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The Gravity of Knowledge
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ABSTRACT

How large are spatial barriers to transferring knowledge? We analyze the international operations of multinational firms to answer this fundamental question. In our model firms can transfer bits of knowledge to their foreign affiliates in either embodied (traded intermediates) or disembodied form (direct communication). Knowledge transfer costs interact with the knowledge intensity of production to determine the geographic structure of multinationals' input sourcing as well as its competitiveness in foreign markets. The model shows how data on observable trade costs and features of multinationals'global operations reveal the size and nature of knowledge transfer costs. Our empirical analysis confirms the model's predictions using firm-level data, quantifies the aggregate implications of the model for the structure of multinationals' operations, and demonstrates that transfer costs shape the knowledge content of intra-firm trade flows.

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1 Introduction

The development and diffusion of knowledge is center stage in many fields of economics. Modern theories of growth and international trade, for instance, place little emphasis on the accumulation of tangible factors such as capital and labor, focusing almost entirely on access to knowledge. With the recent advances in communication technology, the access to knowledge is greater than it has ever been, but just how mobile is knowledge? This is a central question to much of economics that is addressed here.

The paper starts from the premise that knowledge moves over geographic space either in embodied or disembodied form. When knowledge moves in embodied form the costs of moving it can be measured as the cost of goods trade. The intangibility of disembodied knowledge, however, makes its movements hard to observe, and the costs of moving this knowledge are difficult to assess. We shed new light on this issue by casting the question in terms of the operations of multinational firms. Multinationals account for much of the world's research and development (R&D), and they have an incentive to endow offshore affiliates with their knowledge as efficiently as possible–after all, knowledge transfer costs raise overall costs and therefore reduce competitiveness.

Multinational affiliates, it turns out, sell less the further away they are from their home country, akin to the gravity finding in trade. Moreover, this gravity effect is strongest for high-R&D, or knowledge-intensive, goods. Our model focuses on the difficulties of communicating knowledge from one person to another versus the costs of moving knowledge in goods. Knowledge can often not fully be codified, and communicating knowledge is prone to errors.[1] The relatively high costs of knowledge-intensive production lead to both lower affiliate sales and the firm's shifting its mix from disembodied (direct communication) towards embodied (trade) knowledge transfer. The paper tests and quantifies a new model of knowledge transfer fleshing this out.

In the model multinational firms produce final goods composed of individual intermediate inputs which vary in the extent that their production requires non-codified knowledge. Inputs highly dependent on non-codified knowledge are called knowledge intensive. Because not all knowledge can be codified, offshore production calls for communication between home country CEOs and affiliate managers. We assume that communication is more costly the more knowledge-intensive inputs are, but these costs are invariant to physical distance. Alternatively, the multinational can transfer knowledge by shipping ready-to-go inputs embodying the knowledge. This entails no communication costs since the input is produced near the expert at home, however shipping incurs trade costs that

[1] Arrow (1969) views knowledge transfer costs mainly as communication costs between teacher and student.

rise in geographic distance. The reason why multinational sales in knowledge-intensive industries suffer most strongly from gravity is that here disembodied knowledge transfer costs are highest, and to avoid them means embodied knowledge transfer whose costs rise in distance.

Two sharp, firm-level predictions emerge from this analysis. First, the knowledge intensity of production affects the level of affiliate sales around the world. The competitiveness of affiliates, measured in terms of their sales, falls as trade costs rise, and the effect of trade costs is strongest for knowledge-intensive goods, precisely because it is here that the scope for offshoring is most limited by costly disembodied knowledge transfer. Second, the knowledge intensity of production affects the composition of knowledge transfers that the multinational will employ. The affiliate's cost share of imports gives the relative importance of embodied knowledge transfer. It falls more slowly with distance in knowledge-intensive industries than in less knowledge-intensive industries. As trade costs increase, multinational affiliates substitute away from importing inputs but their ability to do so is constrained by how high disembodied knowledge transfer costs are. Therefore, trade costs have the weakest influence on affiliate imports in relatively knowledge-intensive industries.

These two predictions are tested using information on the sales and intermediate goods trade of individual multinationals from the United States' Bureau of Economic Analysis. Confronting the model with this rich micro dataset, we find striking support for both predictions using variation in multinational activity across industries and countries. Consistent with the model, there is strong evidence that both the level of affiliate sales and its imports are affected by the ease to which knowledge can be transferred across space. A quantitative analysis based on these micro estimates shows that both market size and geography are central determinants of aggregate foreign direct investment (FDI). This is in contrast to the benchmark model which largely ignores the geography dimension.

Moreover, the model predicts that as trade costs change relative to communication costs, the nature of trade in terms of its knowledge intensity changes systematically. Specifically, an increase in trade costs makes disembodied knowledge transfer more attractive so that the average knowledge intensity of inputs that continue to be traded increases. Despite the large body of work on the factor service content of trade, this is one of the few results on the knowledge content of trade that we are aware of. We find strong supportive evidence for this prediction from the international trade of U.S. multinational firms.

This paper develops a new theory for the distribution of knowledge across countries, the subject of much analysis in macroeconomics and growth (Lucas 1993, Aghion and Howitt 1998, and Jones 2002). At the same time, our analysis provides a new framework for explaining the labor market effects of offshoring (Blinder 2006, Levy and Murnane 2005) in terms of the firms' ability to transfer knowledge abroad. The allocation of activities within firms and across geographic space speaks not only to international trade (Antras, Garicano, and Rossi-Hansberg 2008) but also to regional economics (Krugman 1991) and industrial organization (Acemoglu, Aghion, Lelarge, van Reenen, and Zilibotti 2007), because the impact of firm organization on economic structure and performance is felt at all of these levels.

In international trade, frictions to economic activity in geographic space are commonly called trade costs. Virtually always they are discussed in terms of gravity, the finding that the volume of trade is declining in distance (see Anderson and van Wincoop 2004). While spatial frictions are important as well between regions within a country (Hillberry and Hummels 2003, Glaeser and Kohlhase 2004), these frictions are not well understood. Knowledge, as an intangible, seems ideally suited to overcoming spatial frictions, although there appear to be limits to the transfer of knowledge. The productivity effects of R&D are declining in distance (Keller 2002), and recent work by Irrazabal, Moxnes, and Opramolla (2010), Ramondo and Rodriguez-Clare (2010), and Arkolakis, Ramondo, Rodriguez-Clare, and Yeaple (2011) is consistent with substantial knowledge transfer costs. We provide unique insights on the nature of spatial frictions by matching a model of disembodied versus embodied knowledge transfer to micro data on all key dimensions, testing, and quantifying it.

This paper makes also progress in the literature on multinational firms. First, we extend the canonical model in which firms can transfer their knowledge without cost to their affiliates (Helpman 1984, Markusen 1984).[2] In particular, by generalizing the benchmark model with heterogeneous firms by Helpman, Melitz, and Yeaple (2004), our analysis reconfirms the importance of geography for aggregate FDI sales, an important issue that cannot be handled by the benchmark model. Moreover, in addition to well-known influences such as factor cost differences (Hanson, Mataloni, and Slaughter 2005), we establish knowledge transfer costs as a determinant of the vertical specialization within multinational firms. Further, in our analysis the vertical specialization decision is determined jointly with the multinational's sales. This highlights the forces generating complementarity between trade and FDI when there is substitution at the activity level (Blonigen 2001). Finally, the analysis shows that the multinational firms' trade-off between disembodied and embodied knowledge transfer shapes the knowledge content of international trade.

The remainder of the paper is as follows. The following section 2 introduces the

[2] Antras, Garicano, and Rossi-Hansberg (2008) and Burstein and Monge-Naranjo (2009) have recently analyzed knowledge embodied in people.

model and shows that knowledge intensity affects both the level of offshoring as well as the breakdown between the firm's production at home and abroad. Also we show how the firm's choice on disembodied versus embodied knowledge transfer affects the knowledge intensity of trade across different trade partners. Moreover, section 2 derives the estimating equations implied by the model. Our data on individual U.S. multinational firms is described in section 3. Section 4 provides evidence on the firm-level predictions of the model. Section 5 quantifies and discusses the model's implications for aggregate multinational activity. In section 6 we examine the robustness of our micro econometric results, while in section 7 evidence is presented on the knowledge content of trade along the line of the model's prediction. A number of concluding observations are offered in section 8.

2 Theory

We begin by introducing the main elements of our model. Any country has a large number of firms that can each produce a unique variety of a differentiated final good. A given firm in the home country can sell its good to consumers abroad in one of two ways. First, the good can be produced at home and exported. Second, the firm can turn multinational, which means setting up an affiliate in the foreign country, producing there, and selling locally. By exporting, the firm incurs trade costs that vary across countries, while if the firm serves the foreign market through affiliate sales it has to pay a fixed cost of opening a plant and it faces the costs of transferring its knowledge: productivity abroad is lower than at home.

Each differentiated final good is produced from a range of intermediate goods and services. The intermediate activities may include market research, R&D toward product design, organization of shop floor production, final assembly, marketing and advertising, and legal services. The ease of knowledge transfer varies by activity. It is relatively difficult, for example, to transfer R&D activities abroad because this technological knowhow is highly non-codified.

This set-up leads to an exports-versus-FDI trade-off for the firm at the level of assembly, and conditional on FDI, the firm faces an exports-versus-FDI decision at the level of each intermediate input. For a given foreign market, inputs with high knowledge transfer costs will be produced at home and exported (*embodied knowledge transfer*), while inputs with low transfer costs will be produced abroad (*disembodied knowledge transfer*). As distance to the foreign market increases, the trade costs of exporting increase. Firms equate trade and disembodied knowledge transfer costs at the margin, and affiliates located far from home have relatively high costs. Because higher costs reduce sales, affiliates in relatively distant countries sell less than affiliates in more nearby countries (gravity).

In the remainder of this section, we first describe the model assumptions, followed by the derivation of the structure of multinational activity that they yield, and we also discuss an extension. We then move to the equations that will be estimated in the empirical work. To improve exposition, all proofs are relegated to the Appendix.

Model Assumptions Consider a world populated by K countries indexed by k and j. Country k is endowed with L_k units of labor, the only primary factor of production. In each country, the representative consumer has preferences over I differentiated goods and one homogeneous good Y given by

$$U = \sum_{i=1}^{I} \Phi^i \ln \left(\int_{\omega^i \in \Omega^i} q(\omega^i)^{\frac{\sigma-1}{\sigma}} d\omega^i \right)^{\frac{\sigma}{\sigma-1}} + \left(1 - \sum_{i=1}^{I} \Phi^i \right) \ln Y, \tag{1}$$

where Φ^i is the expenditure share of good i, Ω^i is the set of available varieties of good i, $q(\omega^i)$ is the quantity of variety ω^i, $\sigma > 1$ is the elasticity of substitution across varieties, and Y is the quantity of the outside good consumed. Each country produces good Y using a single unit of labor and so wages everywhere can be normalized to unity.[3]

In country k, there are N_k^i firms in industry i that have the ability to produce a unique variety using a variety-specific composite intermediate. Firms are heterogeneous in terms of their productivity: Firm ω^i with productivity $\varphi(\omega^i)$ requires $1/\varphi(\omega^i)$ units of the composite intermediate to produce one unit of output. In industry i, the composite intermediate is produced from a continuum of (firm-specific) intermediates that vary in their knowledge intensity:

$$M^i = \left(\int_0^{\infty} \beta(z|\phi^i)^{\frac{1}{\eta}} m(z)^{\frac{\eta-1}{\eta}} dz \right)^{\frac{\eta}{\eta-1}}, \tag{2}$$

where $m(z)$ is the quantity of an intermediate of knowledge intensity z, $\beta(z|\phi^i)$ is the cost share parameter of intermediate z in an industry with knowledge intensity ϕ^i, and $\eta \geq 1$ is the elasticity of substitution across intermediates. It is assumed that in all industries $\int_0^{\infty} \beta(z|\phi^i)dz = 1$. We give meaning to different knowledge intensities across industries by assuming that $\beta(z|\phi^i)$ is log supermodular in z and ϕ^i.[4] Specifically, if $z' > z''$ and $\phi^1 > \phi^2$, that is, industry 1 is more knowledge intensive than industry 2, then log supermodularity implies $\frac{\beta(z'|\phi^1)}{\beta(z'|\phi^2)} > \frac{\beta(z''|\phi^1)}{\beta(z''|\phi^2)}$. Intuitively, a more knowledge-intensive industry is so because it requires relatively more knowledge-intensive intermediate inputs than a less knowledge intensive industry.

[3] Wage equalization is not crucial to what follows. Keller and Yeaple (2008) show that similar results are obtained in a model where factor costs are lower in the South than in the North.

[4] Costinot (2009) has employed these concepts recently.

Each firm must decide whether and how to serve each of the world's K markets. A firm in industry i that is located in country j can always assemble its variety in country j and then export the finished good to any country k, which requires iceberg-type trade costs $\tau^i_{jk} \geq 1$. For $j = k$, $\tau^i_{jk} = 1$, and for $j \neq k$, $\tau^i_{jk} > 1, \forall i$. Alternatively, this firm may assemble its final good in country $k \neq j$ to serve the local market, which requires the firm to incur fixed cost f^a_k. Once a firm has decided where to assemble its final product to serve country k, it must decide where to produce each intermediate input. If intermediate z is produced in home country j, one unit of labor produces one unit of intermediate z. If that intermediate is exported from country j to country k (*embodied knowledge transfer*), it is subject to the iceberg-type trade cost τ^i_{jk}. Alternatively, the affiliate in country k can produce that intermediate for itself (*disembodied knowledge transfer*). Local production of an intermediate allows the firm to avoid trade costs, but exposes the affiliate to efficiency losses that are increasing in the knowledge intensity of production. As in Arrow (1969) this efficiency loss stems from the lack of physical proximity between the inventors of the technological knowledge (located in country j) and the users of this knowledge (located in country $k \neq j$).[5] This efficiency loss takes the form of a increase in the local labor requirement and is given by the function $t(z)$, where $t(0) = 1$, $t'(z) > 0$, and $\lim_{z\to\infty} t(z) > \tau^i_{jk}$.[6]

In summary, trade costs vary across countries and industries while knowledge transfer costs due to communication failure vary across inputs of different knowledge intensities but not across foreign countries. Knowledge transfer costs are zero only when CEOs and production managers can meet face-to-face. Note that while face-to-face contact will clearly be the exception for day-to-day problem solving in a multinational–a firm that is spread over different countries–it might occur only rarely even for multi-plant operations within a country. This is a point we will return to in the conclusions.

The geography of input sourcing The cost of obtaining input z of a foreign assembly plant facing trade costs of τ is $c(z) = \min\{t(z), \tau^i_{jk}\}$. The assumptions on the function $t(z)$ guarantee that there exists a marginal input

$$\widehat{z}(\tau) = t^{-1}(\tau^i_{jk}). \tag{3}$$

[5] Technological knowledge is difficult to communicate because it is often not fully codified (Polanyi 1966), and it is most easily transferred through face-to-face interaction because that allows immediate feedback (see Koskinen and Vanharanta 2002).

[6] In an earlier version of the paper, we provided explicit microfoundations for a specific functional form with these properties. Specifically, more knowledge intensive intermediates required more tasks to be completed and each task had a constant probability of failure due to imperfect communication.

such that inputs $z < \widehat{z}(\tau)$ are produced locally and inputs $z > \widehat{z}(\tau)$ are imported.[7] This sourcing pattern combined with equation (2) implies that the cost of the composite intermediate input to an affiliate facing trade cost τ with knowledge intensity of ϕ^i is

$$C^M(\tau,\phi^i) = \left(\int_0^{\widehat{z}(\tau)} \beta(z|\phi^i) t(z)^{1-\eta} dz + \tau^{1-\eta} \int_{\widehat{z}(\tau)}^{\infty} \beta(z|\phi^i) dz \right)^{\frac{1}{1-\eta}}. \quad (4)$$

Letting $\varepsilon^{MC}(\tau,\phi^i)$ be the elasticity of $C^M(\tau,\phi^i)$ with respect to trade costs, we have

$$\varepsilon^{MC}(\tau,\phi^i) = \frac{\tau^{1-\eta} \int_{\widehat{z}(\tau)}^{\infty} \beta(z|\phi^i) dz}{\int_0^{\widehat{z}(\tau)} \beta(z|\phi^i) t(z)^{1-\eta} dz + \tau^{1-\eta} \int_{\widehat{z}(\tau)}^{\infty} \beta(z|\phi^i) dz}. \quad (5)$$

This expression can be used to prove the following lemma.

Lemma 1 *Let industry* 1 *be knowledge intensive relative to industry* 2 *($\phi^1 > \phi^2$). Then the elasticity of marginal cost with respect to trade costs τ is greater in industry* 1 *than industry* 2*, i.e. $\varepsilon^{MC}(\tau,\phi^1) > \varepsilon^{MC}(\tau,\phi^2) > 0$.*

The marginal cost of production of an affiliate in the relatively knowledge intensive industry is more sensitive to trade costs than of an affiliate in the less knowledge-intensive industry because the former relies more heavily on imported inputs than the latter. To see this, first note that Shephard's lemma implies that the share of imported inputs $M(\tau,\phi^i)$ in total costs $TC(\tau,\phi^i)$ is

$$\theta(\tau,\phi^i) \equiv \frac{M(\tau,\phi^i)}{TC(\tau,\phi^i)} = \varepsilon^{MC}(\tau,\phi^i).$$

The import cost share $\theta(\tau,\phi^i)$ varies across countries and industries as follows.

Proposition 1 *(*import cost share*) Let industry* 1 *be knowledge intensive relative to industry* 2 *($\phi^1 > \phi^2$). (i) The import cost share is greater in industry* 1 *than industry* 2 *for any given level of τ, ($\theta(\tau,\phi^1) > \theta(\tau,\phi^2)$); (ii) the import cost share is declining in trade cost in all industries; and (iii) the rate of decline in the import cost share is slower in the more knowledge intensive industry ($\partial \log\theta(\tau,\phi^2)/\partial\tau < \partial \log\theta(\tau,\phi^1)/\partial\tau < 0$).*

[7] For ease of notation we omit the indices on τ whenever possible.

The geography of affiliate sales Proposition 1 and Lemma 1 are important implications of the model: the affiliates of firms in more knowledge intensive industries are less able to substitute away from imported inputs as trade costs rise and so their marginal costs are more sensitive to trade costs. Our data allow us to measure the import cost share $\theta(\tau, \phi^i)$ directly, but data on affiliate marginal costs $C^M(\tau, \phi^i)$ do not exist. To infer variation in marginal costs across countries, in the following we establish a link between the marginal costs of affiliates and their host country sales.

The preferences (1) imply that demand in country k is

$$q^i(\varphi) = \left(\frac{\sigma}{\sigma-1}\right)^{\sigma-1} B_k^i (p_k^i(\varphi))^{-\sigma}, \tag{6}$$

where $p_k^i(\varphi)$ is the price of a variety in industry i charged in country k by a firm with productivity φ, and B_k^i is the markup-adjusted demand level for industry i in country k.[8] The optimal pricing rule for a firm facing the iso-elastic demand curve given by (6) is to charge a constant mark-up over marginal cost of producing the final good, $p_k^i(\varphi) = \frac{\sigma}{\sigma-1}\frac{C^f(\tau,\phi^i)}{\varphi}$, where

$$C^f(\tau, \phi^i) = \begin{cases} C^M(\tau, \phi^i) & \text{if country } k \text{ is served via a local affiliate} \\ \tau & \text{if country } k \text{ is served by exports from } j \end{cases},$$

where $C^M(\tau, \phi^i)$ is given by equation (4).

For a firm of productivity φ local affiliate sales are

$$R_k^i(\varphi, \tau, \phi^i) = \begin{cases} B_k^i \varphi^{\sigma-1} \left(C^M(\tau, \phi^i)\right)^{1-\sigma} & \text{if } B^i \varphi^{\sigma-1} \left(C^M(\tau, \phi^i)^{1-\sigma} - \tau^{1-\sigma}\right) \geq \sigma f_k^a \\ 0 & \text{otherwise} \end{cases}. \tag{7}$$

According to equation (7), the sales of local affiliates are zero if the profits of exporting the final good exceed those of opening a local affiliate (the right hand side condition) and positive otherwise. Conditional on opening an affiliate, sales are large when (a) the foreign market is large (B_k^i), (b) when the firm is more productive ($\varphi^{\sigma-1}$), and (c) when the cost of the composite intermediate is low ($C^M(\tau, \phi^i)$). An important implication of equation (7) is that variation across countries in fixed costs (f_k^a) to open an affiliate only affect the likelihood that a firm invests in a given foreign location, while it does not affect the volume of sales conditional on entry.

Let $\varepsilon^R(\tau, \phi^i)$ be the elasticity of affiliate local sales revenue with respect to trade costs τ. We have the following proposition concerning this elasticity:

[8] This is $B_k^i \equiv \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \Phi^i E_k / \int_{\omega^i \in \Omega^i} p_k(\omega^i)^{1-\sigma} d\omega^i$.

Proposition 2 (Affiliate Sales) *Conditional on opening an affiliate, (i) an increase in trade costs τ is associated with lower affiliate sales ($\varepsilon^R(\tau, \phi^i) < 0$), and (ii) the elasticity of these sales with respect to trade costs is larger in absolute value in more knowledge intensive industries.*

The intuition for the effect of trade costs on the intensive margin (the volume of sales conditional on entry) is straightforward: the marginal costs of firms in more knowledge intensive industries are rising faster in trade costs because they have less scope for substituting local production for imported intermediates and so their local sales are more sensitive to trade costs as well.

Extension: Fixed Costs of Knowledge Transfer Recent quantitative models of multinational production typically maintain tractability by assuming that knowledge transfer costs take the form of variable, not fixed costs.[9] This is also the case here, even though it is worth noting that our framework allows already for fixed costs of affiliate production (f_k^a), which are absent in much of the literature. Nevertheless, fixed costs may be particularly relevant in the context of knowledge transfers. While a full treatment is beyond the scope of this paper, the following extension captures what we think would be their central implication in any model: firms with large operations incur fixed costs of knowledge transfers in order to lower their marginal costs, while small firms do not.

Suppose that firms may invest in information and communication technology (ICT) in order to lower the efficiency cost of knowledge transfer, but doing so requires incurring an additional fixed cost F^T. Having installed ICT, the efficiency loss of remote production falls from $t(z)$ to $t(\alpha z)$, $\alpha \in (0,1)$ for all z and for all foreign locations. In this setting, the following proposition holds.

Proposition 3 *In each industry, there exists a threshold productivity $\widehat{\varphi}^{ICT}$ such that firms with productivity $\varphi > \widehat{\varphi}^{ICT}$ incur the fixed cost F^T. Firms that incur the fixed cost have lower import cost shares in all countries relative to other firms in their industry.*

Firms that reduce the efficiency loss of disembodied technology transfer reduce their reliance on imported intermediates and reduce their affiliates' marginal cost of production. It is only profitable to incur this fixed cost when aggregate affiliate sales will be large, which will happen when the scale of a firm's foreign operations is large as will be the case if it is very productive (high φ).

[9] Burstein and Monge-Naranjo (2009), McGrattan and Prescott (2010), Ramondo (2007), and Ramondo and Rodriguez Clare (2010).

In the empirical analysis that follows, we develop model specifications that capture Propositions 1 and 2, which are driven by variable knowledge transfer costs. At the same time, we will also allow for fixed costs of knowledge transfer as captured by Proposition 3.

Key model predictions to be tested The model has a number of implications for multinational activity and trade. First, it predicts that the average knowledge intensity of trade between countries is increasing in the distance between them (from equation (3)). Further, the model has testable implications for multinational behavior at the firm level (Propositions 1, 2, and 3). The empirical analysis below will focus on the predictions that are specific to our model, as opposed to the result that import cost shares and sales are declining in trade costs, which could be simply due to cultural or taste differences increasing with distance from home. The main empirical implications for imports and sales as a function of knowledge intensity, based on Propositions 1 and 2, are summarized as follows.

Hypothesis 1: The percentage rate of decline of the share of inputs imported from the home country in total costs (IM^i_{jk}/TC^i_{jk}) as trade costs (τ^i_{jk}) increase is *slower* in relatively knowledge-intensive industries (high ϕ^i).

Hypothesis 2: Holding fixed the demand level, B^i_k , the percentage rate of the decrease in affiliates' local revenues (R^i_{jk}) as trade costs (τ^i_{jk}) increase is *faster* in more knowledge-intensive industries (high ϕ^i).

In deriving these hypotheses, we have strived to keep the model simple and the set of assumptions parsimonious. Central is the ability of firms to choose between embodied knowledge transfer using imported inputs and the disembodied knowledge transfer required for offshore production. First, we assume that affiliate import costs rise in distance while disembodied transfer costs do not, but all we need is that the disembodied transfer costs rise at a slower rate than trade costs. Second, the knowledge intensity of different activities matters because their technologies can be more or less codified. We assume that communication costs vary with the degree of codification while trade costs do not, although it is enough for our results if communication costs rise faster in knowledge intensity than trade costs. These two, arguably mild, assumptions yield that affiliates import the relatively knowledge intensive inputs so that the average knowledge intensity of trade rises with distance. Finally, the assumption of log supermodularity, which here simply means that knowledge intensive industries use more knowledge intensive intermediates in a precisely defined manner, allows the model to be connected to firm-level data so that Hypotheses 1 and 2 can be tested.[10]

Estimating Equations Based on this theory we now specify an econometric model of the input sourcing and local sales behavior of U.S. multinational affiliates. Three elements are critical. First, to test Hypotheses 1 and 2, the effect of changes in trade costs on both the firm's input sourcing and sales decisions must vary with knowledge intensity. Second, in the presence of fixed costs of opening an affiliate it is important to correct for potential selection of firms across destinations. Third, the model must account for local demand conditions and firm productivity.

Intensive Margin We begin by specifying the affiliate's reliance on inputs imported from its home country conditional on owning an affiliate. The cost share of imported inputs of an affiliate of firm ω in industry i in country k at time t is given by

$$\ln\left(\frac{M^i_{\omega kt}}{TC^i_{\omega kt}}\right) = \alpha^{CS}_{\omega t} + \left(\delta^{CS}_1 + \delta^{CS}_2 KI^i_t\right)\ln\tau^i_k + \beta^{CS}_X \ln X^i_{kt} + \varepsilon^i_{\omega kt}, \tag{8}$$

where $\alpha^{CS}_{\omega t}$ is an firm-year fixed effect, KI^i_t is our measure of knowledge intensity, and τ^i_k is an ad valorem measure of trade costs between the United States and country k.[11] Further, X^i_{kt} is a vector of controls including important host country characteristics (such as market size), and $\varepsilon^i_{\omega kt}$ is the error term.[12]

The model has the following predictions on the signs of the coefficient estimates. First, while in general an increase in trade costs is associated with the increased offshoring of production to the affiliate so that $\left(\delta^{CS}_1 + \delta^{CS}_2 KI^i_t\right) < 0$, according to Hypothesis 1 this effect should be less pronounced in more knowledge intensive industries so that $\delta^{CS}_2 > 0$.

Our model of the local affiliate sales, $\ln R^i_{\omega kt}$, of firm ω in industry i in country k at time t is symmetric to (8) up to the coefficients and so is given by

$$\ln R^i_{\omega kt} = \alpha^R_{\omega t} + \left(\delta^R_1 + \delta^R_2 KI^i_t\right)\ln\tau^i_k + \beta^R_X \ln X^i_{kt} + \eta^i_{\omega kt}. \tag{9}$$

The sales of affiliates in their host country should be decreasing in trade costs so that $\left(\delta^R_1 + \delta^R_2 KI^i_t\right) < 0$, and according to Hypothesis 2 this effect should be more pronounced in knowledge intensive industries so that $\delta^R_2 < 0$. The prediction $\delta^R_2 < 0$ is exactly the opposite to the model's prediction in the import cost share equation, where $\delta^{CS}_2 > 0$. The fact that import and sales behavior are predicted to vary in qualitatively different ways as trade costs change provides a powerful test of the theory.

[10] For a formal treatment, see section B.1, where also a number of additional assumptions are discussed.

[11] We have dropped the source country subscript j as it is always the United States in our data.

[12] We do not include KI^i_t by itself because since all firms belong to a single industry the specification controls for industry-year fixed effects.

We will estimate (8) and (9) through two methods. First the firms' locational decisions are taken as given and these equations are estimated via ordinary least squares (OLS). We then adjust the econometric model to allow for locational decisions to be endogenous and explicitly model the extensive margin. In the presence of fixed costs of opening a foreign plant, firms that face unusually large costs abroad relative to the cost of exporting their final good or face unusually low demand abroad will not be observed in our data. Therefore, all of the variables included in equations (8) and (9) also feature in the likelihood that an affiliate appears in our sample. Fortunately, theory also indicates that fixed costs associated with opening a foreign plant will influence the likelihood of observing an affiliate without affecting the level of activity conditional on being observed, see equation (7). Thus, proxies of fixed costs at the country-level are appropriate exclusion restrictions. We estimate the likelihood that an affiliate appears in our sample with a probit model.

In the two-step Heckman (1976) model this probit is estimated in conjunction with variants of our import cost share and sales equations. The changes relative to equations (8) and (9) are as follows. First, since selection is based on firm characteristics, we want to employ cross-firm variation; consequently we replace the firm-year fixed effects with industry and year fixed effects. Second, we include parent domestic sales as a proxy for firm productivity. If fixed costs to disembodied knowledge transfer are important, we would expect that firm productivity enters with a negative sign in the import cost share equation as more productive firms sell enough units to justify the local fixed cost. In the sales equation we expect to find a positive coefficient on firm productivity, indicating that relatively productive firms sell more than less productive firms.

In addition to selection, there are a number of other important econometric and measurement issues. First, to address the potential endogeneity of knowledge intensity, KI_t^i, we eskew firm-level measures of knowledge intensity in favor of industry averages and control for firm-fixed effects where possible. Second, we show empirical results for a number of plausible measures of knowledge intensity. Also a range of robustness checks with other determinants of multinational activity will be conducted.

We now turn to describing the data set.

3 Data

Firm-level data of the international structure of U.S. multinationals' operations come from the Bureau of Economic Analysis (BEA) surveys of *U.S. Direct Investment Abroad*.[13] A

[13] U.S. direct investment abroad is defined as the direct or indirect ownership or control of a single U.S. legal entity of at least ten percent of the voting securities of an incorporated foreign business enterprise or the equivalent interest in an unincorporated foreign business enterprise.

U.S. multinational firm is the combination of a single U.S. legal entity that has made the direct investment, called the U.S. parent, and at least one foreign business enterprise, called the foreign affiliate. As a result of confidentiality assurances and penalties for non-compliance, the BEA believes that coverage in this survey is close to complete and the level of accuracy is high.

We have linked the BEA data for each U.S. parent whose main-line-of-business is a manufacturing industry to each of its majority-owned foreign affiliates for each of the benchmark years 1994, 1999, and 2004. For each U.S. parent we observe the location of all of their manufacturing affiliates, the value of the affiliates' imports of intermediate inputs from the United States, and the value of affiliate sales to various destinations.[14] A large share of the typical affiliate's imports come from its U.S. parent firm (intra-firm trade). These data are aggregated over each country-year pair to form a single firm-country-year observation for each of our main dependent variables: affiliate import cost shares and local affiliate sales. In addition to local sales, we also present results on affiliate sales to the U.S. and to third countries. Each observation is assigned to the parent firm's industry.[15] In our final sample, the activity of more than 1,000 U.S. multinationals and 3,000 affiliates is classfied into 48 distinct industries.[16]

We also use the BEA data for firm productivity and to construct our main measure of knowledge intensity. Firm productivity is measured by the market share of the parent firm in the United States.[17] For each parent firm, we observe total R&D expenditures and the parent firm's total sales by year. Aggregating over each industry for each year, we construct the industry's R&D intensity, the ratio of R&D expenditures to sales. We use primarily R&D intensity as the variable measuring the unobserved knowledge intensity. It is a plausible measure of knowledge intensity because the outcome of R&D is often tacit information. Moreover, in industries with high R&D intensity production techniques are subject to rapid change and frequent communication needs between managers in the home country and the affiliate.

We also consider alternative measures of knowledge intensity. Several of these are inspired by the recent literature on offshoring (Levy and Murnane 2005, Costinot, Oldenski, and Rauch 2009). According to this literature, offshoring of production activities is relatively more difficult in industries in which production activites are non-routine or that require the exercise of judgment. We use the Occupational Information Network

[14] Intermediate input imports in the BEA data are identified as imports "for further processing". We have also employed the broader measure of all affiliate imports, which gives similar results.

[15] To do so we have concorded the later year NAICS-based categories into 1994 SIC-based categories.

[16] In three food processing industries and one fabricated metal industry, there is virtually no trade between parent and affiliate. These industries were dropped from the sample.

[17] This is consistent with heterogeneous firm models in the spirit of Melitz (2003).

(O*NET) data from the Bureau of Labor Statistics that ranks occupations by the extent to which these occupations require (i) the extensive analysis of data, (ii) the processing of information, or (iii) the exercise of judgement and the need for decision making. Aggregating over occupations using labor requirements by industry for the year 2004, we construct alternative measures of the difficulty of offshoring activities by industry. We also employ industry-level values of the share of computers in total capital as alternative measures of knowledge intensity (source: Bureau of Labor Statistics).

The *ad-valorem* measure of trade costs is defined as

$$\tau_{kt}^{i} = 1 + fc_{kt}^{i} + tariff_{kt}^{i},$$

where fc_{kt}^{i} is an *ad-valorem* measure of freight costs, and $tariff_{kt}^{i}$ is an *ad-valorem* measure of tariffs, both at the industry-country-year level. Freight costs, fc_{kt}^{i}, are constructed from trade values including cost, insurance, freight (c.i.f.) to values that do not include this (free on board, or f.o.b. values) in the Feenstra, Romalis, and Schott (2002) dataset following the methodology of Hanson, Mataloni, and Slaughter (2005).[18] The tariff measure, $tariff_{kt}^{i}$ is calculated from figures in the United Nations' Trade Analysis and Information System (TRAINS) dataset and extracted with the World Integrated Trade Solutions (WITS) software of the World Bank, where we use the same method of computing industry-level values as employed to construct freight costs.

We now turn to a number of other variables. According to the model the size of foreign demand determines the scale of foreign operations and so directly affects the volume of local sales and indirectly can affect the import cost share. Therefore, we include GDP and the size of the host country's population, which are taken from the Penn World Tables. Other controls are motivated by determinants of FDI that are outside our model. To allow for comparative advantage to affect the structure of affiliate operations, we control for factor price differences across countries by interacting a country's skill abundance with an industry's skill intensity and a capital abundance with capital intenity. Our measure of skill abundance is human capital per worker, and the analogous measure of capital abundance is capital per worker (source: Hall and Jones 1999). We also consider comparative advantage based on institutional quality as proposed by Nunn (2007), which is also the source of our skill and capital intensity variables.

We employ a number of variables that are directly related to international transactions costs: an indicator variable for common language between the host country and the U.S.,

[18] From U.S. import data disaggregated by country-industry-year, the freight cost is computed as the ratio of freight and insurance charges to the customs value of imports. The resulting figures are then aggregated to BEA industry classifications using U.S. exports to that country as weights. Note that these proxy trade costs are based on the industry of final production itself, not on information on the trade costs of intermediate inputs; the latter is not available.

from Hanson, Mataloni, and Slaughter (2005), and the costs of making a phone call, from the World Competitiveness Yearbook (1999). Moreover, some research suggests that multinationals may engage in transfer pricing by altering the value of within-firm transactions to reduce their global tax burden. We address this by including the host country's maximum marginal corporate tax rate (source: University of Michigan World Tax Database).

A major strand of work views multinational firms as vehicles that internalize (within the firm) relationships where contracting on the transfer of technological knowledge is crucial (Ethier 1986). We expect that countries in which intellectual property rights (IPRs) are strongly enforced will be those in which relationships between independent firms are more prevalent. In contrast, countries with weak IPRs may require more frequently the in-house, that is, multinational, mode of organization. To make sure that our results are not principally driven by make-versus-buy decisions related to a country's IPR regime, we control for the quality of country's IPR regime using data from Park (2008).

Recent work has also emphasized that the quality of a country's legal institutions will affect the boundary of the firm in the presence of contract incompleteness, especially for knowledge-intensive goods. While our analysis is consistent with both FDI and foreign outsourcing, we want to be certain that our findings are not primarily due to factors that determine the make-versus-buy decision. We include therefore as another variable the quality of the judicial system of a country; this has recently been emphasized by Nunn (2007), which is also the source of our data.

In the sample selection specifications we proxy for country-level fixed costs using two measures. First, the difficulty of entry due to barriers is captured through World Bank data from the World Development Indicators database. We use as exclusion restrictions the Costs of Starting a Business and a country's Foreign Market Potential, defined as the distance-weighted size of a country's surrounding markets. As our dependent variable is solely related either to domestic demand (local affiliate sales) or trade frictions with the United States (import cost share) it is not directly determined by the proximity of a country to other potential markets. Yet, in a model that allowed for affiliates to serve not only the local but also third-country markets the proximity of other large markets would motivate an additional inflow of FDI. This motivates the use of Foreign Market Potential as an exclusion variable (source: CEPII Market Potentials Database). In our analysis of the knowledge intensity of trade we employ the U.S. Census Bureau's data base on related party trade, while disaggregated data on R&D and sales, as well as the relationship between firm size and firm rank is obtained from the COMPUSTAT database.

Major features of our data are as follows.[19] About 56% of all affiliate sales are going

[19]Full summary statistics are shown in Table A of the Web Appendix.

to the local market, while about 17% of total affiliate sales are to the United States, and the remaining 27% are sales to third countries. If one takes the share of sales that are destined for the United States as an indicator of factor-cost driven FDI, sometimes called vertical FDI, the implication is that U.S. outward FDI is predominantly motivated by non-factor cost motives–such as market access.[20] The knowledge intensity of an industry is measured by R&D over sales, with a sample mean of 4.5%, while the mean trade costs are about 14%. Finally, the average import cost share is about 5%, with a one standard deviation above the mean of 37%. This means that while many affiliates do not import large amounts of goods from their parents, imported intermediates play a major role for some affiliates. Of course, the literature has long considered the transfer of knowledge, not goods, as key to the theory of multinationals (Markusen 2002, Ch. 1). By examining goods and knowledge flows within the same framework, we provide a synthesis view.

The following section presents the empirical results.

4 Empirical Results

We begin the presentation of the results by providing evidence on the affiliate's import cost share and affiliate sales, equations (8) and (9), taking the location of affiliates as given. The estimation method is OLS, which has the benefits that the results are easily interpreted and that we can rely on variation across affiliates of a given multinational firm and a given year. Next, we estimate the full model by accounting for the location decision of multinationals, where the sales and import cost equations are estimated jointly with a selection equation determining entry in a particular foreign market. As we will show there is strong evidence in support of the model.

Table 1a shows the results for the intensive margin of multinational activity. In this and the following tables, evidence on the import share and sales of the affiliate are presented side by side in order to highlight the differential impact of knowledge intensity on these two aspects of multinational activity. In column 1 we include only trade costs, TC, and the trade cost-knowledge intensity interaction ($TC \times KI$), in addition to firm-year fixed effects. The linear trade cost effect is negative while the $TC \times KI$ coefficient is positive. A less pronounced decline of the import share with trade costs for knowledge intensive industries is expected from the model, because communication problems in knowledge intensive industries limit the substitution of FDI for trade.

[20] Among the affiliate sales to the U.S., the great majority go to the parent company. This is consistent with the idea that the affiliate primarily adds unskilled-labor intensive stages before the intermediate product is sent back to the parent. In contrast, local sales are predominantly to unaffiliated parties, and third-country sales are split between affiliated and unaffiliated parties.

A number of country variables that may also affect the affiliates' import cost shares are added in column 2. While the host country's population and its GDP are not significant, the host country's maximal corporate tax rate has a positive sign. This is consistent with a role for transfer pricing, where multinationals overcharge the value of shipments to affiliates if these are located in high-tax countries. Skill endowment and capital endowment variables have no significant relation with the import share, however a high IPR index is associated with lower imports. As long as affiliate production leads to stronger technological learning for firms in the host country than exporting from home (Keller and Yeaple 2009), high levels of IPR protection will make multinational firms less reluctant to move sensitive production processes abroad because it is associated with less leakage of technological knowledge. Further, high judicial quality in the host country favors local production over imports from the home country. To the extent that local production involves outsourcing to independent suppliers while imports are primarily within firm, this is in line with recent work based on the property rights approach of the firm (Antras 2003).

Communication problems are central to our analysis of international knowledge transfer, and we include two direct measures of communication costs in the specification shown in column 2. Affiliate imports are relatively high both in English-speaking host countries and in countries that are expensive-to-call. To the extent that offshore production requires advice via frequent telephone conversations, the latter is consistent with our emphasis on communication costs. One might also expect that better communication through a common language leads to lower imports, however, we find the opposite. Importantly, the inclusion of these variables does not change the finding that affiliate imports are less sensitive to trade costs in knowledge-intensive industries (Hypothesis 1), even though the coefficient on $TC \times KI$ falls somewhat with the inclusion of the variables.

As we have shown above, differences across firms will affect their location behavior. In the empirical analysis below, these firm differences will be modeled and not differenced out through firm fixed effects. It is thus useful to see how the results of Table 1a change as we replace firm fixed effects with industry fixed effects, and add a firm-level variable, parent sales, as proxy for firm productivity. Column 3 shows that the results are quite similar. Moreover, the more productive firms tend to have relatively low import shares. This is consistent with fixed costs of knowledge transfer, as shown in Proposition 3 above.[21]

The results for local affiliate sales are shown on the right side of Table 1a. Sales are declining in trade costs from the United States, and this effect is particularly strong in knowledge intensive industries (column 4). The latter finding confirms Hypothesis 2 of the model. Adding country variables does not change this result, even though the effect

[21] This finding is not only due to differences in affiliate age, see Table G in the Web Appendix.

become somewhat less pronounced (column 5). Affiliate sales are larger in countries with high GDP, because the potential for sales is higher in these markets. The finding that high IPR leads to low imports *and* to high affiliate sales suggests that with strong IPR regimes multinationals are willing to move more technological knowledge. Moreover, sales are falling in the host countries' judicial quality and its skill endowment, in part perhaps because such countries have the same comparative advantage as the United States.

In column 6 we show sales results with industry- instead of firm fixed effects. While most results are similar, in particular the coefficient on $TC \times KI$, there are some differences. The linear trade cost coefficient is not significant anymore, and moreover, neither judicial quality nor the host country's skill endowment affect affiliate sales anymore. The coefficient on parent sales is positive and less than one. This suggests that relatively productive firms sell more also through their foreign affiliates, although home productivity advantages translate abroad less than one for one.

So far our empirical analysis has exploited variation across industries with different knowledge intensity as well as variation across different host countries, and one might wonder to what extent the results are driven by either dimension. One way to explore this is to introduce country fixed effects in the regression, as commonly done in the gravity of trade literature. Moreover, one might be concerned with the fact that TC is the only country variable interacted with knowledge intensity, the key industry characteristic, because the $TC \times KI$ variable might simply capture variation that is due to an omitted variable. In the following Table 1b, therefore, we explore these concerns.

The import cost share specification in column 1 of Table 1b is the same as column 3 of Table 1a except that country fixed effects have been included. We see that country fixed effects matter, for example in that the R^2 rises and the size of the linear TC coefficient is lower, however the estimate for the $TC \times KI$ interaction is quite similar to before. Further, it may be that IPR protection plays a particularly important role for knowledge-intensive industries for internalization reasons. We therefore include the $IPR \times KI$ interaction while at the same time dropping the country fixed effects (column 2 of Table 1b); the $IPR \times KI$ variable turns out to be not significant. In column 3 we include two additional knowledge-intensity interactions, with skill endowment and with judicial quality, while in column 4 also country fixed effects are included as well. In either specification the coefficient estimate for the $TC \times KI$ variable is positive, consistent with Hypothesis 1, and quantitatively similar.

We perform the same steps for the affiliate sales equation in the four columns of Table 1b on the right, and here the outcome is somewhat different. While the inclusion of country fixed effects by themselves does not impact the estimate on the trade cost-knowledge intensity ($TC \times KI$) variable by much (column 5), if on top of that all three additional knowledge-intensity interaction variables are included the coefficient on $TC \times KI$ falls to around -13 and is only marginally significant (column 8). However, this seems to be due in large part to the high correlation of the skill-, judicial quality-, and IPR-knowledge intensity interactions, which all enter significantly if added jointly (column 7) even though this is not the case if they are added one at a time. For example, in the specification underlying column 6 the $IPR \times KI$ coefficient is estimated to be negative (and insignificant) whereas upon the inclusion of further knowledge-intensity interactions it turns positive and significant, see column 7. This suggests that including a large number of knowledge-intensity interactions generates a specification error that makes the results unreliable. Overall, we conclude from this analysis that the findings are not primarily driven by cross-industry variation and omitted alternative knowledge intensity interactions. In section 6 below we will perform further robustness analyses.

Multinational Affiliate Entry and Activity In the following we treat the entry decision of the multinational firm in a particular foreign market jointly with the decisions of how much to sell and which fraction to import from the home country. Our analysis employs Heckman's (1976) well-known two-step approach to analyze the extensive margin of multinational operation. In the first step, we run a probit to estimate the probability of the presence of a given multinational firm in a given host country. From this we obtain the Mills ratio, which addresses the sample selection problem under the assumptions made in Heckman (1976).[22]

The results are presented in Table 2. The first three columns are for the import cost share as the dependent variable, while the last three are for sales. Each column presents results for a specification with a different set of exclusion variables in the selection equation, shown in the lower part of Table 2. In all specifications and in both step one and step two, the full list of country variables of Table 1a is included. While we present some on the first and more detail on the second step of the estimation, not all coefficients are reported to save space.

Consider first column 1 of Table 2. The number of observations now is 45,121, the sum of cases where affiliate activity is actually observed and where the firm did end up not opening an affiliate in this particular country. The exclusion variable in column 1 is the World Bank's Cost of Starting a Business. Because these fixed costs are independent of the volume of imports and sales, this measure can plausibly serve as an exclusion restriction. The Costs of Starting a Business enters with a negative sign, consistent with

[22] To address sample selection with Heckman's (1976) approach we have to make strong parametric assumptions, including joint normality, and our analysis of sample selection is specific to those. This is the reason why we report the less restrictive OLS results for the intensive margin.

the hypothesis that host countries in which there are higher fixed costs of starting a business are less likely to attract multinational affiliates. Also the significant Mills ratio indicates that selection is an issue.

Countries with larger population are more likely to have inward FDI, a finding consistent with fixed costs of FDI. In addition, firms with larger parent sales are more likely to open an affiliate abroad. This is in line with our model and it confirms the well-known result that FDI entry is driven in part by high firm productivity.

What is the key impact of selection in terms of knowledge transfer and the gravity of multinational sales? Comparing column 1 of Table 2 with column 3 of Table 1a, in the Heckman specification trade costs have smaller impact on reducing the import cost share than according to the least squares specification (coefficient on TC of -1.7 versus -3.7). Primarily, this appears to be due to affiliates that operate at high distances from the U.S. which tend to have low import cost shares, and the main way this is captured by the least squares estimator is a high (in absolute terms) elasticity of imports with trade costs.

Once selection is accounted for it appears that firms that operate in high-TC locations tend to be high productivity firms. In the Heckman results the coefficient on parent sales in the second stage is much higher (in absolute terms) than in the least-squares regression (-0.37, versus -0.05). Accounting for the selection of firms at high versus low values of trade costs may therefore explain why the coefficient on TC moves closer to zero.

While this shows that selection has an important effect on the trade cost elasticity of the affiliates import cost share, the impact on the degree to which the trade cost elasticity varies with knowledge intensity is much smaller: the coefficient on $TC \times KI$ changes only from about 24 to about 20 (see Table 1a, column 3, and Table 2, column 1). The evidence in favor of Hypothesis 1 thus far is, according to these Heckman results, not driven by the extensive margin decision of firms.

This result is robust to employing different exclusion variables. In column 2 we employ the foreign market potential (FMP) of the host country, computed as the distance-weighted size of the market, excluding the host market itself. A high FMP raises the probability that a U.S. firm opens an affiliate in that country (coefficient of about 0.23). There is less evidence for sample selection than before, with the Mills ratio insignificant. This may have to do with changes in the sample size. At the same time, the trade cost-knowledge intensity interaction variable $TC \times KI$ is positive and its magnitude is similar to before.

In column 3 both Costs of Starting a Business and FMP are employed as exclusion variables. They both come in with the expected sign, and the Mills ratio is significant. In the second-step the import cost share is declining in trade costs, and this effect is less strong in knowledge-intensive industries. This result confirms earlier evidence in favor of

Hypothesis 1.

Turning to the second hypothesis, Table 2 on the right side shows the influence of knowledge intensity on the gravity of U.S. affiliates' sales. Because the selection equations for the import cost shares and sales differ only in terms of the number of uncensored observations (see Table 2, bottom), the estimated coefficients are similar.[23] The Mills ratio is now positive. This is what one expects if some unobserved determinant of opening an affiliate in a particular country, such as firm productivity, at the same time leads to higher affiliate sales.

How does accounting for sample selection affect the sales results? First, compared to the earlier results of Table 1a, column 6, sales are falling now stronger (and significantly, at standard levels) with trade costs, with the coefficient on TC moving from around -0.2 to -0.8 in Table 3. Second, the impact of productivity on affiliate sales becomes somewhat stronger than before. Taken together, accounting for sample selection means lower sales in distant locations, especially if the firm has relatively low productivity. The findings regarding Hypothesis 2 are unchanged: gravity in sales is particularly strong in industries where knowledge is difficult to transfer. We estimate coefficients on the $TC \times KI$ variable of about -18, versus -16 in the comparable least-squares specification. We conclude that the support for our model's Hypotheses 1 and 2 is not due to selection generating the particular sample for which we observe FDI.[24]

It turns out that the previous results for the trade cost-knowledge intensity variable are largely unchanged in a number of robustness checks discussed in Section 6. We therefore now turn to discussing the economic magnitudes implied by our estimates.

5 Economic Magnitudes

In this section, we use the model together with the econometric estimates to quantify the economic impact of disembodied knowledge transfer costs. First, we parameterize the cost function by using the econometric estimates and calculate the implied effect of the disembodied knowledge transfer frictions on affiliates' marginal costs. This should shed light on the puzzling reports of plants overseas being less productive than home plants of the same firm even though to the casual observer the plants appear to be identical. Second, building on the affiliate cost estimates we further parameterize the model to assess how important disembodied knowledge transfer costs are in explaining aggregate sales of

[23]There is a subtle difference in the interpretation of the first step: in the import specifications, the affiliate is present *and* has positive imports, while for sales, it is that the affiliate is present.

[24]We have explored whether these Heckman results change appreciably with the inclusion of additional knowledge intensity interactions; as shown in Table C of the Web Appendix, this is not the case.

multinational affiliates.

Affiliate Marginal Cost To operationalize the cost equation (4), we assume that the elasticity of substitution across intermediate inputs is equal to unity, that the knowledge transfer cost function is given by $t(z) = \exp(\lambda z)$, and that the cost share function $\beta(z|\phi^i)$ is exponential with parameter $1/\phi^i$. This implies that

$$\ln \frac{M^i_{jk}}{TC^i_{jk}} = -\frac{1}{\lambda \phi^i} \ln \tau^i_k.$$

By further assuming that $1/\phi^i = \delta_0 - \delta_1 KI^i$ we arrive at a reduced form that is exactly consistent with our estimating equation. Using the coefficient estimates from column 1 of Table 1a and evaluating the expression at the average knowledge intensity, we obtain $1/\lambda\phi = 2.794 - 36.089 \times 0.042 = 1.278$.[25] As we are working with industry averages, industry indices are henceforth dropped.

With this parameterization, the marginal cost of obtaining the composite intermediate for the average affiliate is

$$C^M(\tau_k, \phi) = \exp\left(\lambda\phi\left(1 - \tau_k^{-\frac{1}{\lambda\phi}}\right)\right). \tag{10}$$

Aggregating trade costs using export weights to obtain country-level average trade costs (τ_k) and using the estimate of $1/\lambda\phi$, we can compute the marginal cost of a given affiliate relative to the marginal cost of a plant in the United States.

The results on average for certain groups of countries are shown in Table 3a. In column 1 the (relative) cost of a plant in the U.S. are shown; it is equal to one irrespective of the destination of final sales. Trade frictions induce variation in the costs of serving foreign markets through exporting and embodied technology transfer, see column 2. The multinational affiliate's average costs inclusive of disembodied knowledge transfer costs, $C^M(\tau_k, \phi)$, is shown in column 3, while the affiliate's average costs under the assumption that countries were to reduce their tariffs by 50% are shown in column 4.

The last row of Table 3a indicates that, across all countries, the average affiliate's marginal cost of production is 9 percent higher than that of a U.S. plant while the marginal cost of exporting is 10 percent higher.These estimates indicate that the endogenous choice between disembodied and embodied knowledge transfer–both of which entail costs–ties the costs of affiliate operation to that of shipping from home, and the marginal cost savings obtained by opening a local affiliate are smaller than in the standard trade-versus-FDI

[25]The Table 1a, column 1 estimates are preferred to make this calculation because without other variables the coefficients have a structural interpretation in terms of the model.

framework. Were host countries to embark on a 50% tariff liberalization, the average effect would be to lower the affiliate cost disadvantage relative to a U.S. plant by 22 percent (column 4). At the other extreme, if trade in intermediate inputs would be banned (τ_k approaches ∞) so that firms could only rely on disembodied knowledge transfer, the cost of the average affiliate would rise to 119 percent above that of a U.S. plant.

Gravity and Knowledge Transfer We now assess the ability of the mechanism in the model to explain aggregate affiliate sales. To do this, we further parameterize the model. First, we assume that the distribution of productivities over the mass of firms is distributed Pareto, $G(\varphi) = 1 - \varphi^{-\upsilon}$. We show in the Web Appendix that the aggregate affiliate sales made by home country firms in country k is then given by

$$\begin{aligned} R_k &= \frac{N\upsilon\left(\sigma\right)^{1-\frac{\upsilon}{\sigma-1}}}{\upsilon-\sigma+1} \times \left[\left(B_k^i\right)^{\frac{\upsilon}{\sigma-1}}\right] \times \left[\left(f_k^a\right)^{1-\frac{\upsilon}{\sigma-1}}\right] \times \\ &\quad \left[C^M(\tau_k,\phi)^{1-\sigma}\left(C^M(\tau_k,\phi)^{1-\sigma} - \tau_k^{1-\sigma}\right)^{\frac{\upsilon}{\sigma-1}-1}\right] \end{aligned} \tag{11}$$

This expression shows that aggregate sales can be decomposed into three components isolated in equation (11) by square brackets. The first captures differences across countries in the level of demand, B_k, facing a typical U.S. firm. The second is differences across countries in the size of the fixed cost, f_k^a, of openning an affiliate. The last bracketed term captures the direct impact of trade costs on aggregate affiliate sales to investing abroad in the presence of embodied and disembodied knowledge transfer costs.

It is useful to compare this expression with that for the standard proximity benefit model of multinational production, Helpman, Melitz, and Yeaple (2004; HMY), which our analysis generalizes. In their model aggregate affiliate sales are given by the same expression as equation (11) except that $C^M(\tau_k, \phi)$ is fixed at unity. In both models, an increase in τ_k raises the proximity benefit of FDI production because it avoids rising trade costs. In HMY this is the only effect, and consequently the model implies that affiliate sales are rising in trade costs. In our model, there are two other effects. First, on the intensive margin an increase in τ_k raises $C^M(\tau_k, \phi)$ and so it reduces affiliate sales. Second, on the extensive margin because affiliates reduce their marginal cost relative to the parent from τ_k only to $C^M(\tau_k, \phi)$ (not to 1), the proximity benefit of affiliate operation is only $C^M(\tau_k, \phi)^{1-\sigma} - \tau_k^{1-\sigma}$ rather than $1 - \tau_k^{1-\sigma}$.

By parameterizing (11) using (10) and employing estimates for σ and $\frac{\upsilon}{\sigma-1}$, each of the square-bracketed terms in equation (11) and its equivalents in the HMY model can be computed, see the Web Appendix.[26] The terms are separable in logarithms, so that we can directly assess the importance of each mechanism for aggregate affiliate sales. Because

[26] We choose $\sigma = 6$ to be consistent with a twenty percent mark-up over marginal cost. Our estimate

market size and geography are the two central determinants of multinational activity, we do so by projecting the log of each square-bracketed term on the log host country GDP and the log of bilateral trade costs, akin to the gravity equation in trade. The results are shown in Table 3b.

The first column shows results from a regression of local affiliate sales on host country GDP and trade costs; this uses aggregate data from the publicly available 1999 U.S. benchmark survey ($n = 30$). Sales vary roughly one for one with GDP, and a one percent increase in trade costs is associated with a 10 percent fall in affiliate sales. How do these results match up with the standard trade-versus-FDI model of HMY? In column 2, labeled Marginal Cost, we run the log of $\left[\left(1-\tau_k^{1-\sigma}\right)^{\frac{\upsilon}{\sigma-1}-1}\right]$, the HMY analog of the third bracketed term in equation (11), on the gravity variables log GDP and log trade costs.[27] The coefficient estimate on trade cost is precisely estimated at around 0.7. This coefficient says that on account of the Marginal Cost mechanism, higher trade costs lead to *higher* affiliate sales. It captures the essence of the proximity argument for FDI: opening more affiliates abroad is the way to avoid rising trade costs. However, as the Data regression shows, an increase in trade costs is associated with *lower* affiliate sales. The standard model gets this part of the story wrong, and the only way to rationalize within the model the lower sales in high-trade cost destinations is to pick up that high-trade cost destinations also tend to have relatively low demand for U.S. products (see column 4).

The results of the Marginal Cost regression for our model, with the third square-bracketed term of equation (11) as the dependent variable, are shown in column 5. The coefficient estimate on trade cost is equal to -2.89. The fact that this is negative means that affiliates' marginal cost increases contribute to affiliates having lower sales in high-trade cost locations. Lower sales with rising trade costs is a major feature of FDI data (see column 1), and higher marginal cost is an excellent candidate for explaining lower sales in virtually any economic model, so we find this qualitative result comforting.

The negative cofficients on trade cost in Fixed Cost and Market Size regressions (columns 6 and 7) mean that higher fixed costs and lower market size in high-trade cost destinations also help to account for the overall finding of lower affiliate sales in high-trade cost locations.[28] It is natural to ask how quantitatively important disembodied knowledge transfer costs, as captured in our analysis by the Marginal Cost term, are in

of $\frac{\upsilon}{\sigma-1} = 1.09$ is obtained by running a log-rank - log size regression on U.S. manufacturing data. This estimate is above the 1.01 used by Irrazabal et al (2010) and slightly below the average industry value found by Helpman, Melitz, and Yeaple (2004) using European firm-level data.

[27] In constructing this Marginal Cost term, we employ our estimates on τ_k, σ, and υ as described above.

[28] The Fixed Cost dependent variable is log $\left[(f_k^a)^{1-\frac{\upsilon}{\sigma-1}}\right]$. Because $\frac{\upsilon}{\sigma-1} > 1$, the results indicate that fixed costs are increasing in GDP and increasing in the size of trade cost.

accounting for variation in aggregate affiliate sales. Given the log-additivity of the three square-bracketed terms that are the dependent variables in Table 3b, columns (5), (6), and (7), the sum of the coefficients on the trade cost regressor is by construction equal to -10.11, the value in the Data regression. Thus, we compute as the contribution of the Marginal Cost, Fixed Cost, and Market Size terms in explaining the overall gravity of multinational affiliate sales about 29% (=(-2.89)/(-10.11)), 16%, and 56%, respectively, as given in the last row of Table 3b. In conclusion, not only can our model explain lower affiliate sales in more distant markets, which the standard model cannot, but the gravity of knowledge mechanism is quantitatively important with almost 30% of the total effect.[29]

In the following we examine the robustness of the firm-level estimates.

6 Alternative Measures of Knowledge Intensity and other Robustness Analysis

In Table 4, we present results for two alternative measures of knowledge intensity. The first is a measure of the importance of a particular occupational skill required in an industry. This variable is based on information in the U.S. Department of Labor's O*NET database. Here we focus on the importance of Analyzing Data as determinant of the knowledge intensity of an industry.[30] The second measure is the share of information technology (IT) capital in total capital, specifically, the computer share.

In Table 4, the R&D intensity results are repeated in columns 1 and 4 for convenience. with OLS estimates in Panel A on top and two-step Heckman results in Panel B at the bottom. Generally the differences between Panel A and Panel B are small, and we focus the discussion on the latter. If knowledge intensity is proxied by Analyzing Data, we estimate a positive coefficient on the trade cost-knowledge intensity ($TC \times KI$) variable in the import cost share equation (column 2B, Table 4). This is in line with Hypothesis 1. While the size of the coefficient is not comparable to that of the R&D intensity specification in column 1B due to different scales, the Analyzing Data variable performs better in the sense that the $TC \times KI$ coefficient is more precisely estimated than with R&D intensity, and the empirical fit of the equation is somewhat improved.

[29] If we compute C^M based on a specification that account for factors not in the model, including wage differences leading to comparative advantage such as column 2 in Table D (in the Web Appendix), this leads to a value of $1/\lambda\phi = 1.979 - 21.915 * 0.042 = 1.06$, and, following the same steps as before, the contribution of disembodied knowledge transfer to the gravity in affiliate sales is estimated at about 29% as well.

[30] The exact definition is: "Identifying the underlying principles, reasons, or facts of information by breaking down information or data into separate parts."

Turning to the sales results on the right, using the Analyzing Data variable the coefficient on $TC \times KI$ is estimated at 0.029 and not significant at standard levels in the sales specification (column 5B). This suggests that the skill of Analyzing Data is not important in explaining why affiliate sales fall particularly strongly with trade costs in certain industries. In contrast, a high computer share is very powerful in explaining gravity for affiliate sales (column 6B): the linear trade cost coefficient is not significant anymore, while the coefficient on the $TC \times KI$ interaction variable is precisely estimated. At the same time, the computer share in total capital yields a negative coefficient on $TC \times KI$ in the import cost share equation (see column 3B), which is not what is expected if the computer share were a good proxy for knowledge intensity in the light of the model. This may be related to the fact that the linear TC variable is not significant in the import cost share equation in column 3B.

These results can be summarized as follows. We find that the Analyzing Data variable performs very well in the import cost share equation (a result that is confirmed for other O*NET measures as shown in the Web Appendix). Moreover, a particular type of information technology capital, namely computers, performs well as an alternative proxy for knowledge intensity in the sales equation. This constitutes support for the model going beyond identifying knowledge intensity with R&D intensity. At the same time, there is no strong support from either the O*NET measures or the computer share for *both* hypotheses. Specifically, while the O*NET variables determine well the split between imports and local affiliate activity, they do not predict well the level of affiliate sales. And while the computer share predicts well the level of affiliate sales, in line with earlier work on foreign outsourcing (Feenstra and Hanson 1999), it does not predict well the import share of the affiliate.

In conclusion, none of these alternative measures are perfectly suited for testing the theoretical mechanism in the model. The available variables pick up specific aspects of the sophistication, codifiability, and communicability that make their performance vary depending on the specific aspect of multinational operation that is analyzed, and one interpretation of the results is that R&D intensity is the most comprehensive measure of knowledge transfer difficulties.

We have estimated additional specifications to examine the robustness of the results with respect to factors outside the model, including comparative advantage, sales to the U.S. and other foreign countries, as well as the ease of communication. Moreover, exploiting the panel structure of the data we have explored dynamic knowledge transfer effects, and also considered additional measures of knowledge intensity. These results, discussed in the Web Appendix, indicate that our findings in support of Hypotheses 1 and 2 of the model are robust.

We now turn to implications of the theory for the knowledge content of multinational trade.

7 The Knowledge Intensity of Multinational Trade

The model predicts that as trade costs rise, multinationals offshore the production of increasingly knowledge-intensive activities, and so the affiliates' imports become increasingly concentrated in goods that are knowledge intensive as well (this follows from equation 3). To examine whether this is borne out by the data, we compute the average knowledge intensity of U.S. exports to affiliates in other countries from the related-party trade data of the U.S Census Bureau.[31] Across 500 possibly traded six-digit NAICS industries with varying R&D intensities, this average reflects the extensive margin of the knowledge intensity of multinational trade.

Figure 1 shows a positive relationship between knowledge intensity and trade costs.[32] Moreover, with an R^2 of 0.44 the fit is quite tight. One might be concerned that this bivariate relationship is driven by other factors, such as the variables that were employed in the regression analysis in section 4. A more specific concern is that the relationship reflects trade costs rising more slowly in distance for highly knowledge-intensive goods because these goods, to some extent intangibles, have lower weight-to-value ratios. However, we have found that the relationship between average knowledge intensity and trade cost is robust to these considerations, see section E of the Web Appendix. This constitutes an important confirmation of the model's prediction regarding the knowledge content of multinational trade.

We now turn to some concluding observations.

8 Conclusions

How large are barriers to transferring knowledge across space, and what is the nature of these barriers? To provide answers to these fundamental questions, we have analyzed the structure of the international operations of U.S. multinational firms. Because these firms develop production knowledge in one location and then seek to deploy this knowledge as

[31] This covers all related-party trade between U.S. entities and foreign entities, where a related-party is one in which there exists at least a 6 percent ownership share. We employ Census rather than BEA data because the former has much greater industry detail while at the same time the firm-level information of the BEA is here not required. The data is for the year 2002.

[32] Data is in logs; the best-fit line corresponds to a weighted regression, with GDP as weights.

efficiently as possible across the globe, we can infer much from their behavior about the size and the nature of knowledge transfer costs.

We proposed a model in which trading inputs means embodied knowledge transfer, while input production through FDI involves disembodied knowledge transfer. The costs of transfer vary with the knowledge intensity and the destination market. For each component of knowledge, firms select the transfer mode in order to minimize their cost of serving each foreign market, and affiliate costs reflect an endogenous mixture of disembodied and embodied knowledge transfer costs. We derived several key predictions from this mechanism. In particular, because production of firms in knowledge intensive industries requires more non-codified knowledge, these firms rely more on embodied knowledge transfer and the affiliates' production cost is more sensitive to variation in trade costs. Also, if disembodied knowledge transfer entails substantial fixed costs, large firms will employ a higher ratio of disembodied to embodied knowledge transfer.

Using rich panel data on individual U.S. multinational firms, we confirmed these predictions of the model. Our results provide evidence that the knowledge intensity of production affects the level of foreign sales as well as the composition of disembodied versus embodied technology transfer that firms use. We show that only when amended with our knowledge transfer mechanism can the standard multinational firm model explain why sales decline with distance from home. Moreover, our mechanism can account quantitatively for a significant portion of the variation in aggregate affiliate sales. Finally, we confirm the model's prediction that the knowledge intensity of trade rises with the distance between trade partners.

Economists know little about the impact of relative cost changes for disembodied versus embodied knowledge transfer, even though both appear to be changing at a rapid pace. Communicating knowledge-intensive information may become cheaper through video-conferencing compared to telephone calls, while at the same time the knowledge embodied in trade inputs becomes more movable because trade barriers and transportation costs are falling. Our results suggest that spatial frictions – in form of both costs of trading goods and of transferring knowledge – cannot be addressed independently. This research provides a starting point for assessing the impact of such changes for production and trade across the globe.

Even in the world of the internet we find that spatial barriers to disembodied knowledge transfer are large, and this has implications for many fields of economics, such as industrial organization, productivity and innovation, and development. In industrial organization it has been shown that firms that are part of a domestic production chain do not nearly transfer as many goods within the chain as existing theories of vertical integration suggest, a finding which may be due to the fact that the key inputs determining firm organization are knowledge inputs (Hortacsu and Syverson 2009). If so, the spatial organization of firms depends critically on the spatial barriers to disembodied knowledge transfer, and as spatial barriers to disembodied knowledge transfer fall, vertical links between firms will be increasingly invisible as there is less embodied knowledge transfer and more disembodied transfer.

Our findings are consistent with the view that the returns to the accumulation of knowledge are reduced in the presence of barriers to effective knowledge transfer, which has implications for the literature on innovation and productivity. Moreover, our work suggests in general that the more knowledge intensive a production process is, the less likely its knowledge will spatially diffuse, which has important implications for cross-country income convergence. Given the relative simplicity of the mechanism highlighted in this paper, we hope to incorporate it into models of endogenous innovation and growth in future work.

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A Appendix

A.1 Proof of Lemma 1 - Elasticity of Marginal Cost

Proof is by contradiction. Suppose $\varepsilon^{MC}(\tau, \phi^1) < \varepsilon^{MC}(\tau, \phi^2)$, then from (5) the following condition must hold

$$\frac{\int_{\widehat{z}}^{\infty} \beta(z|\phi^1)dz}{\int_0^{\widehat{z}} \beta(z|\phi^1)t(z)^{1-\eta}dz + \tau^{1-\eta}\int_{\widehat{z}}^{\infty} \beta(z|\phi^1)dz} < \frac{\int_{\widehat{z}}^{\infty} \beta(z|\phi^2)dz}{\int_0^{\widehat{z}} \beta(z|\phi^2)t(z)^{1-\eta}dz + \tau^{1-\eta}\int_{\widehat{z}}^{\infty} \beta(z|\phi^2)dz}$$

which simplifies to

$$\int_{\widehat{z}}^{\infty} \beta(z|\phi^1)dz \int_0^{\widehat{z}} \beta(z|\phi^2)t(z)^{1-\eta}dz < \int_{\widehat{z}}^{\infty} \beta(z|\phi^2)dz \int_0^{\widehat{z}} \beta(z|\phi^1)t(z)^{1-\eta}dz. \tag{12}$$

Let $z' > z''$, then log supermodularity implies

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

Now integrate this expression with respect to z'' over $[0, z')$ and integrate this expression with respect to z' over $[z', \infty)$ to obtain

$$\int_{z'}^{\infty} \beta(z|\phi^1)dz \int_0^{z'} \beta(z|\phi^2)t(z)^{1-\eta}dz > \int_{z'}^{\infty} \beta(z|\phi^2)dz \int_0^{z'} \beta(z|\phi^1)t(z)^{1-\eta}dz.$$

Replacing z' with $\widehat{z}$ yields an expression that contradicts (12). **QED**

A.2 Proof of Proposition 1 - Import Cost Share

Part (i) follows directly from Lemma 1 and the definition of the import cost share. To prove part (ii) take the logarithm of (5) and differentiate with respect to τ to obtain

$$\frac{\partial\theta(\tau, \phi^i)}{\partial\tau}\frac{\tau}{\theta(\tau, \phi^i)} = -(\eta - 1)(1 - \theta(\tau, \phi^i)) - \frac{\partial\widehat{z}}{\partial\tau}\frac{\beta(\widehat{z}|\phi^i)\tau}{\int_{\widehat{z}}^{\infty} \beta(z|\phi^i)dz} < 0. \tag{13}$$

To prove part (iii), use (13), the fact that part (i) implies $\theta(\tau, \phi^1) > \theta(\tau, \phi^2)$, and the fact that the monotone likelihood ratio property implies

$$\frac{\beta(\widehat{z}|\phi^1)\tau}{\int_{\widehat{z}}^{\infty} \beta(z|\phi^1)dz} < \frac{\beta(\widehat{z}|\phi^2)\tau}{\int_{\widehat{z}}^{\infty} \beta(z|\phi^2)dz},$$

to obtain

$$-\left[(\eta - 1)(1 - \theta(\tau, \phi^2)) + \frac{\partial\widehat{z}}{\partial\tau}\frac{\beta(\widehat{z}|\phi^2)\tau}{\int_{\widehat{z}}^{\infty} \beta(z|\phi^2)dz}\right] < -\left[(\eta - 1)(1 - \theta(\tau, \phi^1)) + \frac{\partial\widehat{z}}{\partial\tau}\frac{\beta(\widehat{z}|\phi^1)\tau}{\int_{\widehat{z}}^{\infty} \beta(z|\phi^1)dz}\right] < 0$$

QED

A.3 Proof of Proposition 2 - Gravity of Affiliate Sales

Parts (i) and (ii) follow from the fact that the elasticity of local affiliate sales revenue with respect to trade costs is proportional to the elasticity of marginal cost with respect to trade costs:

$$\varepsilon_R(\tau, \phi_i) = (1-\sigma)\varepsilon_{C^M}(\tau, \phi_i),$$

and from Lemma 1.**QED**

A.4 Proof of Proposition 3 - Fixed Cost of Knowledge Transfers

We first show that the affiliates of a firm that installs ICT equipment have lower marginal costs and a lower import cost share in all countries relative to a firm that does not We then show that only highly productive firms will install such equipment.

The marginal imported input, $\widetilde{z}(\tau)$, of the affiliate of a firm that has incurred F^T that faces trade costs τ is given by $\widetilde{z}(\tau) = \widehat{z}(\tau)/\alpha > \widehat{z}(\tau)$,where $\widehat{z}(\tau)$ is given by equation (4). The marginal cost of the composite intermediate of such a firm, $C^M(\tau, \phi^i, \alpha)$, is

$$C^M(\tau, \phi^i, \alpha) = \left(\int_0^{\widetilde{z}(\tau)} \beta(z|\phi^i) t(\alpha z)^{1-\eta} dz + \tau^{1-\eta} \int_{\widetilde{z}(\tau)}^{\infty} \beta(z|\phi^i) dz \right)^{1/(1-\eta)}$$

which is strictly increasing in α. Hence, $C^M(\tau, \phi^i, \alpha) < C^M(\tau, \phi^i, 1)$ for $\alpha < 1$.

The import cost share is

$$\theta(\tau, \phi^i, \alpha) = \frac{\tau^{1-\eta} \int_{\widetilde{z}(\tau)}^{\infty} \beta(z|\phi^i) dz}{\int_0^{\widetilde{z}(\tau)} \beta(z|\phi^i) t(\alpha z)^{1-\eta} dz + \tau^{1-\eta} \int_{\widetilde{z}(\tau)}^{\infty} \beta(z|\phi^i) dz},$$

where $\alpha < 1$ if $F^T(\phi^i)$ is incurred and $\alpha = 1$ otherwise. We now show that $\theta(\tau, \phi^i, \alpha) < \theta(\tau, \phi^i, 1)$. Suppose instead that $\theta(\tau, \phi^i, \alpha) > \theta(\tau, \phi^i, 1)$, then

$$\frac{\int_{\widetilde{z}(\tau)}^{\infty} \beta(z|\phi^i) dz}{\int_0^{\widetilde{z}(\tau)} \beta(z|\phi^i) t(\alpha z)^{1-\eta} dz + \tau^{1-\eta} \int_{\widetilde{z}(\tau)}^{\infty} \beta(z|\phi^i) dz} > \frac{\int_{\widehat{z}(\tau)}^{\infty} \beta(z|\phi^i) dz}{\int_0^{\widehat{z}(\tau)} \beta(z|\phi^i) t(z)^{1-\eta} dz + \tau^{1-\eta} \int_{\widehat{z}(\tau)}^{\infty} \beta(z|\phi^i) dz}$$

$$\frac{\int_0^{\widehat{z}(\tau)} \beta(z|\phi^i) t(z)^{1-\eta} dz}{\int_0^{\widetilde{z}(\tau)} \beta(z|\phi^i) t(\alpha z)^{1-\eta} dz} > \frac{\int_{\widehat{z}(\tau)}^{\infty} \beta(z|\phi^i) dz}{\int_{\widetilde{z}(\tau)}^{\infty} \beta(z|\phi^i) dz} > 1$$

where the last step follows from $\widehat{z}(\tau) < \widetilde{z}(\tau)$. Hence,

$$0 > \int_{\widehat{z}(\tau)}^{\widetilde{z}(\tau)} \beta(z|\phi^i) t(\alpha z)^{1-\eta} dz + \int_0^{\widehat{z}(\tau)} \beta(z|\phi^i) \left(t(\alpha z)^{1-\eta} - t(z)^{1-\eta} \right) dz$$

Because $t(\alpha z)^{1-\eta} \geq t(z)^{1-\eta}$ for $\eta \geq 1$ the term on the right hand of this expression must be positive, which contradicts the assertion. We conclude that $\theta(\tau, \phi^i, \alpha) < \theta(\tau, \phi^i, 1)$.

The profit on sales to country k of a firm of productivity φ in industry i with an affiliate in country k is given by

$$\Pi_k^{i,ICT}(\varphi) = B_k^i \varphi^{\sigma-1} C^M(\tau, \phi^i, \alpha)^{1-\sigma} - f_k^a, \tag{14}$$

and the profit of this firm were it to not install the ICT would be

$$\Pi_k^{i,N}(\varphi) = \max\left\{B_k^i \varphi^{\sigma-1} C^M(\tau, \phi^i, 1)^{1-\sigma} - f_k^a, 0\right\}. \tag{15}$$

Let K^{ICT} be the set of countries the firm would open an affiliate if it installs ICT and let K^N be the set of countries the firm would open an affiliate if it did not install ICT. It is immediate from the condition in (8) that $K^N \subset K^{ICT}$ because $C^M(\tau, \phi^i, \alpha)^{1-\sigma} > C^M(\tau, \phi^i, 1)^{1-\sigma}$ so the profit associated with local production will be higher relative to exporting from the home country. The profit gain associated with installing ICT is thus given by

$$\sum_{K^{ICT}} \left(\Pi_k^{i,ICT}(\varphi) - \Pi_k^{i,N}(\varphi)\right) - F^T.$$

This expression is strictly increasing, continuous and unbounded from above in φ and negative for sufficiently small φ, hence there exists a cutoff productivity $\widehat{\varphi}^{ICT}$ that satisfies $\sum_{K^{ICT}} \left(\Pi_k^{i,ICT}\left(\widehat{\varphi}^{ICT}\right) - \Pi_k^{i,N}\left(\widehat{\varphi}^{ICT}\right)\right) = F^T$. Further, all firms with $\varphi > \widehat{\varphi}^{ICT}$ will invest in ICT and all others will not. **QED**

B Web Appendix

B.1 Generalizations of the Theory

In this section, we elaborate on generalizations of the simple model presented in the paper lead to qualitatively similar results. First, the assumption that shipping costs were uniform across goods could have been weaken to all these costs to vary across goods according to

$$\tau_{jk}(z) = \tau_{jk} \times g(z)$$

where $g(z) \geq 1$ and $t'(z) > g'(z)$. The key assumption is that trade costs do not rise faster than disembodied knowledge transfer costs. Second, the assumption that knowledge transfer costs did not rise in trade costs can be adjusted so that

$$t(z;\tau) = \delta(\tau)t(z),$$

where $\delta'(\tau) \geq 0$ and $\tau\delta'(\tau)/\delta(\tau) < 1$. The key assumption is that trade costs rise faster in distance than do disembodied knowledge transfer costs. Third, the assumption that the only variation across industries was in the composition of inputs used in the production of the composite intermediate input can be generalized to allow an industry's knowledge intensity to affect intermediate input transfer costs directly according to

$$t^i(z) = t(\phi^i)f(z),$$

where $t'(\phi_i) > 0$. As long as $f(z)$ is not too convex in z it is straightforward to show that this is sufficient to generate our results, and it reinforces the composition effect in the model.

Some of the model assumptions cannot be generalized. For instance, if the elasticity of substitution across goods is relatively low in knowledge intensive industries, as opposed to be identical across industries as we have assumed, this would limit the transmission of higher marginal costs to affiliate sales, thereby confounding Proposition 2 which supports Hypothesis 2. In contrast, if inputs were relatively substitutable in knowledge intensive industries, which seems implausible, this too would have confounding effects on the relationship between trade costs and the import share.

B.2 Decomposition for the Gravity Regression

This section contains the supporting material for the decomposition implemented in section 5.

Deriving the Decomposition Equations From equation (8) in the text, we find that all firms with productivity exceeding a cutoff ($\varphi \geq \widehat{\varphi}_k$) will open an affiliate in country k. This cutoff is the solution to

$$B_k(\widehat{\varphi}_k)^{\sigma-1}\left(C^M(\tau,\phi)^{1-\sigma}-\tau^{1-\sigma}\right)=\sigma f_k^a. \tag{16}$$

The total sales of affiliates to country k and industry i is obtained by aggregating over the individual firms that own an affiliate:

$$\begin{aligned} R_k &= N\int_{\widehat{\varphi}_k}^{\infty} R_k^i(\varphi,\tau_k,\phi)dG(\varphi) \\ &= NB_kC^M(\tau_k,\phi)^{1-\sigma}\int_{\widehat{\varphi}_k}^{\infty}\varphi^{\sigma-1}dG(\varphi) \\ &= NB_kC^M(\tau_k,\phi)^{1-\sigma}\frac{\upsilon}{\upsilon-\sigma+1}\widehat{\varphi}_k^{-\upsilon+\sigma-1} \end{aligned}$$

substituting for the cutoff using (16), we obtain (11). We now derive an expression for the fixed cost of opening an affiliate in country k. First, note that the number of home firms that own an affiliate in country k is given by $N_k = N\widehat{\varphi}_k^{-\upsilon}$ Combining this expression with (11) and (16), we arrive at the following expression:

$$\frac{R_k}{N_k}=f_k^a\left(\frac{\upsilon\sigma}{\upsilon-\sigma+1}\frac{C^M(\tau_k,\phi)^{1-\sigma}}{C^M(\tau_k,\phi)^{1-\sigma}-\tau_k^{1-\sigma}}\right). \tag{17}$$

This equations shows that the fixed cost parameters for each country can be recovered given estimate of τ_k and $C^M(\tau_k,\phi)$ that were discussed in the first half of the quantitative section, average affiliate size R_k/N_k, and parameters σ and υ. Finally, given this same information and the derived f_k^a, we can then use (11) to isolate the mark-up adjusted demand level B_k.

Estimating dispersion As a generalization of Helpman, Melitz, and Yeaple (2004), we may estimate the bundle of parameters $\upsilon/(\sigma-1)$ as done in that paper. We employ COMPUSTAT data for 1999 and calculate the domestic sales as the difference between total firm revenues and the value of exports. As the Pareto approximation of the size distribution is only appropriate in the upper tail, we restrict attention to the top 10% of firms. Using the bias correction method in Gabaix and Ibragimov (2011), the regression of the logarithm of a firm's rank in the distribution on the logarithm of a firm's sales yields a coefficient of 1.093 with a T-statistic of over 104 and an R-squared in excess of 0.98.

C Summary Statistics

Table A gives summary statistics for the firm-level BEA sample, while Table B provides summary statistics for the country-level analysis of the knowledge intensity of multinational trade of section 7 in the text.

D The robustness of the firm-level estimation results

In this section a number of additional robustness checks are discussed.

Additional Knowledge Interactions To complement our analysis in the text that has included additional knowledge intensity interactions to examine whether the results on $TC \times KI$ are driven by omitted variables (Table 1b), we now report analogous results for the Heckman (1976) estimator, see Table C. In column 1 the IPR interaction $IPR \times KI$ is added in the import cost share equation; it does not enter significantly and the trade cost-knowledge intensity variable is virtually unchanged compared to before (see colum 3, Table 2). Similar results are obtained by including in addition the skill endowment-knowledge intensity interaction as well as the judicial quality-knowledge intensity interaction, see Table C, column 2.

Including further knowledge intensity interactions reduces the coefficient estimate on $TC \times KI$ in the sales equation in absolute value, from about -18 to about -13, see column 4 of Table C. Also here, however, part of this appears to be driven by a specification error arising from the high degree of correlation between the three additional knowledge intensity interactions: the $IPR \times KI$ variable changes from negative (almost significant) to positive (and significant) upon the inclusion of the skill- and judicial quality-knowledge interactions. Overall we conclude that the results for the estimates on the trade cost-knowledge intensity variable are robust to the inclusion of additional knowledge intensity interactions.

Comparative Advantage The model of Helpman (1985) suggests that imports of intermediate inputs should be high when countries are very different in terms of their endowments so that comparative advantage plays a role. In his model, high human capital countries develop technologies and intermediates of relatively high skill intensity. In the following we consider three specific sources of comparative advantage, arising from skill abundance, capital abundance, and institutional factors. Our approach, following Romalis (2004) and Nunn (2007), is based on multiplying a country characteristic (such as skill abundance) by the corresponding industry characteristic (skill intensity). If the empirical support for Hypotheses 1 and 2 presented above masks comparative advantage forces at work, including these variables should alter our findings on the $TC \times KI$ variable.

The results from including all three sources of comparative advantage in the imports regression are shown in columns 1 (OLS) and 2 (Heckman) of Table D. It turns out that none of the comparative advantage interaction variables has a significant effect on the import cost share of U.S. multinational affiliates, and consequently, the impact on the trade cost-knowledge intensity ($TC \times KI$) variable is small.

On the right side of Table D the corresponding results for affiliate sales are shown. Generally, comparative advantage has a stronger impact on affiliate sales than on the affiliate's import cost share. According to the Heckman specification (column 4), U.S. affiliates have relatively low local sales of skill intensive goods in skill abundant countries. This may be because the host country has a comparative advantage in the same goods that U.S. multinationals specialize in and so product market competition is more intense. We also find that affiliate sales are higher in countries with an institutional comparative advantage. While the three comparative advantage interactions raise the (absolute) size of the $TC \times KI$ coefficient somewhat, overall there is little evidence to suggest that our previous results on Hypotheses 1 and 2 are importantly driven by comparative advantage.

Third-Country and Richer FDI Patterns So far we have analyzed the sales of multinational affiliates to unaffiliated parties in the local (host country) market. We are mindful however that affiliate sales also go back to the home market, the United States, in which case the products were most likely intermediate goods. Another possibility is that affiliate sales go into third markets. This may be final products, a phenomenon that is sometimes called export platform FDI. It could also be that multinational firms maintain a network of affiliates abroad in which different affiliates specialize in particular inputs, so that the multinational's input sourcing decisions are not exclusively between home and host country. As noted above, the FDI data we are working with allows to separate sales to the local (host country) market from sales to home (the U.S.) and from sales to third markets. In this section we expore these different sales destinations; see Table E for the results.[33]

On the left side, we repeat the OLS and Heckman results for local sales from Tables 1a and 2 for convenience. Results for onward sales to third markets are in columns 3 and 4, for sales to the U.S. in columns 5 and 6, while columns 7 and 8 show results for All Sales. Consider first affiliate sales to third countries. Here, the impact of trade costs

[33] For affiliate imports, we know the fraction that is intermediate inputs ("for further processing"), as well as the fraction that comes from the multinational parent as opposed to other U.S. entities. The large majority of imports in the data are intermediates shipped by the parent.

is positive, in line with a 'trade-cost jumping' argument: if the sales do not go to the local market, they are higher the further away the host country is from the United States. This is because a greater distance to the United States means that the firm would have to incur higher and higher trade costs if it would not sell through an affiliate. Also note that host country GDP is not as important for third-market sales as it is for local sales. This supports our interpretation of the coefficient in the local sales regressions as being a measure of sales potential. Moreover, whether the local language is English or not has no significant impact on third-market sales. While in the case of third-market sales there is no evidence that sample selection matters, the coefficient on $TC \times KI$ remains negative and, with about -36, it is about twice as large in absolute value as in the case of local sales.

An even stronger impact of knowledge intensity on the degree of gravity in affiliate sales exists in the case of sales back to the United States, as seen from the results in columns 5 and 6. This is plausible because for these sales there is typically two-way shipping, intermediate goods from the U.S. to the FDI host country, and back to the United States. The linear trade cost effect for affiliate sales to the U.S. is also larger than for local- or third-market sales. Moreover, the GDP of the host country plays even less of a role for affiliate sales to the U.S. than for third-market FDI. This suggests that market access considerations do not drive this FDI, but lower factor cost motives (assembly in the South) may be the motive. As expected, the results for All Sales in columns 7 and 8 pick up elements from all three sales destinations. The coefficient on the trade cost-knowledge intensity interaction is about -30, which supports Hypothesis 2 derived above. We take the results on $TC \times KI$ to mean that frictions to disembodied knowledge transfer matter whether there are strong market access motives to FDI or not.

Imports from Affiliates in Third-Countries In the model, all imports of the affiliates come from the U.S., both from the parent and from unaffiliated sources located in the United States. One might be concerned, however, that imports from third-country affiliates may be higher whenever more embodied knowledge is imported from the parent country. If this were the case and the effect would 'pass' the control variables, it may produce an important bias for our import share results. Unfortunately in the BEA data (and nowhere else that we know of) there is no information on bilateral trade of affiliates with non-parent countries. To explore this possibility in a more limited way we have pursued two strategies, see Table F for results.

In the first, we add a measure of prevalence of third-country sales on the right hand side of the regression. It is reasonable to assume that third-country affiliate imports will tend to be high whenever third-country sales (which we observe) are high. While third-country imports could come also from unaffiliated parties, and correspondingly third-country sales could be to unaffiliated parties, we expect there to be a strong positive correlation between third-country sales and imports from affiliates in third countries. We have thus computed the ratio of third-country sales of its affiliates relative to its total sales for each multinational firm, and include it on the right hand side of our hypothesis 2-regressions. The results are in Table F, column (2) for OLS and column (4) for the full model including extensive margin, compared to the benchmark results in (1) and (3), which are from Table 1a and Table 2, respectively. In both the OLS and the Heckman specification, the third-country sales variable enters significantly with a negative coefficient, indicating that imports from the U.S. tend to be low whenever third-country sales are high. This is consistent with imports from the parent and imports from third-country affiliates being substitutes for each other. While the third-country sales variable enters significantly, its inclusion has virtually no effect on our estimates of the trade cost x knowledge intensity ($TC \times KI$) variable.

We have also split the sample into two subsamples, the observations with low imports from the U.S. and the observations with high imports from the U.S. If our result is obtained primarily because affiliates that import relatively much from the U.S. import relatively much embodied knowledge in general, one would expect that the results for the sample with generally low imports from the U.S. are quite different than the results for the sample with generally high imports from the U.S. In Table F, columns (5) and (6) we report the results for these two samples. The estimated coefficients on the $TC \times KI$ intensity variable are very similar in both subsamples, even though the coefficient for the low import share sample is less precisely estimated.

Overall we conclude from this that it is unlikely that the results in support of Hypothesis 2 are in imported ways driven by imports from affiliates from third-countries that are not accounted for.

The Nature of International Knowledge Transfer: Dynamics In our static model, the costs of knowledge transfer are variable in the sense that per unit of intermediate good produced in the affiliate, the resource costs are higher than if it was produced in the multinational home country. In a multi-period setting, it would be possible to distinguish between a number of different knowledge transfer costs. First, it may be that there are ongoing communication frictions that do not diminish over time, perhaps because the number of possible problems is very large relative to the actual number of production steps that are required. Second, it may be that some of the knowledge transfer costs are of the once-and-for-all type. In the latter case, one would expect that over time affiliates produce more locally and import less from home. While making the model fully dynamic is beyond the scope of this paper, given the panel nature of our data where affiliates are (potentially) observed in 1994, 1999, and 2004, Table G provides evidence on this.

The specifications in Table G are identical to those in Table 1a and Table 2 except that we include a variable which is equal to one if the affiliate existed in the previous period (five years earlier). In the intensive-margin specification for the import cost share, Table G, column 1, the affiliate age variable comes in positive, whereas once sample selection is accounted for affiliate age has a negative coefficient (column 2). The latter is consistent with the idea that technology transfer costs are in part fixed, in the sense that over time the affiliate relies more on local input production. Moreover, the largely unchanged coefficient on the trade cost-knowledge intensity variable $TC \times KI$ indicates that these fixed technology transfer costs exist side-by-side with ongoing (variable) technology transfer costs. Note that the coefficient on parent sales changes from about -0.3 to -0.15 with the inclusion of the age variable. One interpretation of that is that firm productivity is to some extent captured by parent sales and to some extent by age.

A similar picture emerges in the affiliate sales specifications, see Table G on the right side. If the affiliate had existed five years earlier already, it tends to have higher sales, and the coefficient on parent sales in the Heckman specification falls from 0.66 to 0.60 (Table 2, column 6, and Table G, column 4). Again it appears that age is an alternative proxy for firm productivity, and moreover, as before the coefficient on the trade cost-knowledge intensity variable is largely unchanged.

Additional Knowledge Intensity Results In this section we extend our analysis of alternative measures of knowledge intensity from Table 4 in the paper with five other measures of knowledge intensity. There is, first of all, a frequently used measure of skills in the labor force, the share of non-production workers in all workers. Second, we present results on three additional occupational measures derived from the O*NET database, namely:

1. Processing information (Mental Processes): Compiling, coding, categorizing, calculating, tabulating, auditing, or verifying information or data.

2. Updating and using relevant information (Work Activities): Keeping up-to-date technically and applying new knowledge to your job.

3. Judgment and decision making (System Skills): Consider the relative costs and benefits of potential actions to choose the most appropriate one.

Third, results are shown for a second information capital variable, namely the share of communication capital in total capital (from the Bureau of Labor Statistics). Table H reports the trade cost-knowledge intensity ($TC \times KI$) coefficient for both least squares and two-step Heckman specifications, for both import cost share and affiliate sales.

The main findings are as follows. First, the communication capital share does not appear to capture the notion of knowledge intensity as laid out in the model, as the $TC \times KI$ coefficient is estimated imprecisely in all four cases. Second, the three O*NET variables give similar results, which are also similar to the Analyzing Data variable employed in Table 4 in the text: proxying knowledge intensity by an O*NET variable yields results in the import equation that support the model, and that are in fact stronger than for R&D intensity. At the same time, the O*NET variables do not predict well how the gravity of affiliate sales varies with knowledge intensity according to the model. Finally, the results based on the share of non-production workers are quite similar to those using the occupation-based O*NET variables. Overall, this analysis is in line of what we found in Table 4 as discussed in the text.

Communication Costs The model assumes that communication costs are symmetric across countries so that only trade costs vary across locations, but this may not be the case in the data. Moreover, it is plausible that trade costs are high when communication costs are high as well, and in that case trade costs will pick up the communication cost differences that is omitted from the regression. A straightforward way of assessing the importance of such effects is to include the communications variables, common language and the costs of phone calls, multiplied by knowledge intensity in the analysis. Table I shows these results.

In the case of the import cost share prediction, the first column repeats the main results from Tables 1a and 2 for convenience. Column 2 indicates that while the common language-knowledge intensity variable plays no role, the interaction of phone call and knowledge intensity enters negatively (and the linear phone call coefficient increases). Generally, there is less FDI in high phone call cost countries, consistent with the higher communication costs to those countries, unless it is an affiliate in a knowledge intensive industry. One explanation might be that conversations over the phone (as opposed to face-to-face) cannot fully address the tacit nature of production in knowledge intensive industries. The trade cost-knowledge intensity coefficient increases, so that the difference in the ability to shift from imports to FDI between low- and high-knowledge intensity industries is now magnified.

In the affiliate sales results on the right side of Table I, we see that including the additional communication cost variables strenghtens the support for the prediction of the model. Here the common language interaction variable matters more: common language is associated with higher sales, unless the industry is knowledge intensive. The coefficient on $TC \times KI$ increases slightly (in absolute value) from around -17 to -23. Generally the results, especially for sales, are consistent with the idea that variation in communication costs plays some role in explaining affiliate activity. At the same time any omitted variable problems resulting from that are likely to be small and do not affect the evidence in favor of Hypothesis 1 and Hypothesis 2.

Overall we conclude from this analysis that the firm-level estimates reported in the text are robust to a broad set of issues.

E The Knowledge Intensity of Multinational Trade: Regression Results

In section 7 of the paper we have discussed the relationship between trade costs from the United States and the knowledge intensity of multinational trade that is implied by the model. In this section we examine the robustness of the positive relationship shown in Figure 1 by moving to a multiple regression framework, see Table J. The first column reports the simple bivariate relationship that is plotted in Figure 1.[34] An increase in trade costs is associated with an increase in the average knowledge intensity of U.S. multinational trade. Indeed, this single regressor accounts for 44 percent of the variation as indicated by the R-squared. In column 2, we add a number of country control variables to the regression. The knowledge intensity of multinational trade is lower in large, developed countries where English is spoken. None of the other coefficients are statistically significant. The coefficient on trade costs is still significantly positive but moderately smaller than in the bi-variate case.

One concern is that the relationship reflects trade costs rising more slowly in distance for highly knowledge-intensive goods because these goods, to some extent intangibles, have lower weight-to-value ratios.To see if this is the case, we have calculated the average weight-to-value ratio of goods traded between the U.S. and each host country and include that measure in the regression; see column 3.[35] The weight-to-value variable turns out to be not statistically significant, while the coefficient on trade costs retains its approximate magnitude and level of statistical significance. The model's prediction that multinational firms change the knowledge content of their international trade in relation to geographic distance (and trade costs) thus finds strong support in the data.

[34] These are weighted least squares results, with GDP as the weight; the results are qualitatively similar when not weighted..

[35] This variable is computed from detailed U.S. Census imports data, adding the values of air and vessel shipments and dividing by the sum of their weight.

Table 1a: Technology transfer and multinational activity

	Import Share			Sales		
	(1)	(2)	(3)	(4)	(5)	(6)
Trade costs	-2.794	-3.786	-3.672	-2.942	-0.770	-0.213
	[0.030]	[<.001]	[<.001]	[<.001]	[0.085]	[0.612]
Trade costs x knowledge intensity	36.089	24.906	23.761	-23.110	-17.149	-19.405
	[0.001]	[0.039]	[0.022]	[0.036]	[0.055]	[0.016]
Population		-0.628	-0.495		-0.207	-0.218
		[0.150]	[0.229]		[0.296]	[0.269]
GDP		0.410	0.357		0.753	0.725
		[0.324]	[0.366]		[<.001]	[<0.001]
Tax rate		0.962	0.916		-0.266	-0.310
		[0.017]	[0.010]		[0.075]	[0.032]
Skill endowment		1.004	0.685		-0.390	-0.434
		[0.214]	[0.381]		[0.083]	[0.034]
Capital endowment		-0.089	0.073		0.483	0.498
		[0.661]	[0.709]		[<.001]	[<.001]
Intellectual property rights prot'n index		-0.408	-0.420		0.179	0.137
		[0.007]	[0.001]		[0.018]	[0.058]
Judicial quality		-2.950	-2.579		-0.852	-0.816
		[0.012]	[0.024]		[0.058]	[0.075]
Common language		0.468	0.481		0.438	0.407
		[<.001]	[<.001]		[<.001]	[<.001]
Cost of phone call		0.499	0.550		0.016	0.093
		[<.001]	[<.001]		[0.770]	[0.093]
Parent Sales			-0.050			0.564
			[0.012]			[<.001]
Firm-Year Fixed Effects	Yes	Yes		Yes	Yes	
Industry & Year Fixed Effects			Yes			Yes
R-squared	0.377	0.447	0.139	0.449	0.557	0.346
# of observations	5,875	5,644	5,961	7,921	7,581	7,726

Note: Dependent variables: imports for further processing from the U.S. relative to total affiliate sales in columns (1), (2), (3), and (4); local affiliate sales to unaffiliated customers in columns (5), (6), (7), and (8). Robust p-values allow for clustering by country-year and are shown in brackets.

Table 1b: Technology transfer choices and additional covariates

	Import Share				Sales			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Trade costs	-0.933	-3.670	-3.729	-0.939	0.423	-0.208	-0.346	0.270
	[0.127]	[<.001]	[<.001]	[0.113]	[0.279]	[0.622]	[0.396]	[0.462]
Trade costs x knowledge intensity	25.123	23.629	25.499	25.123	-17.757	-19.661	-14.998	-13.289
	[0.005]	[0.023]	[0.015]	[0.005]	[0.017]	[0.017]	[0.091]	[0.107]
Population	-0.416	-0.496	-0.502	-0.526	-0.430	-0.218	-0.221	-0.947
	[0.538]	[0.227]	[0.219]	[0.384]	[0.487]	[0.268]	[0.252]	[0.102]
GDP	-0.450	0.357	0.367	-0.465	1.375	0.725	0.732	1.382
	[0.116]	[0.365]	[0.349]	[0.098]	[<.001]	[<.001]	[<.001]	[<.001]
Skill endowment		0.683	1.401			-0.436	0.606	
		[0.382]	[0.201]			[0.034]	[0.008]	
Skill endowment x Knowledge intensity			-14.605	-9.225			-21.180	-20.455
			[0.070]	[0.296]			[<.001]	[<.001]
Intellectual property rights prot'n index	0.060	-0.406	-0.479	0.009	0.071	0.158	0.088	0.036
	[0.495]	[0.003]	[0.002]	[0.932]	[0.382]	[0.029]	[0.283]	[0.664]
Intellectual property rights prot'n index x knowledge intensity		-0.234	1.545	1.369		-0.387	1.532	1.519
		[0.688]	[0.190]	[0.263]		[0.400]	[0.036]	[0.044]
Judicial quality		-2.581	-2.913			-0.817	-1.461	
		[0.024]	[0.041]			[0.074]	[0.001]	
Judicial quality x knowledge intensity			5.430	0.247			11.482	10.973
			[0.523]	[0.977]			[0.005]	[0.008]
Parent Sales	-0.032	-0.050	-0.050	-0.033	0.564	0.564	0.565	0.564
	[0.102]	[0.011]	[0.010]	[0.095]	[<.001]	[<.001]	[<.001]	[<.001]
Industry & Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	No	No	Yes	Yes	No	No	Yes
R-squared	0.223	0.139	0.141	0.223	0.358	0.346	0.349	0.362
# of observations	5,961	5,961	5,961	5,961	7,726	7,726	7,726	7,726

Note: Dependent variables: imports for further processing from the US parent relative to total affiliate sales in columns (1), (2), (3), and (4); local affiliate sales to unaffiliated customers in columns (5), (6), (7), and (8). Also included are the other independent variables of Table 1a, namely Tax rate, Capital endowment, Common language, and Cost of phone call. Robust p-values allow for clustering by country-year and are shown in brackets.

Table 2: Technology transfer and the extensive margin

	Import Share			Sales		
	(1)	(2)	(3)	(4)	(5)	(6)
Second Stage						
Trade costs	-1.744	-3.806	-2.037	-0.751	-1.607	-0.772
	[0.002]	[<.001]	[<.001]	[0.036]	[<.001]	[0.029]
Trade costs x knowledge intensity	20.599	24.030	22.349	-18.060	-16.034	-18.223
	[0.046]	[0.011]	[0.024]	[0.005]	[0.023]	[0.004]
Parent Sales	-0.365	-0.028	-0.297	0.665	0.835	0.658
	[<.001]	[0.594]	[<.001]	[<.001]	[<.001]	[<.001]
Selection Equation						
Trade costs	-0.982	-1.087	-0.904	-0.857	-0.937	-0.767
	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]
Trade costs x knowledge intensity	3.762	1.510	3.560	3.043	0.662	2.719
	[0.229]	[0.623]	[0.250]	[0.298]	[0.818]	[0.348]
Parent Sales	0.216	0.214	0.217	0.242	0.240	0.243
	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]
Population	-0.272	-0.185	-0.297	-0.182	-0.095	-0.201
	[<.001]	[<.001]	[<.001]	[<.001]	[0.044]	[<0.001]
GDP	0.671	0.594	0.675	0.648	0.568	0.644
	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]
Cost of Starting Business	-0.181		-0.188	-0.174		-0.183
	[<.001]		[<.001]	[<.001]		[<.001]
Foreign Market Potential		0.225	0.257		0.237	0.269
		[<.001]	[<.001]		[<.001]	[<.001]
Mills Ratio: λ	-1.993	0.137	-1.572	0.579	1.607	0.541
	[<.001]	[0.659]	[<.001]	[<.001]	[<.001]	[<.001]
Wald χ^2 (59 d.o.f.)	819.98	960.12	883.34	1,755.42	1,456.15	1,853.08
	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]
# of obs.	45,121	46,562	45,121	45,121	46,562	45,121

Note: Dependent variables: imports for further processing from the US parent relative to total affiliate sales in columns (1), (2), and (3); local affiliate sales to unaffiliated customers in columns (4), (5), and (6). All specifications include in both stages the following variables: Population, GDP, Parent Sales, Tax rate, Skill Endowment, Capital Endowment, Intellectual Property Rights Index, Judicial Quality, Common Language, and Cost of Phone Call (not all estimates shown). All specifications include industry and year fixed effects. P-values are shown in brackets.

Table 3a: The Marginal Cost of Exporting versus FDI Production
(for the average firm)

	Cost of Plant in the U.S.	Cost of U.S. Plant inclusive of trade costs	Cost of Affiliate, Actual	Cost of Affiliate after 50% Tariff Cut
Canada	1.00	1.02	1.02	1.02
South America	1.00	1.16	1.14	1.10
Europe	1.00	1.06	1.05	1.05
Australia, New Zealand and Asia	1.00	1.12	1.10	1.07
Global	1.00	1.10	1.09	1.07

Table 3b: Knowledge Transfer and Aggregate Affiliate Sales

	Data	Helpman, Melitz, Yeaple (2004)			This Paper		
Dependent Variable	Local Sales	Marginal Cost	Fixed Costs	Market Size	Marginal Cost	Fixed Costs	Market Size
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GDP	0.92	-0.002	-0.04	0.96	0.00	-0.04	0.96
	(6.94)	(-0.48)	(-7.03)	(7.04)	(0.30)	(-5.19)	(7.03)
Trade Cost	-10.11	0.692	-0.538	-10.27	-2.89	-1.57	-5.65
	(-3.86)	(10.99)	(-4.66)	(-3.80)	(-31.39)	(-10.51)	(-2.10)
R-squared	0.69	0.82	0.74	0.69	0.97	0.83	0.66
Share of Trade Cost Effect	100%	-7%	5%	102%	29%	16%	56%

Notes: All variables are in logarithms. The constant term is suppressed in all regressions. Robust t-statistics in parentheses. N = 30 observations.

Table 4: Alternative Measures for Knowledge Intensity

	Import Share			Sales		
Panel A: Intensive Margin						
Knowledge Intensity variable	R&D Intensity	Analyzing Data	Computer Share	R&D Intensity	Analyzing Data	Computer Share
	(1A)	(2A)	(3A)	(4A)	(5A)	(6A)
Trade costs	-3.786	-12.267	-0.547	-0.770	-2.484	0.047
	[<.001]	[<.001]	[0.600]	[0.085]	[0.066]	[0.924]
Trade costs x knowledge intensity	24.906	0.169	-131.109	-17.149	0.020	-80.025
	[0.039]	[<.001]	[0.042]	[0.055]	[0.376]	[0.002]
Population	-0.628	-0.618	-0.511	-0.207	-0.249	-0.207
	[0.150]	[0.143]	[0.238]	[0.296]	[0.209]	[0.291]
GDP	0.410	0.405	0.297	0.753	0.795	0.754
	[0.324]	[0.315]	[0.471]	[<.001]	[<.001]	[<.001]
R-squared	0.447	0.450	0.448	0.557	0.556	0.557
# of obs	5,644	5,644	5,644	7,581	7,581	7,581
Panel B: Ext. & Int. Margin						
	(1B)	(2B)	(3B)	(4B)	(5B)	(6B)
Trade costs	-2.037	-9.190	-0.109	-0.772	-3.013	0.253
	[<.001]	[<.001]	[0.875]	[0.027]	[0.007]	[0.595]
Trade costs x knowledge intensity	22.349	0.140	-71.218	-18.223	0.029	-97.429
	[0.029]	[<.001]	[0.044]	[0.003]	[0.135]	[<.001]
Population	-0.375	-0.355	-0.298	-0.233	-0.279	-0.229
	[0.049]	[0.061]	[0.117]	[0.071]	[0.030]	[0.076]
GDP	-0.259	-0.250	-0.311	0.922	0.970	0.936
	[0.192]	[0.205]	[0.114]	[<.001]	[<.001]	[<.001]
Mills ratio: λ	-1.572	-1.486	-1.496	0.541	0.551	0.593
	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]
Wald χ^2 (57 d.o.f.)	883.34	923.64	894.72	1,853.08	1,838.26	1,839.96
	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]	[<.001]
# of obs	45,121	45,121	45,121	45,121	45,121	45,121

Note: Dependent variables: imports for further processing from the US parent relative to total affiliate sales in columns (1), (2), and (3); local affiliate sales to unaffiliated customers in columns (4), (5), and (6). **Panel A**: Specifications by least squares, firm-year fixed effects included. Robust p-values allow for clustering by country-year and are shown in brackets. **Panel B**: Specifications by two-step Heckman, industry and year fixed effects included. Second-stage coefficients reported. Exclusion variables: Cost of Starting Business, Foreign Market Potential. P-values are shown in brackets. Other variables included: Tax rate, Skill Endowment, Capital Endowment, Intellectual Property Rights index, Judicial Quality, Cost of Phone Call, and Common Language.

Figure 1
Knowledge Intensity of Exports is Rising in Trade Costs

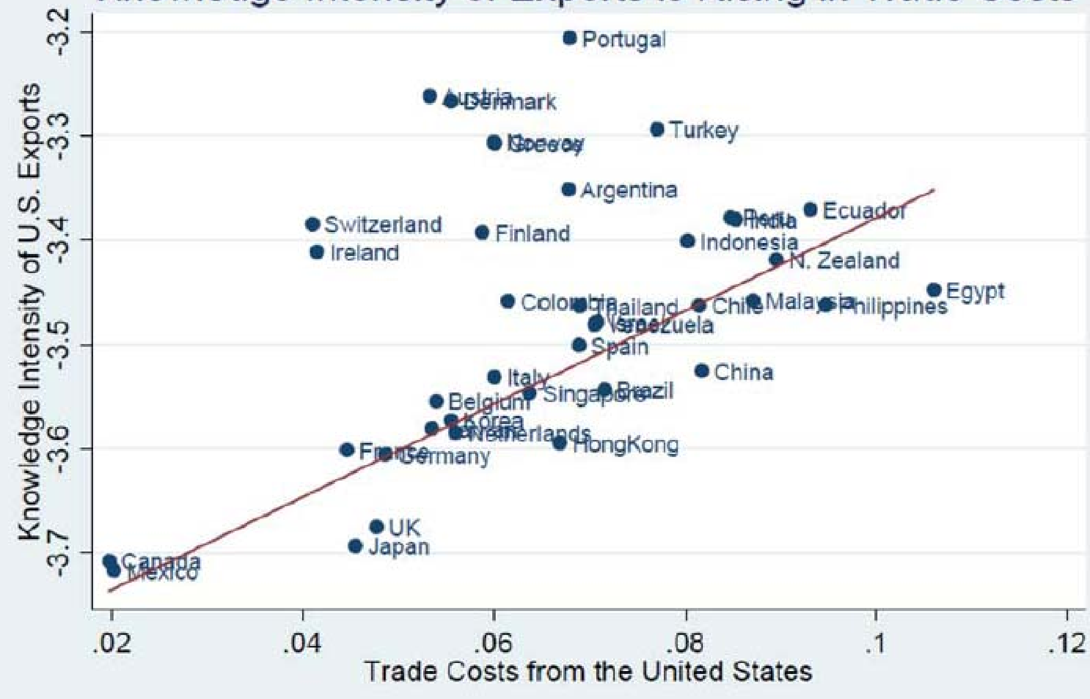

Table A: Summary Statistics for Section 4

	Mean	Standard Deviation
Firm-level data		
Affiliate Sales, total	10.900	1.696
To local unaffiliated customers	10.388	1.771
To U.S. customers	7.932	2.850
To 3rd country customers	9.236	2.509
Parent Sales	13.705	1.544
Import Cost Share	-3.005	1.961
Industry Characteristics		
R&D Intensity	0.045	0.039
Analyzing Data	51.974	8.677
Computer Share	0.024	0.011
Skill Intensity	0.426	0.124
Capital Intensity	0.804	0.395
Contract Intensity	0.538	0.202
Other Variables		
Trade Cost	0.133	0.108
Phone Call	0.621	0.605
IPR protection index	3.701	1.080
GDP	19.521	1.244
Population	10.205	0.984
Tax Rate	3.524	0.241
Common Language	0.231	0.422
Skill Endowment	0.772	0.216
Physical Capital Endowment	10.250	0.983
Judicial Quality	0.669	0.212
Cost of Starting a Business	1.074	0.662
Foreign Market Potential	14.487	1.198

Note: All variables, except Industry Characteristics and Common Language, are in natural logaritms.

Table B: Summary Statistics for Section 7

	Mean	Standard Deviation
Knowledge Intensity	-3.471	0.128
Trade Costs	0.065	0.019
Cost of Phone Call	0.582	0.619
IPR Protection Index	1.393	0.150
GDP per Capita	9.429	0.756
Population	16.138	1.424
Maximal Tax Rate	-1.093	0.516
Common Language	0.085	0.252
Skill Endowment	0.801	0.207
Judicial Quality	0.694	0.202
Value-to-Weight	0.385	1.383

Note: All variables except Common Language are in natural logarithms.

Table C: Technology transfer in the full model with additional covariates

	Import Share		Sales	
	(1)	(2)	(3)	(4)
	Second Stage			
Trade costs	-2.058	-2.008	-0.763	-0.965
	[<.001]	[<.001]	[0.031]	[0.007]
Trade costs x knowledge intensity	22.818	21.013	-18.570	-12.710
	[0.022]	[0.037]	[0.004]	[0.055]
Intellectual property rights Protection	-0.635	-0.689	0.241	0.176
	[<.001]	[<.001]	[<.001]	[0.009]
Intellectual property rights protection x knowledge intensity	0.386	1.740	-0.464	1.435
	[0.390]	[0.107]	[0.122]	[0.040]
Judicial quality	-1.622	-1.476	-1.088	-1.878
	[<.001]	[0.007]	[<.001]	[<.001]
Judicial quality x knowledge intensity		-4.432		14.236
		[0.435]		[<.001]
Skill endowment	1.431	1.590	-0.593	0.565
	[<.001]	[<.001]	[<.001]	[0.012]
Skill endowment x knowledge intensity		-3.226		-23.756
		[0.545]		[<.001]
	Selection Equation			
Cost of Starting Business	-0.188	-0.187	-0.183	-0.183
	[<.001]	[<.001]	[<.001]	[<.001]
Foreign Market Potential	0.258	0.259	0.269	0.270
	[<.001]	[<.001]	[<.001]	[<.001]
Mills Ratio: λ	-1.572	-1.549	0.540	0.567
	[<.001]	[<.001]	[<.001]	[<.001]
Wald χ^2	884.26	895.06	1,853.21	1,879.32
	[<.001]	[<.001]	[<.001]	[<.011]
# of observations	45,121	45,121	45,121	45,121

Note: Dependent variables: imports for further processing from the US parent relative to total affiliate sales in columns (1) and (2); local affiliate sales to unaffiliated customers in columns (3) and (4). All specifications include also in both stages the following variables: Population, GDP, Parent Sales, Tax rate, Capital Endowment, Common Language, and Cost of Phone Call (not all estimates shown). All specifications include industry and year fixed effects. P-values are shown in brackets.

Table D: Technology Transfer and Comparative Advantage

	Import Share		Sales	
	(1)	(2)	(3)	(4)
Trade costs	-3.782	-1.979	-0.762	-0.522
	[<.001]	[<.001]	[0.089]	[0.144]
Trade costs x knowledge intensity	24.767	21.915	-16.703	-23.667
	[0.040]	[0.030]	[0.056]	[<.001]
Population	-0.663	-0.372	-0.185	-0.202
	[0.124]	[0.052]	[0.346]	[0.116]
GDP	0.445	-0.265	0.733	0.897
	[0.279]	[0.183]	[<.001]	[<.001]
Tax rate	0.978	1.149	-0.274	-0.457
	[0.015]	[<.001]	[0.067]	[<.001]
Skill Endowment	0.778	1.570	-0.273	0.948
	[0.345]	[0.003]	[0.302]	[0.007]
Skill Endow. x Skill Intensity	3.386	-0.324	-1.853	-3.609
	[0.252]	[0.771]	[0.328]	[<.001]
Capital Endowment	-0.106	-0.178	0.497	0.623
	[0.601]	[0.159]	[<.001]	[<.001]
Capital Endow. x Capital Intensity	0.049	-0.121	-0.051	0.016
	[0.348]	[0.180]	[0.021]	[0.770]
Judicial Quality	-2.738	-1.230	-1.363	-1.808
	[0.039]	[0.034]	[0.002]	[<.001]
Judicial Quality x Contract Intensity	-0.477	-0.679	0.987	1.334
	[0.609]	[0.284]	[0.021]	[0.002]
Intell. Property Rights Index	-0.423	-0.619	0.193	0.248
	[0.005]	[<.001]	[0.011]	[<.001]
Cost of Phone Call	0.499	0.625	0.018	0.045
	[<.001]	[<.001]	[0.741]	[0.262]
Common Language	0.473	-0.350	0.434	0.650
	[<.001]	[0.002]	[<.001]	[<.001]
Parent Sales		-0.298		0.662
		[<.001]		[<.001]
Mills ratio: λ		-1.581		0.554
		[<.001]		[<.001]
R-squared	0.448		0.558	
Wald χ^2 (62 d.o.f.)		884.65		1878.37
		[<.001]		[<.001]
# of observations	5,644	45,121	7,581	45,121

Note: Dependent variables: imports for further processing from the US parent relative to total affiliate sales in columns (1) and (2); local affiliate sales to unaffiliated customers in columns (3) and (4). Specifications (1) and (3) are least squares, and (2) and (4) are two-step Heckman with Cost of Starting Business and Foreign Market Potential as exclusion variables. (1) and (3) have firm-year fixed effects and robust p-values based on clustered s.e.s at the country-year level are shown in brackets; (2) and (4) have industry and year fixed effects, with p-values in brackets.

Table E: Sales to different customers: Local, Third-country, U.S., and All

	Local Sales		Third-Country Sales		U.S. Sales		All Sales	
	Intensive Margin	Int. & Ext. Margin	Intensive Margin	Int. & Ext. Margin	Intensive Margin	Int. & Ext. Margin	Intensive Margin	Int. & Ext. Margin
Trade costs	-0.770 [0.085]	-0.772 [0.029]	2.808 [0.005]	2.863 [<.001]	-4.859 [0.005]	-1.405 [0.167]	-0.314 [0.549]	0.252 [0.425]
Trade costs x knowledge intensity	-17.149 [0.055]	-18.223 [0.004]	-36.442 [0.049]	-38.376 [0.002]	-60.503 [0.049]	-47.242 [0.014]	-31.022 [0.003]	-30.078 [<.001]
Population	-0.207 [0.296]	-0.233 [0.071]	-0.224 [0.660]	-0.219 [0.333]	-0.131 [0.819]	-0.571 [0.086]	-0.242 [0.224]	-0.270 [0.018]
GDP	0.753 [<.001]	0.922 [<.001]	0.477 [0.345]	0.338 [0.156]	-0.007 [0.990]	-0.351 [0.285]	0.589 [0.003]	0.484 [<.001]
Tax rate	-0.266 [0.075]	-0.433 [<.001]	-1.482 [<.001]	-1.252 [<.001]	1.740 [<.001]	1.971 [<.001]	-0.125 [0.343]	-0.030 [0.689]
Skill endowment	-0.390 [0.083]	-0.591 [<.001]	-2.445 [<.001]	-2.510 [<.001]	-1.299 [0.103]	0.122 [0.767]	-1.044 [<.001]	-0.910 [<.001]
Capital endowment	0.483 [<.001]	0.622 [<.001]	-0.289 [0.251]	-0.382 [0.002]	-0.555 [0.111]	-1.213 [<.001]	0.244 [0.020]	0.115 [0.060]
IPR prot'n index	0.179 [0.018]	0.216 [<.001]	0.999 [<.001]	0.976 [<.001]	0.160 [0.624]	-0.171 [0.264]	0.416 [<.001]	0.322 [<.001]
Judicial quality	-0.852 [0.058]	-1.087 [<.001]	2.730 [0.025]	2.655 [<.001]	-0.737 [0.587]	-0.705 [0.364]	-0.070 [0.875]	0.054 [0.842]
Common language	0.438 [<.001]	0.642 [<.001]	0.124 [0.575]	0.065 [0.639]	0.944 [<.001]	-0.339 [0.044]	0.447 [<.001]	0.290 [<.001]
Cost of phone call	0.016 [0.770]	0.034 [0.395]	-0.710 [<.001]	-0.712 [<.001]	-0.558 [0.012]	-0.059 [0.584]	-0.119 [0.078]	-0.090 [0.014]
Parent Sales		0.658 [<.001]		0.559 [<.001]		0.243 [<.001]		0.555 [<.001]
Mills ratio: λ		0.541 [<.001]		-0.072 [0.776]		-2.283 [<.001]		-0.255 [0.015]
Firm-Year FEs	Yes		Yes		Yes		Yes	
Industry and Year FEs		Yes		Yes		Yes		Yes
R-squared	0.557		0.537		0.504		0.567	
Wald χ^2 (59 d.o.f)		1,853.08 [<.001]		1,822.86 [<.001]		1,048.01 [<.001]		2,665.31 [<.001]
# of observations	7,581	45,221	5,132	45,121	4,496	45,121	8,184	45,121

Note: dependent variable is local affiliate sales to unaffiliated customers in columns (1) and (2); affiliate sales to third countries in columns (3) and (4); sales to the U.S. in (5) and (6); and all affiliate sales in columns (7) and (8). Specifications (1), (3), (5) and (7) by least squares, and specifications (2), (4),(6) and (8) by two-step Heckman; exclusion variables Cost of Starting Business and Foreign Market Potential. p-values, robust and allowing for clustering by country-year in columns (1), (3), (5), and (7) are shown in brackets.

Table F: Imports from affiliates in third-countries

	Ordinary Least Squares		Heckman Second Stage		Low Import Share	High Import Share
	(1)	(2)	(3)	(4)	(5)	(6)
Trade costs	-3.672 [<.001]	-3.601 [<.001]	-2.037 [<.001]	-2.008 [<.001]	-1.029 [0.042]	-1.197 [0.001]
Trade costs x knowledge intensity	23.761 [0.022]	23.424 [0.023]	22.349 [0.024]	22.385 [0.024]	11.987 [0.191]	11.494 [0.055]
Parent Sales	-0.050 [0.012]	-0.036 [0.052]	-0.297 [<.001]	-0.268 [<.001]	0.031 [0.180]	-0.033 [0.013]
Third-Country Sales		-0.787 [0.010]		-1.429 [<.001]		
Mills Ration: λ			-1.572 [<.001]	-1.532 [<.001]		
Industry & Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.139	0.141			0.071	0.091
Wald χ^2			883.34 [<.001]	896.03 [<.001]		
# of observations	5,961	5,961	45,121	45,121	3,003	2,958

Note: Dependent variable: imports for further processing from the US parent relative to total affiliate sales. Other independent variables included are Population, GDP, Tax rate, Skill Endowment, Capital Endowment, Intellectual property rights protection index, Judicial quality, Common language, and Cost of phone call. Exclusion variables in the Heckman specifications are Cost of Starting Business and Foreign Market Potential. P-values are shown in brackets, robust to clustering by country-year in the OLS specifications.

Table G: The Nature of Technology Transfer Costs and Dynamics

	Import Share		Sales	
	(1)	(2)	(3)	(4)
Trade costs	-3.691 [<.001]	-2.746 [<.001]	-0.722 [0.087]	-0.634 [0.061]
Trade costs x knowledge intensity	22.404 [0.053]	23.409 [0.017]	-17.199 [0.040]	-18.300 [0.004]
Affiliate existed in (t-1)	0.329 [0.001]	-1.678 [<.001]	0.578 [<.001]	1.476 [<.001]
Population	-0.446 [0.274]	-0.378 [0.047]	-0.234 [0.201]	-0.242 [0.057]
GDP	0.246 [0.531]	-0.058 [0.764]	0.755 [<.001]	0.914 [<.001]
Tax rate	0.950 [0.017]	1.081 [<.001]	-0.291 [0.039]	-0.475 [<.001]
Skill Endowment	0.969 [0.211]	1.122 [<.001]	-0.353 [0.074]	0.462 [0.003]
Capital Endowment	-0.030 [0.875]	-0.075 [0.439]	0.423 [<.001]	0.539 [<.001]
Judicial Quality	-2.559 [0.022]	-2.093 [<.001]	-0.687 [0.087]	-0.854 [0.004]
Intell. Property Rights Index	-0.422 [0.002]	-0.526 [<.001]	0.175 [0.024]	0.187 [0.001]
Cost of Phone Call	0.515 [<.001]	0.538 [<.001]	0.071 [0.209]	0.061 [0.116]
Common Language	0.370 [0.003]	0.017 [0.852]	0.355 [<.001]	0.504 [<.001]
Parent Sales		-0.146 [<.001]		0.596 [<.001]
Mills ratio: λ		-1.581 [<.001]		0.830 [<.001]
R-squared	0.447		0.572	
Wald χ^2 (60 d.o.f.)		876.98 [<.001]		2,647.04 [<.001]
# of observations	5,961	45,121	7,726	45,121

Note: Dependent variables: imports for further processing from the US parent relative to total affiliate sales in columns (1) and (2); local affiliate sales to unaffiliated customers in columns (3) and (4). Specifications (1) and (3) are least squares, and (2) and (4) are two-step Heckman with Cost of Starting Business and Foreign Market Potential as exclusion variables; second step results shown. (1) and (3) have firm-year fixed effects and robust p-values based on clustered s.e.s at the country-year level are shown in brackets; (2) and (4) have industry and year fixed effects, with p-values in brackets.

Table H: Additional Knowledge Intensity Results

	Knowledge Intensity variable				
	Share of Non-Production Workers	ProcInfo	Upknow	JudgInfo	Communication Capital Share
Panel A: Least Squares					
Import Share	10.000 [0.003]	0.185 [<.001]	0.171 [<.001]	0.207 [<.001]	-44.474 [0.684]
Sales	1.283 [0.531]	0.033 [0.194]	0.024 [0.348]	0.042 [0.172]	15.506 [0.876]
Panel B: Two-step Heckman					
Import Share	8.335 [0.002)	0.163 [<.001]	0.161 [<.001]	0.180 [<.001]	-13.649 [0.905]
Sales	1.107 [0.537]	0.044 [0.039]	0.030 [0.138]	0.053 [0.031]	38.365 [0.625]

Note: Reported is the coefficient for the Trade Cost x Knowledge Intensity variable. Each entry corresponds to a separate estimation. In the Import Share results, the dependent variable is imports for further processing from the U.S. relative to total affiliate sales. In the Sales results, the dependent variable is local sales to non-affiliated parties. Second-step results are shown in the Heckman specifications, where the exclusion variables are Cost of Starting a Business and Foreign Market Potential. OLS specifications include firm-year fixed effects, and two-step Heckman specifications have industry and year fixed effects. All specifications include Trade Costs, Population, GDP, Tax rate, Skill endowment, Capital endowment, Intellectual Property Rights protection, Judicial quality, Common Language, and Cost of Phone Call. P-values in brackets; they are robust and clustered on country-year for OLS, and following Heckman (1976) in the two-step specifications.

Table I: Additional Results on Communication and Technology Transfer

	Import Share		Sales	
Panel A: Least Squares				
	(1A)	(2A)	(3A)	(4A)
Trade Costs	-3.786 [<.001]	-4.041 [<.001]	-0.770 [0.085]	-0.540 [0.311]
Trade costs x Knowledge intensity	24.906 [0.039]	30.215 [0.021]	-17.149 [0.055]	-21.635 [0.081]
Common Language	0.468 [<.001]	0.507 [0.003]	0.438 [<.001]	0.665 [<.001]
Common Language x Knowledge intensity		-2.110 [0.280]		-4.516 [<.001]
Cost of Phone Call	0.499 [<.001]	0.638 [<.001]	0.016 [0.770]	0.016 [0.830]
Cost of Phone Call x Knowledge Intensity		-2.828 [<.001]		0.517 [0.589]
Panel B: Two-step Heckman				
	(1B)	(2B)	(3B)	(4B)
Trade costs	-2.037 [<.001]	-2.786 [<.001]	-0.772 [0.027]	-0.383 [0.290]
Trade costs x Knowledge intensity	22.349 [0.029]	40.347 [<.001]	-18.223 [0.003]	-25.875 [<.001]
Common Language	-0.347 [0.003]	-0.310 [0.025]	0.642 [<.001]	0.904 [<.001]
Common Language x Knowledge intensity		-0.954 [0.486]		-5.373 [<.001]
Cost of Phone Call	0.624 [<.001]	0.882 [<.001]	0.034 [0.395]	-0.051 [0.357]
Cost of Phone Call x Knowledge intensity		-5.337 [<.001]		1.676 [0.022]

Note: Dependent variables: imports for further processing from the US relative to total affiliate sales in columns (1) and (2); local affiliate sales to unaffiliated customers in columns (3) and (4). Columns (1) and (3) repeat results from Tables 2 and 3 for convenience. **Panel A**: Specifications by least squares, firm-year fixed effects included. Robust p-values allow for clustering by country-year and are shown in brackets. **Panel B**: Specifications by two-step Heckman, industry and year fixed effects included. Second-stage coefficients reported. Exclusion variables: Cost of Starting Business, Foreign Market Potential. P-values are shown in brackets. Other variables included: GDP per capita, Population, Tax rate, Skill Endowment, Capital Endowment, Intellectual Property Rights index, and Judicial Quality. Also included in the two-step Heckman specifications are Parent Sales.

Table J: The Knowledge Intensity of Multinational Trade

	(1)	(2)	(3)
Trade Costs	5.111 [<.001]	3.700 [<.001]	3.231 [0.014]
Phone Call		0.008 [0.755]	0.015 [0.539]
IPR Protection Index		0.076 [0.603]	0.131 [0.378]
GDP per capita		-0.099 [0.058]	-0.095 [0.083]
Population		-0.064 [<.001]	-0.070 [<.001]
Tax Rate		0.071 [0.166]	0.093 [0.055]
Common Language		-0.067 [0.086]	-0.021 [0.669]
Skill Endowment		-0.154 [0.240]	-0.221 [0.120]
Judicial Quality		0.245 [0.192]	0.152 [0.417]
Weight-to-Value			0.013 [0.417]
R-squared	0.440	0.793	0.802
N	39	36	35

Note: The dependent variable is the average knowledge intensity of U.S. related-party exports. All regressions have a constant (coefficient not reported). All variables except Common Language are in natural logarithms. Robust t-statistics shown in brackets.