliates might even be stronger than its impact on the overall sales of importer affiliates because of the extensive margin responses to increasing trade costs. In other words, gravity forces could be stronger for affiliates who do not report intra-firm trade relative to affiliates who import from their parents.

2.7 Conclusion

This paper begins by documenting a new empirical regularity: foreign affiliate sales decrease with trade costs regardless of whether they engage in intra-firm transactions. This is at odds with existing models of multinational production and intra-firm trade in which the observed gravity of foreign sales is explained by affiliates' need for intermediate inputs from their parents. Furthermore, as reported in Ramondo et al., intra-firm trade is highly concentrated among a small set of large multinationals and, in fact, the vast majority of U.S foreign affiliates do not even engage in cross-border transactions with other firms within the same corporation.

In order to reconcile the theory and the evidence, we propose a unified framework to improve our understanding of the nature and structure of multinational firms and their complex network of affiliates. To account for the extensive margin of intra-firm trade and the gravity of MP for firms of all sizes, including those that do not engage in intra-firm trade; this paper develops a multi-country model of heterogeneous firms,

[48] In fact, we also show the conditions under which the FDI gravity equation holds even with positive extensive margin. In general, this will be the case for a wide range of parameter values.

in which parents decide whether or not to supply foreign affiliates with intermediate inputs and if so, optimally decide the fraction that will be imported from the parent company. In our model an affiliate's marginal cost is affected by the parent's decision regarding the method of knowledge transfer. On the one hand, exporting intermediate inputs embodying knowledge to an affiliate entails the standard iceberg-type trade costs as well as a fixed cost of establishing an adequate platform to carry on cross-border transactions within the boundaries of the firm. On the other hand the marginal cost of direct knowledge transfer from parent to affiliates through remotely communication increases with geographical barriers but rises less than the costs of exporting intermediate inputs. As a result, in equilibrium (i) only the most productive multinational firms choose to export to their affiliates and (ii) foreign sales for both the affiliates who import from their parent and those who do not are affected by gravity forces.

The model constructed in this paper provides a guide to further develop a quantitative framework that allows us to measure the gains from multinational production and the consequent transfer of knowledge across countries in an economy where exports, foreign sales, as well as intra-firm transaction across borders, are subject to selection and concentrated in a few large firms.

Tables and Figures

Table 2.1: List of Countries

Countries		
Australia*	Italy*	Spain*
Austria*	Japan*	Sweden*
Belgium-Luxembourg*	Latvia	Switzerland*
Canada*	Lithuania	Turkey*
Czech Republic*	Mexico*	United Kingdom*
Denmark*	Netherlands*	United States*
Estonia	New Zealand*	
Finland*	Norway*	
France*	Poland*	
Germany*	Portugal*	
Greece*	Romania	
Hungary*	Russian Federation	
Ireland*	Slovakia	
Israel	Slovenia	

Note: The symbol (*) means that the country belongs to the OECD.

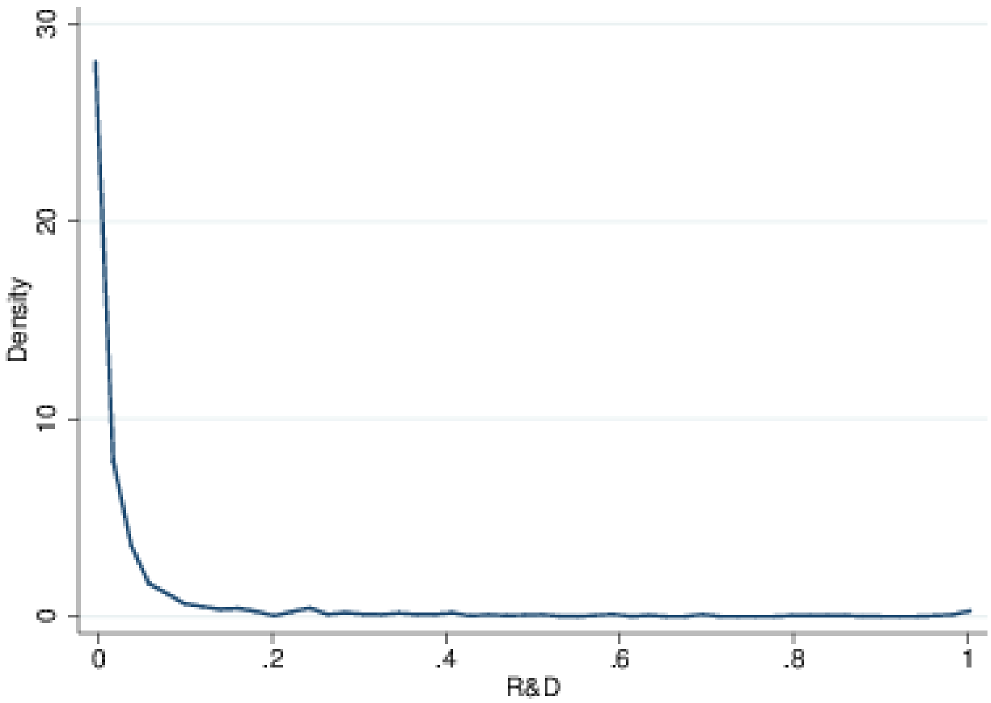


Figure 2.2: Research and Development Share

Notes: this figure shows the density of the parent's R&D expenditure share in each of the 104 manufacturing sectors of the NACE classification at 3-digit level of disaggregation. 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 parents operating in the same 3-digit level industry. The density is shown for the pool of firm-sector pairs in the sample

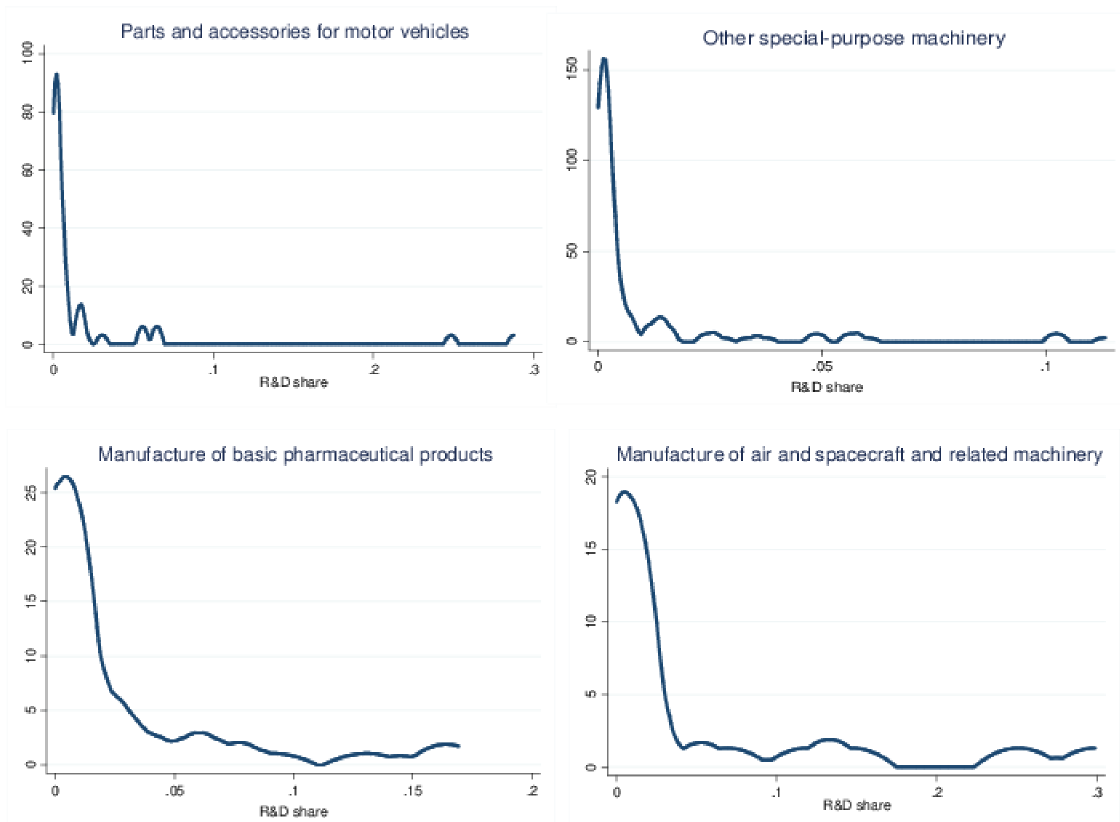


Figure 2.3: Density of Firms' R&D Shares for Selected Industries

Notes: this figure shows the density of the parent's share of R&D expenditure for four selected 3-digit NACE sector classifications: (1) manufacture of parts and accessories for motor vehicles—NACE 293 (top-left panel); (2) manufacture of other special-purpose machinery—NACE 289 (top-right panel); (3) manufacture of basic pharmaceutical products—NACE 211 (bottom-left panel); and 4) 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 parents operating in the same 3-digit sectoral classification.

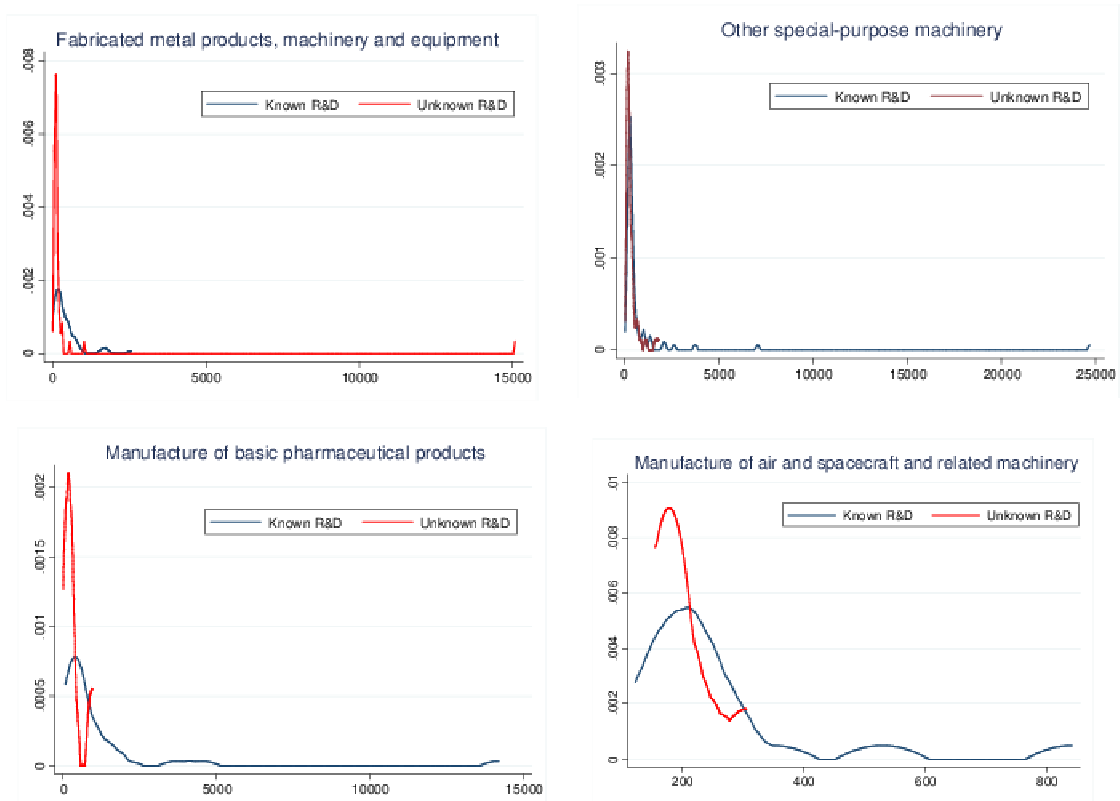


Figure 2.4: Density of Firm Productivity by R&D group

Notes: this figure shows the productivity density for two groups of parent firms: those for which ORBIS data contain information regarding the expenditure on research and development activities (Known R&D); and those parents for which there are missing values for R&D (Unknown R&D). The productivity density is shown for both groups in four selected industries at 3-digit NACE sector classification: (1) manufacture of parts and accessories for motor vehicles—NACE 293 (top-left panel); (2) manufacture of other special-purpose machinery—NACE 289 (top-right panel); (3) manufacture of basic pharmaceutical products—NACE 211 (bottom-left panel), and 4) manufacture of air and spacecraft and related machinery—NACE 303 (bottom-right panel). Firm productivity is measured by the output per worker of the U.S parent. Only one third of the U.S parent firms (that have at least one affiliate overseas) show positive values for R&D expenditures.

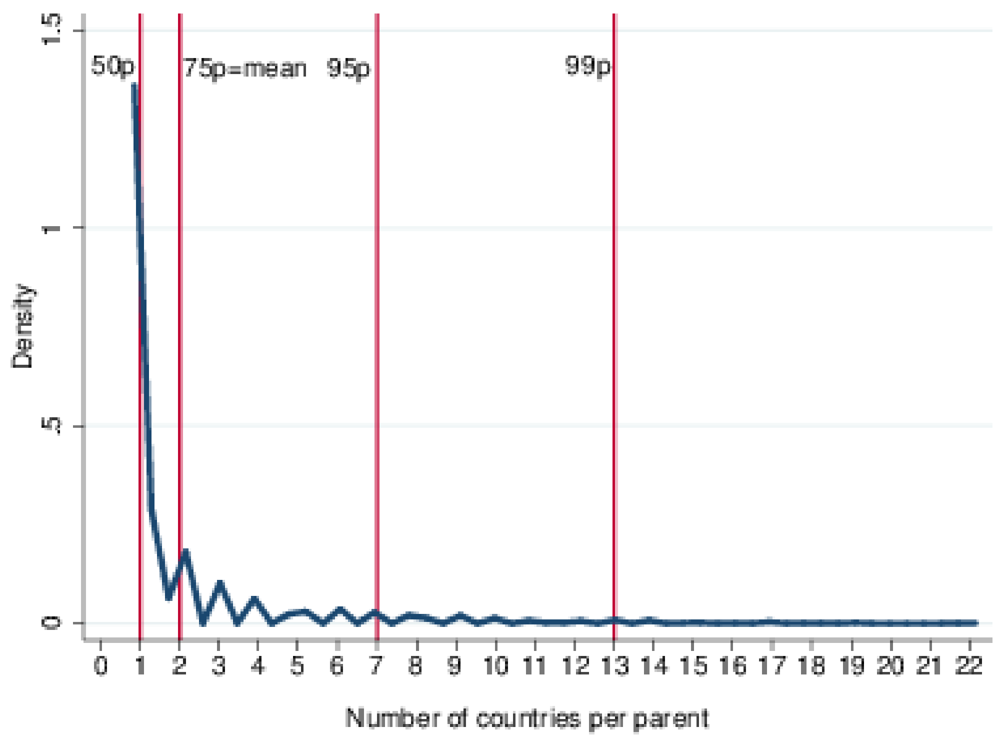


Figure 2.5: Market Penetration

Notes: this figure represents the density of the number of markets in which U.S. parent firms produce. The vertical lines represent the cutoff at the 50, 75, 95 and 99 percentile, respectively. Half of the firms have operations in only one or two foreign countries. Only a few parents engage in multinational activity in more than seven foreign markets.

Table 2.2: Gravity Equation of MP (country-sector level)

Dep. Variable	MP sales		N. of firms	
	(1)	(2)	(3)	(4)
ln *Dist*	–0.6999***	–0.7044***	–0.5525***	–0.0893**
	(0.2165)	(0.1190)	(0.0687)	(0.0427)
Border	–2.8115***	–0.6675	–0.0831	1.7173***
	(0.6920)	(0.6752)	(0.2231)	(0.2990)
Language	0.3939*	1.0690	0.3643**	0.3681
	(0.2069)	(0.9952)	(0.0711)	(0.3664)
Colony	–0.0449	1.1371***	0.5632**	1.9199***
	(0.1822)	(0.3812)	(0.0648)	(0.1366)
RTA	1.5951***	1.5730**	–0.1314	–0.3411*
	(0.3972)	(0.7277)	(0.1237)	(0.1896)
Capital (relative US)	2.1510***		2.1014***	
	(0.6134)		(0.2844)	
ln *GDPperc*	0.5664*		0.7646***	
	(0.3928)		(0.1184)	
Rule of Law	–0.0198**		–0.0196**	
	(0.0094)		(0.0028)	
Country FE	No	Yes	No	Yes
Sector FE	Yes	Yes	Yes	Yes
N.Observations	1779	1779	1880	1880

Notes: Dependent variables: foreign affiliate sales relative to parent sales operating in each host country-sector pair in columns (1) and (2); number of U.S. parents with at least one affiliate in each host country-sector pair in columns (3) and (4). The regressors include the natural log of the distance between the U.S. and the host market (ln *Dist*); a dummy for the participation of the host market in a regional trade agreement (*RTA*), a dummy for common border (*border*), common language (*language*), and whether or not the host market and United States had a colonial relationship (*colony*). Other controls include the level of capital endowment (*Capital*), the natural log of GDP per capita, and a measure of the institutional quality of the host country (*Rule of Law*). Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$.

Table 2.3: **Gravity Equation of MP (country-sector level)**

Dep. Variable	Number of firms			
	(<50p)	(>50p)	(<50p)	(>50p)
ln *Dist*	–0.3536***	–0.5443***	–0.4954***	–0.4774***
	(0.0573)	(0.0819)	(0.0743)	(0.0672)
Border	n/a	n/a	–0.3300	-0.1060
			(0.2440)	(0.2142)
Language	0.1747	0.7719***	0.2371***	0.3315***
	(0.1282)	(0.1938)	(0.0790)	(0.0738)
Colony	1.3362***	0.7263**	0.4838***	0.3913***
	(0.1330)	(0.2360)	(0.0651)	(0.0608)
RTA	0.5152***	–0.2478	0.0628	–0.1443
	(0.1543)	(0.2291)	(0.1388)	(0.1243)
Capital (relative US)			1.8563***	1.6531***
			(0.2701)	(0.2720)
ln *GDPperc*			0.5076***	0.4968***
			(0.1232)	(0.1153)
Rule of Law			–0.0129***	–0.0136***
			(0.0031)	(0.0029)
Country FE	Yes	Yes	No	No
Sector FE	Yes	Yes	Yes	Yes
N.Observations	938	942	938	942

Notes: Dependent variables: number of US parents with at least one affiliates in each host country-sector pair. The regressors include the natural log of the distance between the U.S. and the host market (ln *Dist*); a dummy for the participation of the host market in a regional trade agreement (*RTA*), a dummy for common border (*border*), common language (*language*), and whether or not the host market and United States had a colonial relationship (*colony*). Other controls include the level of capital endowment (*Capital*), the natural log of GDP per capita, and a measure of the institutional quality of the host country (*Rule of Law*). Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. n/a mean not available, because a variable is collinear with country fixed effects

Table 2.4: Gravity Equation of MP (country-sector level)

Dep. Variable	MP Sales			
	(<50p)	(>50p)	(<50p)	(>50p)
ln *Dist*	–0.8568***	–0.8399***	–0.2594	–0.4007*
	(0.1601)	(0.1235)	(0.0687)	(0.2660)
Border	–0.9984**	–0.3156	–1.4844	–2.3741***
	(0.4678)	(0.7528)	(0.2231)	(0.8410)
Language	1.6716	1.1554	0.3216**	0.3004
	(1.4587)	(0.9505)	(0.0711)	(0.2294)
Colony	0.3474	1.2135**	0.5915**	–0.0531
	(1.3918)	(0.4905)	(0.0648)	(0.1904)
RTA	0.8893	1.5286**	–0.7275	1.7651*
	(1.3877)	(0.6900)	(0.1237)	(0.1896)
Capital (relative US)			1.4399***	1.8031***
			(0.2844)	(0.6635)
ln *GDPperc*			0.7646***	0.9009**
			(0.1184)	(0.4539)
Rule of Law			–0.0196**	-0.0197*
			(0.0028)	(0.0102)
Country FE	Yes	Yes	No	No
Sector FE	Yes	Yes	Yes	Yes
N.Observations	875	904	875	904

Notes: Dependent variables: foreign affiliates sales relative to parent's sales operating in each host country-sector pair. The regressors include the natural log of the distance between the U.S. and the host market (ln *Dist*); a dummy for the participation of the host market in a regional trade agreement (*RTA*), a dummy for common border (*border*), common language (*language*), and whether or not the host market and United States had a colonial relationship (*colony*). Other controls include the level of capital endowment (*Capital*), the natural log of GDP per capita, and a measure of the institutional quality of the host country (*Rule of Law*). Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$.

Table 2.5: Gravity Equation of MP (country-sector level)

Dep. Variable	Number of firms			
	(<25p)	(>75p)	(<25p)	(>75p)
ln *Dist*	–0.2780***	–0.4082***	–0.3604***	–0.2499***
	(0.0289)	(0.0479)	(0.0674)	(0.0600)
Border	n/a	n/a	–0.1449	0.1369
			(0.2123)	(0.1782)
Language	0.0830	0.3979***	0.2649***	0.3179***
	(0.2251)	(0.0976)	(0.0732)	(0.0662)
Colony	0.2217	0.4821***	0.3449***	0.2496***
	(0.2114)	(0.1272)	(0.0616)	(0.0534)
RTA	0.3339***	–0.4197***	–0.0920	–0.1666*
	(0.1089)	(0.1226)	(0.1129)	(0.1011)
Capital (relative US)			1.3084***	1.2075***
			(0.2844)	(0.2343)
ln *GDPperc*			0.3277***	0.2043**
			(0.1117)	(0.0926)
Rule of Law			–0.0080**	-0.0061***
			(0.0029)	(0.0023)
Country FE	Yes	Yes	No	No
Sector FE	Yes	Yes	Yes	Yes
N.Observations	762	780	762	780

Notes: Dependent variables: Number of U.S. parents with at least one affiliates in each host country-sector pair. The regressors include the natural log of the distance between the U.S. and the host market (ln *Dist*); a dummy for the participation of the host market in a regional trade agreement (*RTA*), a dummy for common border (*border*), common language (*language*), and whether or not the host market and United States had a colonial relationship (*colony*). Other controls include the level of capital endowment (*Capital*), the natural log of GDP per capita, and a measure of the institutional quality of the host country (*Rule of Law*). Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$. n/a mean not available, because a variable is collinear with country fixed effects

Table 2.6: Gravity Equation of MP (country-sector level)

Dep. Variable	MP Sales			
	(<25p)	(>75p)	(<25p)	(>75p)
ln *Dist*	–1.0994***	–0.7857***	–0.6170*	–0.8584***
	(0.1897)	(0.1464)	(0.3553)	(0.2971)
Border	–5.0072**	–0.2373	–1.8248	–3.4116***
	(0.2.1279)	(0.7628)	(1.2137)	(0.9378)
Language	3.8818*	1.7033	0.5525**	0.6566**
	(1.1.7287)	(1.1007)	(0.2874)	(0.2631)
Colony	2.1475	1.8609	–1.0250***	–0.0164
	(1.7119)	(1.2184)	(0.2286)	(0.2220)
RTA	2.1991	2.1108**	0.3802	1.8904***
	(1.6473)	(0.9123)	(0.6421)	(0.4956)
Capital (relative US)			1.0083***	2.5191***
			(0.9921)	(0.7881)
ln *GDPperc*			–0.4518	1.1348**
			(0.5731)	(0.5132)
Rule of Law			0.0083**	–0.0318***
			(0.0146)	(0.0114)
Country FE	Yes	Yes	No	No
Sector FE	Yes	Yes	Yes	Yes
N.Observations	703	753	703	753

Notes: Dependent variables: foreign affiliate sales relative to parent sales operating in each host country-sector pair. The regressors include the natural log of the distance between the U.S. and the host market (ln *Dist*); a dummy for the participation of the host market in a regional trade agreement (*RTA*), a dummy for common border (*border*), common language (*language*), and whether or not the host market and United States had a colonial relationship (*colony*). Other controls include the level of capital endowment (*Capital*), the natural log of GDP per capita, and a measure of the institutional quality of the host country (*Rule of Law*). Robust standard errors reported in parentheses. Significance is denoted: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$.

2.8 Appendix A: Proofs

Lemma II.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* $\varphi^1 > \varphi^2$, $\varepsilon^{MC}(\tau_{ni}, \varpi, \varphi^1) > \varepsilon^{MC}(\tau_{ni}, \varpi, \varphi^2) > 0$.

Proof. 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,

$$\int_{\tilde{z}}^{\infty} \beta(z|\varphi^1)dz \int_{0}^{\tilde{z}} \beta(z|\varphi^2)t(z)^{1-\eta}dz < \int_{\tilde{z}}^{\infty} \beta(z|\varphi^2)dz \int_{0}^{\tilde{z}} \beta(z|\varphi^1)t(z)^{1-\eta}dz. \tag{2.27}$$

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

$$\beta(z'|\varphi^1)\beta(z''|\varphi^2)t(z)^{1-\eta} > \beta(z'|\varphi^2)\beta(z''|\varphi^1)t(z)^{1-\eta}. \tag{2.28}$$

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

$$\int_{\tilde{z}}^{\infty} \beta(z|\varphi^1)dz \int_{0}^{\tilde{z}} \beta(z|\varphi^2)t(z)^{1-\eta}dz > \int_{\tilde{z}}^{\infty} \beta(z|\varphi^2)dx \int_{0}^{\tilde{z}} \beta(z|\varphi^1)t(z)^{1-\eta}dz \tag{2.29}$$

Contradiction □

Lemma II.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, and iii) the rate of decline in the import cost share is slower in the more knowledge intensive firms.*

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

$$\xi_{\theta,\tau} = -(\eta - 1)(1 - \theta(\tau, \varphi)) - \frac{\partial \tilde{z}(\tau)}{\partial \tau} \frac{\beta(z|\varphi)\tau}{\int_{\tilde{z}(\tau)}^{\infty} b(z|\varphi)dz} < 0. \tag{2.30}$$

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 $\theta(\tau,\varphi^1) > \theta(\tau,\varphi^2)$ □

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

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

That is, only the most productive foreign affiliates in country n engage in intrafirm trade with their parents (import intermediate inputs form their parents).

Proof. An affiliate chooses to import from its parent if,

$$\varphi^{\sigma-1}B_n\left[\Delta C_{ni}^{M}(\tau_{ni},\mathcal{I}(\varphi),\varphi,\varpi)\right] \geq w_i f_{ni}^{int}, \tag{2.31}$$

The first term in the left hand side of the equation above $\varphi^{\sigma-1}$ is increasing in φ. The second term $\Delta C_{ni}^{M}(\tau_{ni},\mathcal{I}(\varphi),\varphi,\varpi) \equiv C_{ni}^{M}(\tau_{ni},\mathcal{I}(\varphi)=1,\varphi)^{1-\sigma} - C_{ni}^{M}(\tau_{ni},\mathcal{I}(\varphi)=0,\varphi)^{1-\sigma}$ is also increasing in φ. Notice that $C(\mathcal{I}=0,\varphi^1) > C(\mathcal{I}=0,\varphi^2)$,[49] whereas $C(\tau=1,\mathcal{I}=1,\varphi^1) = C(\tau=1,\mathcal{I}=1,\varphi^2)$. By Lemma II.1, $\varepsilon^{MC}(.,\varphi^1) > \varepsilon^{MC}(.,\varphi^2)$, then moving from no intra-firm trade to importing any fraction 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). □

Proposition 2: *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

$$\varepsilon_{ni}^{r}(\varphi,\tau_{ni},\mathcal{I}) = (1-\sigma)\varepsilon_{ni}^{MC}(\varphi,\tau_{ni},\mathcal{I}) \tag{2.32}$$

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. □

[49]Notice that $C(\mathcal{I}=0,\varphi) = \bar{t} = \int_0^{\infty}\beta(z|\varphi)t(z)^{1-\eta}dz$, which is indeed increasing in φ under the assumptions about $\beta(z|\varphi)$ and $t(z)$.

2.9 Appendix B: Detail Derivations

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

$$\Pi_n = \sum_{i=1}^{N} J_n \left\{ \int_{\varphi_{in}}^{\varphi_{in}^{fdi}} \pi_{in}(\varphi) dG(\varphi) + \int_{\varphi_{in}^{fdi}}^{\varphi_{in}^{int}} \pi_{in}^{fdi}(\varphi) dG(\varphi) + \int_{\varphi_{in}^{int}}^{\infty} \pi_{in}^{int}(\varphi) dG(\varphi) \right\}, \quad (2.33)$$

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

$$\Pi_n = \frac{\sigma - 1}{\sigma\kappa} \sum_{i=1}^{N} R_{in} + R_{in}^{fdi} + R_{in}^{int} \quad (2.34)$$

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

$$\Pi = \frac{\sigma - 1}{\sigma\kappa} \sum_{n \in N} \sum_{i \in N} R_{in} + R_{in}^{fdi} + R_{in}^{int} \quad (2.35)$$

$$= \frac{\sigma - 1}{\sigma\kappa} Y \quad (2.36)$$

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 $X_n = L_n + \Pi_n = L_n + sL_n$. 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[50]

$$X_{ni} = J_i \int_{\varphi_{ni}}^{\varphi_{ni}^{fdi}} \sigma\varphi^{\sigma-1}\left(\mu X_n/P_n^{1-\sigma}\right)\tau_{ni}^{1-\sigma} dG(\varphi) \tag{2.37}$$

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

$$X_{ni}^{fdi} = J_i \int_{\varphi_{ni}^{fdi}}^{\varphi_{ni}^{int}} \sigma\varphi^{\sigma-1}\left(X_n/P_n^{1-\sigma}\right)\left[\tau_{ni}^{\alpha} exp(\phi)\right]^{1-\sigma} dG(\varphi) \tag{2.38}$$

$$X_{ni}^{int} = J_i \int_{\varphi_{ni}^{int}}^{\infty} \sigma\varphi^{\sigma-1}\left(X_n/P_n^{1-\sigma}\right)\left(exp(\phi(1-\tau_{ni}^{\frac{\alpha-1}{\phi}}) + \alpha \ln)\right)^{1-\sigma} dG(\varphi) \tag{2.39}$$

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 (2.22). 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;

$$\xi_{X^{fdi},\tau} = \overbrace{\alpha(1-\sigma)}^{\text{Intensive margin}} + \overbrace{\frac{\kappa-(\sigma-1)}{(\varphi_{ni}^{fdi})^{\sigma-1-\kappa} - (\varphi_{ni}^{int})^{\sigma-1-\kappa}}\left[\xi_{\varphi^{int},\tau}(\varphi_{ni}^{int})^{\sigma-1-\kappa} - \xi_{\varphi^{fdi},\tau}(\varphi_{ni}^{fdi})^{\sigma-1-\kappa}\right]}^{\text{Extensive margin}} \tag{2.40}$$

The extensive margin is negative if and only if, $\xi_{\varphi^{fdi},\tau}(\varphi^{fdi})^{\sigma-1-\kappa} > \xi_{\varphi^{int},\tau}(\varphi^{int})^{\sigma-1-\kappa}$. This will be the case if, $\frac{\alpha C^M(.,\mathcal{I}=0)^{1-\sigma} - \tau^{1-\sigma}}{\varepsilon^{MC} C^M(.,\mathcal{I}=1)^{1-\sigma} - \alpha C^M(.,\mathcal{I}=0)^{1-\sigma}} > \left(\frac{f_{ni}^{fdi} - f_{ni}}{f_{ni}^{int}}\right)^{(1-\sigma)(\sigma-1-\kappa)} \left(\frac{C_{2ni}}{C_{1ni}}\right)^{(1-\sigma)(\sigma-1-\kappa)}$. For FDI cutoff be well defined, we require $f_{ni}^{int} > (f_{ni}^{fdi} - f_{ni})\frac{C_{2ni}}{C_{1ni}}$. If f_{ni}^{int} is way larger than the last term then the last term of the previous inequality becomes very small

[50]Notice that we do not include the intrafirm export in the total exports. It is easy to show that total intrafirm exports is constant share of the importer total affiliates sales.

and approaches zero as $f_{ni}^{int} \to \infty$. Therefore, there exists $f_{ni}^{int} < \infty$ such that the extensive margin is negative. If this condition does not hold, all what we need to have FDI-gravity is $-\frac{\xi_{\varphi^{int},\tau}(\varphi_{ni}^{int})^{\sigma-1-\kappa} - \xi_{\varphi^{fdi},\tau}(\varphi_{ni}^{fdi})^{\sigma-1-\kappa}}{\varphi_{ni}^{fdi})^{\sigma-1-\kappa} - (\varphi_{ni}^{int})^{\sigma-1-\kappa}} < \frac{\alpha(\sigma-1)}{\kappa-(\sigma-1)}$, 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.

Derivation of the marginal cost of intermediate input composite: equation (2.12)

$$C_{ni}^{M}(\tau,\phi,\mathcal{I}) = \begin{cases} \tau^{\alpha}\exp\left\{\int_0^{\infty}\frac{1}{\phi}exp(-z/\phi)zdz\right\} & \text{if} \quad \mathcal{I}=0 \\ \exp\left\{\int_0^{\tilde{z}}\frac{1}{\phi}exp(-z/\phi)(\alpha\ln\tau + z)dz + \ln\tau\int_{\tilde{z}}^{\infty}\frac{1}{\phi}exp(-z/\phi)dz\right\} & \text{if} \quad \mathcal{I}=1 \end{cases} \tag{2.41}$$

Integrating by parts and substituting out $\tilde{z} = (1-\alpha)\ln\tau_{ni}$, the required results are obtained.

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