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ABSTRACT

This paper studies the international mobility of technology through the lens of multinational firms. We show that gravity applies to the activity of multinational firms, and the strength of gravity is greatest in technologically-complex, research and development intensive industries. To explain gravity in the weightless economy, we develop a model in which a multinational's production can be fragmented into intermediates that vary in the codifiability of their technology. Poorly codified technology requires face-to-face communication to transfer accurately, leading to production inefficiencies that can be avoided if an affiliate instead imports intermediates embodying this technology from its parent firm. Because intermediate input trade incurs shipping costs, affiliates' sales are subject to the force of gravity, and this force is strongest in technologically complex industries. An additional implication of this mechanism is that affiliates are more constrained in their ability to substitute local production for intermediate imports in technologically complex industries. We confirm these predictions and show that trade costs increase the average technological complexity of intra-firm trade. Our analysis offers a new perspective on the mobility of technology, which is a topic crucial to a wide range of fields in economics.

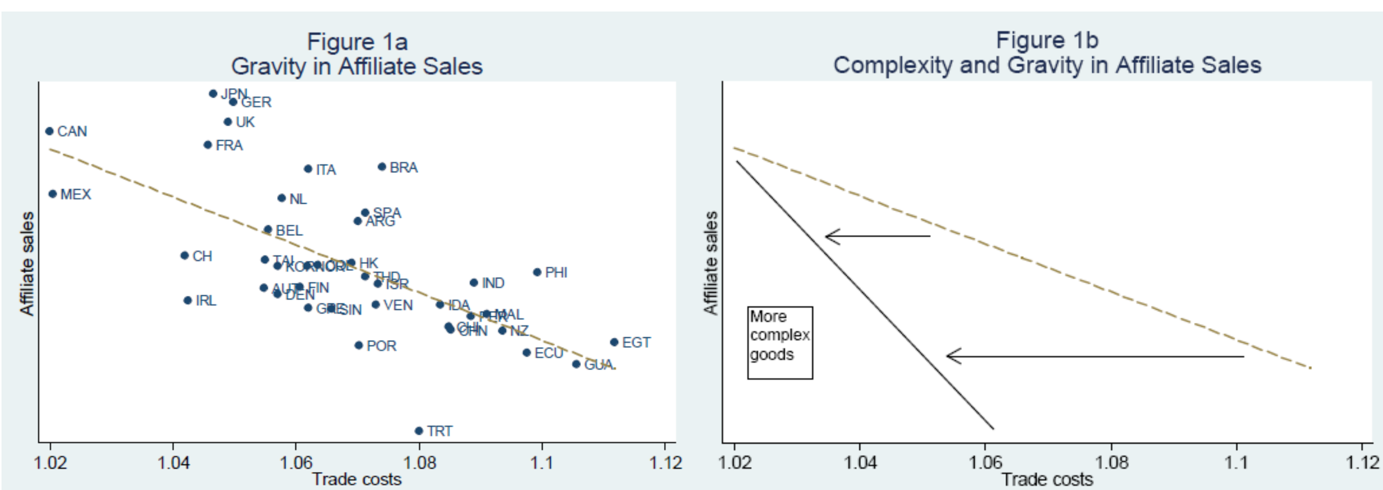
Wolfgang Keller
Department of Economics
University of Colorado at Boulder
Boulder, CO 80309-0256
and NBER
Wolfgang.Keller@colorado.edu

Stephen R. Yeaple
Department of Economics
The Pennsylvania State University
520 Kern Building
University Park, PA 16802-3306
and NBER
sry3@psu.edu

1 Introduction

The development and geographical diffusion of technology is center stage in many fields of economics. For instance, modern theories of growth and international trade place little emphasis on the accumulation of tangible factors, such as capital and labor, and focus almost entirely on access to technology. Given the recent advances in communication technology, this emphasis on internationally variable access to technology may seem misplaced. After all, in the world of the internet, technology would seem to be weightless in the sense that physical distance plays no role in the transfer of technology.[1]

Multinational enterprises have long been acknowledged as key players in the development and international transfer of technology. According to the modern theory of the multinational firm, multinationals exploit international economies of scale by developing technologies that may then be transferred to its affiliates worldwide (see Markusen 2002). Therefore, it is natural to investigate the structure of individual firms' international operations for evidence of the costs of transferring technology internationally.



As Figure 1a shows, the size of US-owned affiliates, normalized by their parent firm's productivity, falls as trade costs from the United States rise. The further away an affiliate is from its U.S. parent,

[1] Quah (1999) gives a characterization of the weightless economy.

the less affiliates of individual multinationals sell in their host country, a relationship that suggests that the marginal cost of serving host country markets is rising as affiliates move away from the home country. Even more intriguing, as shown in Figure 1b, the negative relationship between affiliate sales and trade costs between the parent and affiliate is strongest in technologically complex industries where research and development is concentrated.[2]

We seek to explain why seemingly weightless technology appears to be subject to the laws of gravity. In our framework a multinational's production process can be fragmented into individual intermediate inputs that vary in their technological complexity, defined as the number of tasks that require non-codifiable information. Enabling the affiliate to produce inputs requires communication between parent and affiliate managers, and we assume that communication costs are higher, the more complex is the input.[3] Alternatively, any input can be produced by the parent and then exported to the affiliate. There are no communication costs for parent production, but exporting requires shipping costs that rise in geographic distance.[4] The trade-off between the communication costs for disembodied technology transfer and shipping costs for embodied technology transfer explains why there is gravity for seemingly weightless technology.

Three predictions emerge from this framework. First, technological complexity affects the level of affiliate sales around the world. We show that the sales of multinational affiliates to their host country fall in the size of trade costs, and the effect of trade costs is more pronounced in industries featuring complex technologies, precisely because in these industries the scope for offshoring is more limited by technology transfer costs. Second, technological complexity is a determinant of the degree

[2]The slope change shown in Figure 1b is based on the results in section 5 below; data confidentiality requirements of U.S. Department of Commerce prevent us from showing further detail.

[3]This modifies the commonly made no-cost transfer assumption within the multinational firm of Helpman (1984), Markusen (1984), and others. The latter emerges as a special case, which we will test in our empirical analysis.

[4]Production by the multinational parent allows relatively easy face-to-face interaction between top managers and line workers, and face-to-face communication is considered to be the most effective form of communication for non-codified information (see Koskinen and Vanharanta 2002).

of a multinational's vertical specialization. As shipping costs increase, multinationals substitute away from importing intermediate inputs from their parent, but their ability to do so is constrained by how high the technology transfer costs for the tasks are. Trade costs have a strong influence on the share of intermediate inputs acquired from the parent in relatively complex industries. A third prediction of the model is that firms change systematically the composition of their international trade in terms of its technological complexity as trade costs change relative to technology transfer costs. Empirical analysis employing detailed information on the activity of individual U.S. multinationals and disaggregated data on intra-firm trade provides striking support for these predictions.

Vertical production sharing between multinational parents and affiliates is also anaylzed by Hanson, Mataloni, and Slaughter (2005), who find that it is facilitated by low intermediate trade costs and large factor price differences. We demonstrate that task complexity is an additional determinant of vertical production sharing.[5] Moreover, our analysis goes beyond asking which part of the multinational firm contributes which inputs to overall production–the composition question– by also determining the level of multinational activity across countries. This uncovers forces generating complementarity between trade and FDI at the same time when there is substitution at the task level (Blonigen 2001).

The tendency of FDI to decline in distance has been noted both at the aggregate and firm level (Markusen and Maskus 2002 and Yeaple 2009, respectively).[6] Rising marginal costs of affiliates may be due to a fixed share of intermediate imports from the parent that are subject to trade costs (Markusen and Zhang 1999, Irrazabal, Moxnes, and Opromolla 2008). In contrast, here the choice of exports versus FDI is endogenous and determined by the transferability of the firm's technology.

[5] In line with our model, Norbaeck (2001) explains his finding of relatively high affiliate import shares in R&D intensive industries for a sample of Swedish multinationals with higher technology transfer costs. Evidence that parent exports rise faster with R&D intensity than affiliate sales is also provided in Brainard (1997).

[6] Also Kleinert and Toubal (2008) have recently noted that there is gravity in FDI sales.

This yields two key hypotheses on the extent of gravity in FDI sales and vertical production sharing, which are tested using firm-level data on intra-firm trade.

In the literature on offshoring, which has become a major policy issue in many countries, Levy and Murnane (2004) hold that routine tasks are the ones that are easy to offshore, while Leamer and Storper (2001) consider codifiability of information to be key. Our work formalizes the way that communication of noncodifiable information leads to technology transfer costs, and we also evaluate empirically how this determines the offshorability of jobs.

The cost of transferring non-codified knowledge from one person to another is also featured in several recent papers. In Burstein and Monge-Naranjo (2009), firm-specific knowledge is embodied in managers, and managing an affiliate in one location necessarily detracts from the productivity of an affiliate in another location. The interaction of international communication costs with the span of control is featured in Antras, Garicano, and Rossi-Hansberg (2008), where FDI arises to conserve the time of top problem solvers in the headquarters of the firm. In our framework, the cost of transferring non-codified knowledge from management to foreign affiliates can be avoided by concentrating the production of traded intermediates embodying that knowledge in close proximity to senior management.[7]

A major literature has recently analyzed the factors defining the boundaries of the firm (McLaren 2000, Grossman and Helpman 2002, Antras 2003, Antras and Helpman 2004).[8] Technological complexity is a force towards in-house production because complexity makes it difficult to anticipate all

[7] Grossman and Rossi-Hansberg's trade in tasks framework (2008a, 2008b) also features imperfect task transferability between countries but abstracts from trade costs and the additional empirical implications.

[8] While much of the recent literature, as well as earlier work such as Horstmann and Markusen (1987), emphasizes incentive problems arising from asset specificity when contracts are incomplete, another factor is to what extent intellectual property rights protection reduces the possibility that arm's length organization is associated with more asset dissipation than integrated production. Recent evidence inlcudes Feenstra and Hanson (2005) and Nunn and Trefler (2008).

contingencies that need to be specified in *ex-ante* contracts (Costinot, Oldenski, and Rauch 2008).[9] Our concern is not the organization of economic activity given that it is offshored, but instead the role of technological complexity in how much production, whether in-house or outsourced, will be moved offshore in the first place. Our model is thus complementary to Costinot, Oldenski, and Rauch's framework. In terms of empirics, the analysis below encompasses the main determinants of firm organization that have been emphasized recently.

This work is part of a small group of papers that study empirically the size of the gains from openness in multi-country general equilibrium models (Eaton and Kortum 2002, Ramondo and Rodriguez-Clare 2008, Burstein and Monge-Naranjo 2008, Garetto 2008, and Irarrazabal, Moxnes, and Opromolla 2008). While these studies focus largely on aggregate evidence, here the focus is on testing key model elements with a unique array of micro information on the trade and investment behavior of individual multinational enterprises. Our micro focus should be very useful to better understand the gains from openness.

Finally, even though the degree of mobility of technological knowledge is crucial for the extent of convergence between firms, regions, or countries, there is little theory that puts the question at the center of the analysis.[10] Our analysis of multinational-led technology transfer leading to gravity provides a new framework for thinking about, for example, the empirical finding of geographically localized international technology diffusion (Keller 2002). It may also help to explain why economic activity is declining with distance within countries, even when the actual transport costs are only a small fraction of the value of shipments.[11]

[9] See also Ethier (1986) on how the exchange of complex information might affect the choice of arm's-length versus integrated production.

[10] Exceptions include Aghion and Howitt (1998), Chapter 12, and Howitt (2000).

[11] Glaeser and Kohlhase (2004) report strong distance effects in U.S. shipments even though 80% of all shipments by value occur in industries where transport costs are less than 4% of total value.

The remainder of the paper is as follows. The following section 2 describes the model and derives our key results. Section 3 presents the empirical predictions on the extent of gravity in sales and substitution between trade and FDI in relation to complexity, and explains how they will be tested. The data is described in section 4, while the empirical results are shown in section 5. Some concluding observations are offered in section 6.

2 Theoretical Framework

Consider a world composed of $K+1$ countries indexed by $k = \{0, 1, ..., K\}$. Each country is endowed with a quantity of labor, the only factor, and N_{ik} enterpreneurs each endowed with the knowledge of how to produce a variety of good i. In each country, the representative consumer has identical, homothetic preferences over I differentiated goods, indexed by i, and a single, freely-traded homogenous good Y, given by

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

where Ω_i is the set of varieties available in industry i, $q_i(\omega)$ is the quantity of output of variety ω consumed, $\sigma > 1$ is the elasticity of demand, and Y is the quantity consumed of the homogenous good. Each country produces good Y using a single unit of labor and so wages are the same in every country. We henceforth normalize the wage to unity. Assuming that firms are too small to affect industry level demands, the preferences (1) imply the following iso-elastic demand for variety ω in country k:

$$q_k(\omega) = B_{ik}(p_k(\omega))^{-\sigma}, \tag{2}$$

where B_{ik} is the endogenous demand level in country k and industry i, and $p_k(\omega)$ is the price of the variety ω in country k.

In industry i each variety can be costlessly assembled from a continuum of firm-specific intermediate inputs (indexed by z) according to the following production function:

$$q_i = \exp\left(\int_0^\infty \beta_i(z) \ln\left(\frac{m(z)}{\beta_i(z)}\right) dz\right), \tag{3}$$

where $m(z)$ is the quantity of firm-specific intermediate m of type z, and $\beta_i(z)$ is the cost share of z for a firm producing a good in industry i. As we explain below, z is an index of the technological complexity of an input. Industries that use predominantly high-z inputs have high cost shares $\beta_i(z)$ for such inputs, and consequently we refer to such industries as technologically complex. In the interest of simplicity, we choose a functional form for $\beta_i(z)$ that summarizes an industry's technological complexity using a single parameter, $\phi_i > 0$:

$$\beta_i(z) = \phi_i \exp(-\phi_i z). \tag{4}$$

This implies that the average technological complexity of intermediate inputs in industry i is $1/\phi_i$, so we refer to industries with low ϕ_i as technologically complex. Further, in the limit as $\phi_i \to \infty$ the average technological complexity goes to zero.

To produce one unit of an intermediate input z, a number of tasks, given by z, must be successfully completed. In the application of each task, problems arise that will, if unsolved, result in the destruction of that unit. A plant's management communicates the problem to the firm's headquarters which must in turn communicate to the plant the solution to the problem. If communication is successful for each task, then one unit of the input is produced for each unit of labor employed. If the solution to any problem fails to be communicated, then the input that is produced is useless.

A firm that has chosen to assemble its product in country k must supply the local plant with intermediate inputs that are either produced in the home country or in the host country k. In making this decision, the firm weighs two types of costs of doing business internationally: shipping costs and technology transfer costs. First, suppose that an input z is produced in the home country. We assume that when production takes place in the headquarter country communication is perfect and no inputs are wasted by the inability to complete successfully a task so that one unit of labor produces one unit of output. In shipping this intermediate input to its affiliate, the parent firm incurs iceberg-type trade costs $\tau_{ik} > 1$.

If the firm produces an intermediate input z in an affiliate located in country k then it avoids shipping costs, but imperfect communication between affiliate and headquarters leads to a loss of productivity. As stressed by Arrow (1969), there can be large efficiency losses when communication between teachers (here the multinationals' parents) and students (here the multinationals' affiliates) fails.[12] In particular, the probability of successful communication between multinational parent and its affiliate located offshore is $\widetilde{\lambda} \in (0,1)$. Assuming that the success rate of communication is independent across tasks, the probability of successful communication is $(\widetilde{\lambda})^z$ and so the expected number of labor units needed to produce a unit of intermediate input z is equal to the inverse of

[12] Technological information is difficult to communicate because it is often not fully codified (Polanyi 1966). The tacit elements of knowledge can be transferred most easily through face-to-face interaction, because it allows immediate feedback so that understanding can be checked and interpretations corrected (see Koskinen and Vanharanta 2002). While face-to-face contact of headquarter and affiliate managers will be the exception for day-to-day problem solving in a multinational firm, it might occur only rarely even for multi-plant operations within a country. This suggests that our argument may carry weight in a closed-economy setting as well. For the case of the multinational firm, Teece (1977) shows that transfer costs account for a substantial portion of all costs of shifting production from multinational parent to affiliate.

$(\widetilde{\lambda})^z$:

$$\begin{aligned} 1/(\widetilde{\lambda})^z &= \exp(-z \ln \widetilde{\lambda}) \\ &= \exp(\lambda z), \end{aligned} \tag{5}$$

where the parameter $\lambda \equiv -\ln \widetilde{\lambda} > 0$ is inversely related to communicability and so measures the inefficiency costs of international technology transfer. Hence, a relatively high value of z is associated with relatively low productivity when production of this intermediate input takes place in the affiliate plant located offshore. Note that the technology transfer costs vary with the input's complexity, but not with geographic distance.

We can now summarize the sense in which high-z inputs are technologically complex in our model. Inputs with high values of z require the successful completion of a relatively high number of tasks. Because there is some difficulty in communicating technological information for each one of these tasks, a relatively high number of tasks translates into a relatively high level of technological complexity. In the empirical analysis below, we will measure technological complexity with R&D intensity. High levels of R&D are likely to generate frequent changes in production techniques and product designs requiring exactly the kinds of problem-solving communication that the model captures.

The following shows how technology transfer costs interact with trade costs and complexity to determine the geography of multinational activity.

Technical Complexity and the Geography of Affiliate Costs Consider a firm with its headquarters in country 0 that has opened an assembly plant in country k and is minimizing the cost of supplying intermediate inputs to that affiliate. The marginal cost of supplying the affiliate with intermediate input z, $c_{ik}(z)$, depends on where the input is produced:

$$c_{ik}(z) = \begin{cases} \tau_{ik} & \text{if imported from parent} \\ \exp(\lambda z) & \text{if produced by affiliate} \end{cases} . \tag{6}$$

There exists a cutoff intermediate input $\widehat{z}_{ik}$ such that all inputs with $z < \widehat{z}_{ik}$ will be produced by the affiliate and all intermediates $z > \widehat{z}_{ik}$ will be imported by the affiliate from the headquarters in country 0, where

$$\widehat{z}_{ik} = \frac{1}{\lambda} \ln (\tau_{ik}) . \tag{7}$$

Higher costs of technology transfer (an increase in λ) lower $\widehat{z}_{ik}$ and thus raise the range of inputs that are produced by the parent and then shipped to the affiliate. Moreover, comparing two countries k_1 and k_2, where trade costs for market k_1 exceed those for market k_2 ($\tau_{ik_1} > \tau_{ik_2}$), the multinational firm will choose to produce a greater range of inputs through local affiliate production in k_1, the country with the relatively high trade costs. This is the simple trade-off between trade and FDI as a function of trade- versus technology transfer costs.

An important empirical implication following directly from (7) concerns the technological complexity of intra-firm trade.

Lemma 1 *As trade costs between the multinational parent and its affiliates increase, the average technological complexity of the parent's exports to its affiliates increases ($d\widehat{z}_{ik}/d\tau_{ik} > 0$).*

The intuition is that the most technologically complex inputs will always be produced by the multinational parent, and if an increase in trade costs reduces the range of parent-completed inputs, the average complexity of intra-firm trade must rise.[13]

[13] Consistent with this, the parents of U.S. multinational firms account for the large majority (about 85%) of the multinational's R&D expenditures (source: BEA).

We now show that the trade-off between trade and technology transfer costs determines the multinational firms' production costs for different locations. Using (3), it can be shown that the marginal cost of producing the final good i in country k is

$$C_{ik} = \exp\left(\int_0^\infty \beta_i(z) \ln c_k(z) dz\right). \tag{8}$$

Substituting (6) into (8), using (7), and integrating by parts, we find that the marginal cost of producing final output in industry i at an affiliate located in country k is

$$C_{ik} = \exp\left(\frac{\lambda}{\phi_i}\left(1 - (\tau_{ik})^{-\frac{\phi_i}{\lambda}}\right)\right). \tag{9}$$

Consider the effect on C_{ik} of an increase in τ_{ik}, the size of trade costs between parent and affiliate. Differentiating (9) with respect to τ_{ik}, we obtain

$$\varepsilon_{\tau_{ik}}^{C_{ik}} \equiv \frac{\tau_{ik}}{C_{ik}} \frac{\partial C_{ik}}{\partial \tau_{ik}} = \exp\left(-\frac{\phi_i}{\lambda} \ln(\tau_{ik})\right) \geq 0. \tag{10}$$

According to equation (10), for any industry in which technology features non-zero complexity (i.e. $1/\phi_i > 0$) an increase in the size of trade cost between affiliate and parent (τ_{ik}) results in an increase in the marginal cost of the affiliate. Further, the size of this increase is strictly increasing in the technical complexity of the industry $1/\phi_i$. Only in the limiting case of $1/\phi_i \to 0$, when technological complexity tends to zero, an increase in trade cost does not result in higher affiliate marginal costs. We summarize this result in the following lemma.

Lemma 2 *An affiliate's marginal cost is increasing in the size of trade cost between parent and affiliate (τ_{ik}), and the elasticity of the marginal cost of the affiliate with respect to τ_{ik}, ($\varepsilon_{\tau_{ik}}^{C_{ik}}$), is* *higher in technologically complex industries (low ϕ_i).*

Notice that this result differs from the typical model of horizontal FDI. There, rising trade costs will at some point dictate switching from exports to FDI, but further trade costs increases beyond that do not affect the marginal costs of the multinational firm.

Equation (10) has two important empirical implications to which we now turn.

Technological Complexity and the Force of Gravity in Sales Because affiliates rely on imported intermediate inputs, their marginal costs of production are rising in trade costs. The rate at which marginal costs rise depend on the firm's technological complexity: firms that require more technologically complex intermediate inputs are more exposed to changes in trade costs because they rely more heavily on inputs that are hard to offshore.

Consider the size of an affiliate's revenues generated on sales to customers in its host country market k. The iso-elastic demand (2) imply that the optimal price charged by the affiliate is $p_{ik} = \sigma C_{ik}/(\sigma - 1)$. Using (2) and substituting for the price, we find that the affiliate's revenues are

$$R_{ik} \equiv p_{ik} q_{ik} = \left(\frac{\sigma}{\sigma - 1}\right)^{1-\sigma} B_{ik} \left(C_{ik}\right)^{1-\sigma}. \tag{11}$$

Totally differentiating this expression with respect to τ_{ik}, we find

$$\varepsilon_{\tau_{ik}}^{R_{ik}} \equiv \frac{\tau_{ik}}{R_{ik}} \frac{\partial R_{ik}}{\partial \tau_{ik}} = -(\sigma - 1)\varepsilon_{\tau_{ik}}^{C_{ik}}. \tag{12}$$

This equation combined with Lemma 2 has the following implication.

Proposition 1 *Holding fixed the demand level, B_{ik}, the value of affiliate revenues generated on sales to local customers, R_{ik}, is decreasing in trade cost τ_{ik}, and the rate of this decrease is highest* *in technologically complex industries (low ϕ_i).*

Proposition 1 explains the gravity relationship shown in Figures 1a and 1b in terms of the interaction between trade costs, technology transfer costs, and technical complexity. When technology is perfectly transferable internationally, as in the limiting case when $1/\phi_i \rightarrow 0$, affiliate sales display no gravity effect. As technology becomes more complex ($1/\phi_i$ increases), the force of gravity becomes increasingly pronounced.

Because we want to test empirical predictions, the practical significance of Proposition 1 (compared to Lemma 2) is immense. Rarely is it the case that researchers have reliable information on affiliate costs, while in contrast figures on affiliate sales do exist. Equations (10) and (11) show how new light can be shed on the geography of international cost differences using observable data on multinational affiliate sales.

Technological Complexity and Vertical Production Sharing The second empirical implication of equation (10) concerns the aggregate volume of intra-firm imports in total affiliate costs as a function of technological complexity and the size of trade costs. By Shephard's Lemma, equation (10) describes the cost share of intermediates imported by an affiliate from its parent firm. Letting IM_{ik} be the aggregate value of the imports of an affiliate in country k and industry i from its parent firm and letting TC_{ik} be the total costs of this affiliate, we have

$$\frac{IM_{ik}}{TC_{ik}} = \exp\left(-\frac{\phi_i}{\lambda}\ln\tau_{ik}\right). \tag{13}$$

From this expression the following proposition is immediate:

Proposition 2 *The share of intermediate inputs imported from the parent firm in total costs (IM_{ik}/TC_{ik})*

is strictly decreasing in transport costs (τ_{ik}) between affiliate and parent, and the rate of decline is slower in technologically complex (low ϕ_i) industries.

For a given increase in transport costs, the cost share of intermediates imported from the parent firm in total affiliate cost is decreasing more slowly in technologically complex industries because these industries are intensive in intermediates whose production is harder to move offshore. In the limit as $1/\phi_i \to 0$ the import share IM_{ik}/TC_{ik} goes to zero: all tasks can be costlessly offshored and the affiliate is not exposed to the cost of importing intermediates from its parent. We will examine this prediction below.[14]

Before turning to the empirical analysis, we briefly describe some extensions of the model that broaden its implications while maintaining its fundamental predictions.[15] First, by adding an assembly stage to production and by giving developing countries a comparative advantage in assembly, the model can explain exports by developing country affiliates to their parent firms and distribution affiliates located in third countries. Second, we can generate variation across firms in their propensity to enter foreign markets–the extensive margin–by incorporating fixed costs of foreign market entry and firm heterogeneity into the analysis. Third, we can have fixed costs to offshoring intermediate inputs that are increasing in the complexity of the input; this would reinforce the basic mechanism presented in our paper, albeit at substantial cost in terms of tractability. Finally, it is straightforward to close the model with a free entry assumption and labor market clearing, which allows to conduct comparative static analysis on the underlying model parameters.

We now turn to the empirical analysis.

[14] Note that $\varepsilon_{\tau_{ik}}^{C_{ik}} = IM_{ik}/TC_{ik}$ (see equation 13), so that the cost share of imported intermediate inputs is a sufficient statistic for the elasticity of marginal costs with respect to the size of trade costs. By estimating the relationship between technological complexity ($1/\phi_i$), trade costs (τ_{ik}), and the import cost share (IM_{ik}/TC_{ik}), one can also infer the effect of these variables on affiliates' marginal costs.

[15] Some of these extensions are discussed in Keller and Yeaple (2008).

3 Model Predictions and the Estimating Equations

The model offers a rich set of predictions on the volume of multinational sales and the trade between parent and affiliates that is supporting it. Moreover, according to the model firms will adjust the composition of intra-firm trade from less to more technologically complex in response to increases in trade costs (Lemma 1). In part 5 the evidence for this will be examined. In the following section, we derive estimation equations for the two hypotheses concerning the impact of technological complexity on the level of affiliate sales and the extent to which the affiliate relies on imports from the parent.

Recall that input complexity raises technology transfer costs, while the costs of embodied technology transfer in form of intermediate input imports from the parent are independent of complexity but increasing in trade costs. The first hypothesis is that an increase in trade costs reduces the level of multinational affiliate sales, and this effect is *strongest* in the most technologically complex industries (see Proposition 1). The second hypothesis is that an increase in trade costs reduces the share of imports in total affiliate costs, and this effect is *weakest* in the most technologically complex industries (see Proposition 2).

In a nutshell, if intermediate inputs are technologically complex, this moderates the substitution from imports to local production while at the same time it magnifies the response of affiliate sales to a change in trade costs. The data most suitable to testing these predictions is the confidential firm-level information from the Bureau of Economic Analysis (BEA) on the stucture of U.S. multinationals' global operations. There, one can directly observe both the size of host country sales of multinational affiliates and the total cost share of intermediate inputs imported by these affiliates from their parent firms. This paper employs information on sales, imports, as well as other data from this source.

We now turn to deriving the estimating equations. First, consider the effect of trade costs on affiliate sales (equation 11). The size of the effect of transport cost should be larger (decreasing faster) in technologically complex industries because technology is more difficult to transfer in those industries. We consider the following linearized version of equation (11) that specifies sales revenue of the affiliate of firm j in industry i and country k at time t, R_{ijkt}, as

$$\ln R_{ijkt} = \varsigma_1 \left[\ln \tau_{ikt} \times CX_{it}\right] + \upsilon_{ijkt}, \tag{14}$$

where CX_{it}, negatively related to the model parameter ϕ_{it}, stands for the technological complexity of industry i at time t. We assume that technological complexity in industry i is proportional to the R&D intensity (R&D expenditures divided by sales) of the firms in industry i. The term τ_{ikt} is trade costs in industry i and country k at time t, based on transport cost and tariff measures, while the error term υ_{ijkt} will pick up other determinants of sales not specified in the model.

We assume further that the other determinants of affiliate sales follow

$$\upsilon_{ijkt} = \gamma_{jt} + \varsigma_0 \ln \tau_{ikt} + \kappa \ln \mathbf{X}_{kt} + \nu_{ijkt},$$

where γ_{jt} are firm-year fixed effects, such as variation in firm productivity, $\mathbf{X}_{kt}$ are observable country characteristics that might affect affiliate sales, such as the host country's income level or the availability of factors, κ is a vector of coefficients, and ν_{jikt} is idiosyncratic noise. We include a linear trade cost term with parameter ς_0 to ensure that the trade cost-complexity variable in equation (14) does not simply pick up the general gravity effect. The estimation equation becomes

$$\ln R_{ijkt} = \gamma_{jt} + \kappa \ln \mathbf{X}_{kt} + \varsigma_0 \ln \tau_{ikt} + \varsigma_1 \left[\ln \tau_{ikt} \times CX_{it}\right] + \nu_{ijkt}. \tag{15}$$

The first key hypothesis of the theory is that the trade cost-complexity effect is negative, $\varsigma_1 < 0$.[16]

One concern in estimating the impact of technological complexity on affiliate sales is endogeneity. The estimating equation (15) addresses this in a number of ways. First, the fixed effects γ_{jt} remove unobserved heterogeneity at the firm level. Second, the inclusion of country characteristics $\mathbf{X}_{kt}$ reduces omitted variable bias. And third, because technological complexity is measured by the R&D intensity of the industry to which firm j belongs, not by firm j's own R&D intensity, in our specification complexity does not vary at the firm level. This makes it unlikely that technological complexity responds to affiliate sales.

We now turn to the second prediction. Consider the cost share of intermediate inputs imported by an affiliate in country k at time t from its parent firm j producing a product in industry j in the affiliate's total cost. In the model, this variable is the firm-level analog to equation (13). Taking logs and adding an error term, we obtain

$$\ln\left(\frac{IM_{ijkt}}{TC_{ijkt}}\right) = -\frac{\phi_{it}}{\lambda}\ln\tau_{ikt} + \epsilon_{ijkt},$$

where ϕ_{it} is the inverse measure of technological complexity, λ is a technological constant, and ϵ_{ijkt} are other industry-firm-country determinants of the import share that are not captured by the model. We parametrize the (inverse of) technological complexity parameter as $\phi_{it} = -\left(\delta_0 + \delta_1 CX_{it}\right)$, where as before complexity CX_{it} is measured by the R&D intensity of the industry, and δ_0 and δ_1 are parameters. Further, we assume that the other determinants of the import share are given by

$$\epsilon_{ijkt} = \eta_{jt} + \rho\ln\mathbf{X}_{kt} + \varepsilon_{jikt},$$

[16] Moreover, the theory also predicts that the elasticity of affiliate revenue with trade costs is non-positive, see equation (12); we expect thus that $\partial\ln R/\partial\ln\tau = \varsigma_0 + \varsigma_1 CX \leq 0$.

where η_{jt} are firm-year fixed effects, such as variation in the ability to offshore technology, $\mathbf{X}_{kt}$ are country characteristics that might affect import shares, such as the strength of intellectual property rights (IPR) protection or the abundance of certain production factors, ρ is a vector of coefficients, and ε_{jikt} is measurement error. This yields our import share estimating equation

$$\ln\left(\frac{IM_{ijkt}}{TC_{ijkt}}\right) = \eta_{jt} + \rho \ln \mathbf{X}_{kt} + \frac{\delta_0}{\lambda} \ln \tau_{ikt} + \frac{\delta_1}{\lambda} \left[\ln \tau_{ikt} \times CX_{it}\right] + \varepsilon_{jikt}. \tag{16}$$

The model predicts that the coefficient estimate $\delta_0/\lambda < 0$ and the coefficient estimate $\delta_1/\lambda > 0$. As trade costs increase, firms substitute local production for imports of intermediate inputs from the parent, but this substitution is more costly in technologically complex industries with hard-to-transfer technologies. Note that the difference in the predicted sign on the interaction between trade cost and complexity, $[\ln \tau_{ikt} \times CX_{it}]$, in the import equation (16) and the affiliate sales equation (15) means that the analysis has a strong empirical bite.

We now turn to the data.

4 Data

Our 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. 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. A U.S. multinational entity 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, BEA believes that coverage is close to complete and levels of accuracy are high.

In building the dataset we first link 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 parent, we extract information on its industry, its total expenditure on research and development, and its total sales.[17] Aggregating over parents by industry and year, we calculate the R&D intensity of each industry as R&D expenditures over sales. This is the variable CX_{it}, the measure of the complexity of each industry's technology. Next, we obtain from the BEA files all of the relevant information concerning affiliate operations. To measure sales of foreign affiliate operations, we employ three different variables. The first is each affiliate's sales to customers in the host country, the second is sales to customers located in the United States, and the third is sales to customers located in other foreign countries. These sales face different demand conditions, and more broadly speaking the motive for engaging in FDI may differ. Employing the different sales variables thus affords us with an oppourtunity to see whether the technology transfer mechanism emphasized in this paper applies to some foreign direct investment more than to other foreign direct investment.

There are also several different measures of imports that we use. They are, from narrow to increasingly broader measure: first, the affiliate's imports of intermediate inputs from the U.S. parent firm, second the affiliate's imports of intermediate goods from the U.S. parent and unaffiliated U.S. parties, and third, each affiliate's total imports from the United States.[18] We then aggregate over all the affiliates of a each parent firm by country and year to form a single country-year-parent

[17] BEA industry definitions changed from SIC-based categories in 1994 to NAICS-based categories in 1999. To match tariff and freight cost data to our firm-level data, we concorded the later year NAICS based categories into 1994 SIC-based categories.

[18] We identify intermediate input imports in the BEA data as imports "for further processing".

observation. We avoid including purely wholesaling affiliates by discarding all affiliates that lack operations in a manufacturing industry. Each country-year-parent observation has then assigned the parent firm's industry.[19]

Our ad-valorem measure of trade costs is defined as

$$\tau_{ikt} = 1 + fc_{ikt} + tariff_{ikt},$$

where fc_{ikt} is an ad-valorem measure of freight costs, and $tariff_{ikt}$ is an ad-valorem measure of tariffs, both at the industry-country-year level. Freight costs, fc_{ikt}, 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).[20] The tariff measure, $tariff_{ikt}$, is calculated from figures in the United Nations' TRAINS dataset and extracted with the WITS software of the World Bank, where we use the same method of computing industry-level values as employed to construct the freight cost measure.

We also assemble variables on other factors known to affect multinational activity (the **X** in equations 15 and 16 above). First, there is information on GDP per capita and population from the Penn World Tables. These variables capture market size effects that we expect to play a role for gravity reasons. The size of the population in a host market may also pick up fixed costs of affiliate operations, which might give rise to increasing returns to scale.

[19] In three food processing industries and one fabricated metal industry, there is virtually no trade between parent and affiliate. These industries with import shares less than 3 percent were dropped from the sample, leaving us with 48 SIC-based BEA industries.

[20] 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.

Skill abundance of the host country may affect FDI because it can lead to a low factor price for skilled labor, thereby making local affiliate production of skill-intensive tasks relatively attractive. Our measure of skill abundance is human capital per worker from Hall and Jones (1999). General factor price differences between the FDI host country and the U.S. are also picked up by GDP per capita. Note that while including a long list of additional variables is conservative in terms of testing the predictions, the variables may in part capture the same variation in the data, which would mean that collinearity problems might arise.

We also 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., from Hanson, Mataloni, and Slaughter (2005), and the costs of making a phone call, from the World Competitiveness Yearbook (1989).[21] Moreover, work on the international tax system emphasizes that multinationals may engage in transfer pricing by altering the value of within-firm transactions to reduce its global tax burden. In order to be able to pick up these effects, we include the host country's maximum marginal corporate tax rate (source: Michigan database).

A major strand of work views multinational firms as vehicles that allow to internalize (within the firm) a relationship where contracting on the transfer of technological knowledge is crucial. We expect that countries in which intellectual property rights (IPR) are strongly enforced will be those in which relationships between independent firms are 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 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).

[21] Cross-country variation in the cost of making a phone call to the United States will also be indicative of differences in within-country communication costs, one of the key factors in Antras, Garicano, and Rossi-Hansberg (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 relatively complex products. While our emphasis on technology transfer costs is consistent with offshoring to both outsource and to produce in a multinational affiliate, we want to be certain that our findings are not primarily due to factors that determine firm organization. We include therefore as another determinant of FDI 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.

Finally, to examine the model's prediction on how the composition of intra-firm trade changes we employ detailed U.S. Census data on foreign related-party trade to construct a measure of the technological complexity of intra-firm U.S. exports.[22]

Table 1 shows summary statistics of the data.

[22] Details on this can be found in the Appendix.

Table 1. Descriptive Statistics

	Mean	Standard Deviation
Affiliate Sales		
Total	10.886	1.665
To local unaffiliated customers	10.397	1.747
To U.S. customers	7.713	2.183
To 3rd Countries	9.076	2.505
Import shares		
From Parent, all imports	-3.038	1.973
From Parent, further processing	-3.115	1.954
From all US, all imports	-2.889	1.927
From all US, further processing	-2.985	1.973
Other Variables		
Technological Complexity	0.050	0.041
Trade Costs	0.099	0.091
Phone Call	0.472	0.615
IPR Protection	0.617	0.650
GDP per capita	9.734	0.630
Population	10.514	1.267
Tax Rate	3.612	0.269
Common Language	0.389	0.488
Human Capital	0.855	0.192
Judicial Quality	0.757	0.185

Note: All variables, except Technological Complexity and Common Language, are in natural logarithms.

There are several interesting features of the structure of U.S. affiliate sales and intermediate import shares. The first four rows show the average sales (in natural logarithms) by location of the final customer. These data reveal that the average affiliate sells much more to customers in its host country than to customers located elsewhere. For instance, the average affiliate revenue in its host country market is more than ten times its revenue on sales to customers in the United States ($e^{10.397}=$ \$33 million compared to $e^{7.713} =$ \$2.2 million). At the same time, there is much more variation across affiliates in export sales than in local sales, as indicated by the larger standard deviations in rows three and four relative to row two. The next four rows in Table 1 report (in natural logarithms) the average import share of U.S. affiliates. The data indicate that the bulk of intermediate input imports are purchased from the parent firm rather than from unrelated parties: the average affiliate's import share from its parent firm of intermediate inputs is $e^{-3.038} = 4.4\%$ while the import share from all U.S. sources is $e^{-2.985} = 5.1\%$.

The following section presents the empirical results.

5 Empirical Results

Two model predictions will be examined with the firm-level data set on U.S. multinational firms. The next section presents evidence on the level of affiliate sales, followed by an analysis of the composition of multinational activity. The section on empirical results will be concluded by investigating the technological complexity of intra-firm trade.

5.1 The Gravity of Multinational Affiliate Sales

The model implies that affiliate sales decline in trade costs, and this decline is more pronounced for relatively complex industries (Proposition 1). The first column of Table 2 establishes the basic gravity relation for affiliate sales, which corresponds to Figure 1a shown above. Central to our argument is the role of complexity, thus in column 2 we allow the sales decline to vary with complexity (compare to Figure 1b above). The coefficient on the Trade Cost-Complexity variable ($\ln \tau_{ikt} \times CX_{it}$) is significantly negative at about -25, whereas the linear trade cost estimate drops by almost a third. These initial results are consistent with task complexity playing a major role.

Table 2. Gravity and Affiliate Sales

	(1)	(2)	(3)	(4)
Trade Costs	-3.831	-2.690	-0.851	-0.578
	[0.000]	[0.000]	[0.106]	[0.214]
Trade Costs * Complexity		-24.804	-20.716	-19.957
		[0.006]	[0.010]	[0.013]
Phone Call			-0.038	-0.015
			[0.532]	[0.785]
IPR Protection			0.198	0.258
			[0.017]	[0.001]
GDP per capita			0.799	1.196
			[0.000]	[0.000]
Population			0.451	0.438
			[0.000]	[0.000]
Tax Rate			-0.115	-0.100
			[0.366]	[0.479]
Common Language			0.230	0.392
			[0.000]	[0.000]
Human Capital				-0.289
				[0.226]
Judicial Quality				-1.462
				[0.001]
R-squared	0.046	0.049	0.190	0.197
N	6,691	6,691	6,419	6,419

Notes: The dependent variable is local affiliate sales to unaffiliated customers. All variables are defined as deviations from the firm-year mean. Robust p-values allow for clustering by country-year and are shown in brackets

Because this analysis so far ignores market size (the term B_{ik} in equation 11 above) and other determinants of FDI sales, in the following we include a number of additional variables. First, as column 3 of Table 2 shows, affiliate sales are increasing in market size, captured by both GDP per capita and population. These are typical gravity findings. The positive estimate on population is also consistent with scale economies in affiliate operations. Second, since communication costs for transferring complex technology are central to the argument, we want to include some direct measures of communication costs. In column 3, a common language in the FDI host country with the U.S.

(i.e. English) is associated with higher affiliate sales, while the costs of a phone call does not enter significantly. We also find that good IPR protection is associated with higher affiliate sales, while a country's tax rate does not play a major role. Including these variables substantially lowers the direct impact of trade costs on affiliate sales, but the extent to which trade costs for complex tasks have additional bite changes comparatively little.

Next we examine the relationship of affiliate sales with the skilled labor endowment of the FDI host country (column 4). Given that the United States are skilled-labor abundant compared to the average sample country, a simple factor proportions prediction would be that U.S. sales are lower, the higher is the host country's skill endowment. Consistent with this we estimate a negative coeffcient for the Human Capital variable, however it is not precisely estimated.[23] The latter might be because here we only exploit within-firm variation in affiliate sales. In addition, a measure of judicial quality is included in the specification. High judicial quality is, somewhat surprisingly, associated with lower FDI sales. This may be in part because of collinearity among some of the country variables.[24]

Since an estimate of about -20 for the Trade Cost-Complexity variable is common to several specifications reported below, it is worth putting this number into context to see how large impact of technological complexity on affiliate sales is. Using the coefficient estimates of Table 2 as well as the summary statistics, we find that when evaluated at average trade costs, the impact of changes in technological complexity is similar in size to that of changes in IPR protection or speaking the same language, but smaller than the effect of changes in population or GDP per capita (about one fifth). Moreover, the complexity effect is comparable in size to the effect of trade costs.[25] If we include the (not significant) linear trade cost coefficient in the calculation, the influence of complexity on affiliate

[23] We have also considered to include wages as independent variables; this leads to very similar results.

[24] For example, the correlation of judicial quality with either GDP per capita or skill abundance is about 0.67.

[25] For this comparison, the effect of technological complexity is evaluated at the average value of trade costs, and analogously, the trade cost effect is calculated for average complexity.

sales is about half that of trade costs. This suggests that technology transfer costs are quantitatively important in explaining the geography of affiliate sales.

There is still a concern that the previous results on the Trade Cost-Complexity variable reflect other factors that vary with complexity. For example, it may be the case that technological complexity exacerbates hold-up problems when contracts are incomplete, and our results are obtained largely because trade costs and the importance of incomplete contracts problems are correlated. To address this concern, we include the interaction between Judicial Quality and Complexity as a separate variable. Along the same lines, in each column of Table 3 a different complexity interaction is included in addition to the Trade Cost-Complexity variable.

The results of Table 3 indicate that complexity does not vary with the IPR regime, the GDP per capita, and judicial quality of the host country (columns 2, 3 and 6). Among the two direct measures of communication, we find that common language raises affiliate sales much less for complex than for non-complex products (column 4). Consistent with our argument, this may be because common language is useful for selling relatively simple goods, whereas selling more complex goods requires communicating tacit technological knowledge, which goes well beyond speaking the same language. Another result is that U.S. affiliates' sales decline more strongly with decreasing skill abundance difference to the FDI host country for the relatively complex goods (column 5).[26]

[26] Relatively low U.S. affiliate sales of complex products in skill abundant host countries might be consistent with a factor abundance model, if the affiliate imports to a great extent intermediates from the U.S. and technological complexity is positively correlated with skill intensity across industries.

Table 3. Gravity in Sales and Complexity Interactions

	(1)	(2)	(3)	(4)	(5)	(6)
Trade Costs	-0.380	-0.640	-0.555	-0.397	-0.704	-0.593
	[0.440]	[0.174]	[0.229]	[0.419]	[0.131]	[0.207]
Trade Costs * Complexity	-24.321	-18.726	-20.495	-22.153	-16.519	-19.633
	[0.005]	[0.025]	[0.013]	[0.020]	[0.055]	[0.014]
Phone Call	-0.085	-0.016	-0.015	-0.015	-0.015	-0.015
	[0.233]	[0.767]	[0.786]	[0.775]	[0.781]	[0.782]
Phone Call*Complexity	1.356					
	[0.140]					
IPR Protection	0.254	0.235	0.258	0.278	0.263	0.258
	[0.001]	[0.005]	[0.001]	[0.000]	[0.001]	[0.001]
IPR * Complexity		0.429				
		[0.633]				
GDP per capita	1.200	1.197	1.203	1.186	1.201	1.197
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
GDP per capita * Complexity			-0.131			
			[0.848]			
Common Language	0.395	0.392	0.392	0.621	0.391	0.392
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Common Language * Complexity				-4.432		
				[0.000]		
Human Capital	-0.294	-0.288	-0.290	-0.307	-0.257	-0.289
	[0.217]	[0.229]	[0.224]	[0.191]	[0.232]	[0.225]
Human Capital * Complexity					-1.058	
					[0.059]	
Judicial Quality	-1.474	-1.462	-1.463	-1.499	-1.491	-1.475
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Judicial Quality * Complexity						0.222
						[0.751]
Population	0.437	0.438	0.438	0.432	0.440	0.438
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Tax Rate	-0.097	-0.100	-0.099	-0.102	-0.110	-0.100
	[0.492]	[0.478]	[0.480]	[0.460]	[0.438]	[0.480]
R-squared	0.198	0.197	0.197	0.201	0.198	0.197
N	6,419	6,419	6,419	6,419	6,419	6,419

Notes: The dependent variable is local affiliate sales to unaffiliated customers. All variables are defined as deviations from the firm-year mean. Robust p-values allowing for clustering by country-year shown in brackets

At the same time, including the Human Capital-Complexity interaction has only a moderate effect on the Trade Cost-Complexity estimate. In general, the inclusion of additional complexity interactions does not change the finding that the bite of trade costs is strongest for more complex products. It is also worth noting that the linear trade cost coefficient, albeit negative, is never significant, confirming the earlier results from Table 2.

We have also experimented with including variables that capture comparative advantage, such as skill abundance times skill intensity and judicial quality time contract intensity.[27] This leads to similar results as those presented in Table 3. Another question is whether the Trade Cost-Complexity variable, based on R&D intensity, really captures differences in technology transfer costs. Alternatively, it may capture other factors, in particular skill or capital intensity in input production. We have explored to interact trade costs with skill- and capital intensity, finding consistent but often much weaker results than for the Trade Cost-Complexity variable (not reported).[28]

The following table sheds additional light on the robustness of the findings by employing different measures of affiliate sales. In addition to sales to local customers, affiliates also sell to affiliated or unaffiliated parties in third markets. Further, they sell back to their home country (here: the United States), in particular to their parents, which may be the foremost example of vertical production sharing. In these cases, demand side determinants, and more generally, possibly the primary motives for FDI are different. At the same time, in all cases the multinational firm has to transfer its technology from parent to affiliate, implying that the cost structure of affiliates should be similar irrespective of the identity of the final customer. The following results present the evidence on this. Two sets of results are reported in Table 4. In columns 1 to 4, we include only trade costs as a regressor. While this omits possibly relevant variables, it brings out most clearly different motives

[27] For recent work along these lines, see Nunn (2007).

[28] In addition, Keller and Yeaple (2008) report results consistent with these estimates for two alternative measures of technological complexity, based on worker skill (nonproduction or production) and on occupational data from the U.S. Department of Labor's O*NET database.

for multinational activity. The second set of results includes the larger set of variables that we have employed before.

Table 4. The Geography of Costs and Sales Destinations

	(1) Local Sales	(2) Sales to U.S.	(3) 3^{rd} co. Sales	(4) All Sales	(5) Local Sales	(6) Sales to U.S.	(7) 3^{rd} co. Sales	(8) All Sales
Trade Costs	-3.831	-7.511	-2.174	-4.257	-0.578	-3.255	3.205	0.100
	[0.000]	[0.000]	[0.000]	[0.000]	[0.214]	[0.022]	[0.001]	[0.840]
Trade Costs * Complexity					-19.957	-60.183	-37.905	-30.036
					[0.013]	[0.027]	[0.028]	[0.001]
Phone Call					-0.015	-0.582	-0.713	-0.212
					[0.785]	[0.003]	[0.000]	[0.000]
IPR Protection					0.258	0.061	0.806	0.409
					[0.001]	[0.818]	[0.000]	[0.000]
GDP per capita					1.196	-0.726	0.111	0.759
					[0.000]	[0.057]	[0.722]	[0.000]
Population					0.438	-0.056	0.283	0.289
					[0.000]	[0.362]	[0.000]	[0.000]
Tax Rate					-0.100	1.166	-1.56	-0.033
					[0.479]	[0.000]	[0.000]	[0.766]
Common Language					0.392	0.725	0.095	0.381
					[0.000]	[0.000]	[0.601]	[0.000]
Human Capital					-0.289	-0.877	-2.205	-0.889
					[0.226]	[0.158]	[0.000]	[0.000]
Judicial Quality					-1.462	0.698	3.039	-0.279
					[0.001]	[0.497]	[0.000]	[0.519]
R-squared	0.046	0.053	0.007	0.065	0.197	0.103	0.205	0.223
N	6,691	3,574	4,147	6,691	6,419	3,487	3,994	6,419

Notes: The dependent variable is local affiliate sales to unaffiliated customers in columns (1) and (5); sales to the U.S. in (2) and (5); sales to other foreign countries in columns (3) and (7), and all sales in (4) and (8). All variables are defined as deviations from firm-year means. Robust p-values allow for clustering by country-year and are shown in brackets.

Column 1 repeats the results for local sales to unaffiliated parties from Table 2, column 1 for convenience. In the second column, the dependent variable is affiliate sales back to the United States. For the most part, these are sales to the parent of the multinational affiliate, but about 15% are to unaffiliated entities in the United States. Sales to unaffiliated parties may also include outsourcing activities of other US-based firms. Here we obtain a considerably higher trade cost elasticity than what is estimated for local sales. This is consistent with problem-solving communication from the affiliate to the multinational parent.

We now turn to affiliate sales to third markets. The dependent variable in column 3 includes both sales to affiliates of the same multinational firm in other countries as well as to unaffiliated entities in third countries (about 55% affiliated and 45% unaffiliated sales). Third-country sales to unaffiliated parties are often referred to as export-platform FDI.[29] For these third-country sales we estimate a relatively low trade cost elasticity of -2.2. A relatively small negative or perhaps even positive effect is plausible because the avoidance of trade costs and hence substitution of affiliate sales for trade is one of the main motives for this type of FDI.[30] Finally, results for total affiliate sales are shown in column 4; the trade cost elasticity is closest to that for local sales to unaffiliated parties in column 1, reflecting the fact that the latter make up about two thirds of all affiliate sales.

The expanded set of variables are included for columns 5 to 8 of Table 4. Some of the results provide evidence for differences in the motive for engaging in FDI. For example, local affiliate sales are relatively high while sales back to the U.S. are relatively low if the host country has a high level of GDP per capita. This suggests that one of the motives for U.S. multinational firms to locate affiliates in low income countries is to produce unskilled-labor intensive intermediate goods which are then exported to the U.S. for final assembly. This is in line with the factor cost saving motive

[29] It is also possible that these are intermediates, in which case the affiliate would be an outsourcing provider.

[30] Yeaple (2008) emphasizes that at larger distance, concentrating assembly in export platform locations can help conserve overhead costs.

for vertical production sharing discussed in Hanson, Mataloni, and Slaughter (2005).

In addition, we often find that the coefficient for a given variable is estimated largest (in absolute value) for third-country sales. This is what one would expect if the choice of production location is highly elastic, and not tied down by proximity to either the U.S. or characteristics of the FDI host economy. For example, while there is some evidence that local sales are lower when the host country is skill abundant (albeit not significantly so, in column 5), if sales are directed to third-country markets the evidence for this factor abundance effect is stronger. Also, relatively high cost of making phone calls lowers third-country sales particularly strongly, consistent with the idea that this country is primarily a hub (or platform) through which sales are channeled, and given some attractive alternative location nearby the country is easily replaced as a hub.

We now turn to the trade cost results for the different sales destination. First, the linear trade cost coefficient is most strongly negative for sales to the United States (see column 6 of Table 4). If the ultimate purpose of FDI is to sell the final product ultimately in the U.S., then higher trade costs to the FDI host country are likely to be a strong disincentive, because they have to be incurred twice. Also, we estimate a positive and significant linear transport cost effect on third-country sales, which is consistent with the hypothesis that sales through export-platform FDI substitute for exports from the home country.

Second, looking at the Trade Cost-Complexity variable, for all affiliate sales measures, technological complexity raises the extent to which sales are declining in trade costs. In terms of magnitude, the estimate is largest for sales that go back to the United States. This supports the idea that irrespective of the ultimate purpose of affiliate activity, the costly transfer of technology plays an important role. Moreover, while only one out of four linear Trade Cost coefficients is estimated to be significantly negative, all four Trade Cost-Complexity variables are significant. This underscores the importance of technological complexity for the overall finding of gravity in FDI.

We now turn to analyzing the affiliate's import activity.

5.2 Multinational Affiliate Imports and Vertical Production Sharing

The main import prediction of the model is that the multinational's substitution of local production for imports is tempered by the costs of technology transfer, which is necessary to produce locally.[31] Consequently, the response of affiliate import shares is weaker in complex industries than in less complex industries (Proposition 2). In contrast to complex affiliate sales, the affiliate's complex intermediate imports fall by less, not more than average as trade costs increase. This difference affords us with a powerful test of the theory.

In Table 5 we present the first set of results on imports. The dependent variable is the log of affiliate imports for further processing from the U.S. parent, divided by total affiliate sales. Column 1 shows that the import share is negatively related to trade costs, however, the coefficient is only marginally significant. This changes drastically once we distinguish complex from less complex imports, see column 2. The Trade Cost-Complexity variable has a positive coefficient, which confirms the prediction of the model. The linear trade cost coefficient is now also more strongly negative. This suggests that it is difficult for the multinational parent to avoid these exports, because transferring the technology underlying complex tasks to the affiliate would be very costly.

[31] The affiliate's imports-to-sales ratio is also predicted to fall as trade costs increase; however, this would likely be true in any model where multinationals can choose to produce locally in order to avoid trade costs.

Table 5. Affiliate Imports and Gravity

	(1)	(2)	(3)	(4)
Trade Costs	-1.280	-2.619	-3.634	-3.544
	[0.128]	[0.007]	[0.000]	[0.000]
Trade Costs * Complexity		28.950	22.491	23.057
		[0.000]	[0.022]	[0.013]
Phone Call			0.356	0.334
			[0.000]	[0.000]
IPR Protection			-0.442	-0.456
			[0.000]	[0.000]
GDP per capita			-0.127	0.085
			[0.374]	[0.711]
Population			-0.136	-0.151
			[0.003]	[0.001]
Tax Rate			0.851	0.779
			[0.003]	[0.003]
Common Language			0.258	0.237
			[0.023]	[0.015]
Human Capital				0.794
				[0.175]
Judicial Quality				-1.371
				[0.127]
R-squared	0.004	0.007	0.068	0.072
N	5,123	5,123	4,929	4,929

Notes: Dependent variable: imports for further processing from the US parent relative to affiliate sales. All variables are defined as deviations from firm-year means. Robust p-values allow for clustering by country-year and are shown in brackets.

How do these conclusions stand up as we include additional variables? First of all, we see that the latter have usually the expected sign. Specifically, if making phone calls is very expensive, the affiliate substitutes imports from the parent for local production. This is expected if phone calls have value for monitoring overseas production. Also, high levels of IPR protection are associated with comparatively high shares of local production. As long as affiliate production leads to stronger technological learning among firms in the host economy than exporting from home (as shown by Keller and Yeaple 2009), high levels of IPR protection will be assuring to the multinational firm because this is associated with less leakage of its technological knowledge. Moreover, a relatively large market in terms of population is associated with a higher share of local production, consistent with the presence of scale economies in multinational activity.

The estimates also indicate that high tax rates are typically associated with high import shares. One explanation for that is transfer pricing, where multinationals undercharge the value of shipments to affiliates if these are located in low-tax countries. Conditional on total sales, this would yield a low import share. Further, affiliates in countries with high quality institutions for contract enforcement have (marginally) lower import shares (column 4). This is consistent with the hypothesis that local production, which requires more heavily contracting with suppliers than importing from the parent, is faciliated by institutions that keep the expected costs of contract disputes low. However, the finding that the impact of trade costs on affiliate imports is relatively low for complex goods remains unchanged. Moreover, the results imply that higher trade costs lead to lower import shares at the average level of complexity. Quantitatively, a given increase in trade costs reduces the import share by about twice as much as an equally-sized reduction of complexity.[32] Thus, while higher complexity leads to *lower* affiliate sales and to *higher* affiliate import shares, the relative importance of trade costs and complexity for affiliate sales and import shares is similar.

One might be concerned that this is due to some other variation in the sample related to complexity. In order to find out, we consider the impact of other complexity interactions; see Table 6. One

[32] Evaluating the trade cost (complexity) effect at the average level of complexity (trade costs).

finding is that the impact of IPR protection depends on complexity (column 2). While generally the share of local production is high when IPR protection is strong, this is less so the case for relatively complex products. If strong IPR production would simply reassure multinationals that it is relatively safe to transfer technology to that particular host country, one might actually expect the opposite result. One possible explanation is that IPR protection, typically through patents, is less effective for complex goods because such technology has often important aspects that cannot be patented to begin with. Aside from IPR protection, we do not find evidence that the affiliate's import share is significantly affected by other complexity interactions.[33] This indicates that the finding that affiliate imports of complex products decline less with trade costs than noncomplex imports is not due to the interaction of complexity with other factors.

[33] As in the case of affiliate sales above, the results are robust to employing variables such as skill abundance times skill intensity and judicial quality time contract intensity.

Table 6. Vertical Production Sharing and Alternative Complexity Interactions

	(1)	(2)	(3)	(4)	(5)	(6)
Trade Costs	-3.721	-3.966	-3.666	-3.481	-3.483	-3.484
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Trade Costs * Complexity	26.636	31.539	25.724	22.127	21.854	21.789
	[0.009]	[0.003]	[0.026]	[0.017]	[0.032]	[0.034]
Phone Call	0.400	0.325	0.333	0.334	0.335	0.335
	[0.004]	[0.001]	[0.000]	[0.000]	[0.000]	[0.000]
Phone Call*Complexity	-1.284					
	[0.428]					
IPR Protection	-0.452	-0.619	-0.455	-0.448	-0.453	-0.455
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
IPR * Complexity		2.914				
		[0.066]				
GDP per capita	0.079	0.088	0.046	0.081	0.087	0.086
	[0.730]	[0.701]	[0.854]	[0.726]	[0.706]	[0.708]
GDP per capita * Complexity			0.713			
			[0.663]			
Common Language	0.234	0.232	0.236	0.317	0.237	0.237
	[0.015]	[0.016]	[0.015]	[0.016]	[0.014]	[0.014]
Common Language * Complexity				-1.544		
				[0.362]		
Human Capital	0.802	0.808	0.800	0.789	0.897	0.787
	[0.171]	[0.169]	[0.175]	[0.176]	[0.181]	[0.182]
Human Capital * Complexity					-2.077	
					[0.593]	
Judicial Quality	-1.360	-1.360	-1.370	-1.384	-1.382	-1.294
	[0.130]	[0.130]	[0.127]	[0.122]	[0.125]	[0.195]
Judicial Quality * Complexity						-1.491
						[0.743]
Population	-0.151	-0.149	-0.151	-0.153	-0.151	-0.151
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Tax Rate	0.776	0.777	0.778	0.775	0.777	0.780
	[0.004]	[0.004]	[0.003]	[0.004]	[0.003]	[0.003]
R-squared	0.073	0.074	0.073	0.073	0.073	0.073
N	4,929	4,929	4,929	4,929	4,929	4,929

Notes: Dependent variable: imports for further processing from the US parent relative to total affiliate sales. All variables are defined as deviations from firm-year means. Robust p-values allow for clustering by country-year and are shown in brackets.

In the following, we extend the robustness analysis by considering broader measures of affiliate import activity. There are two alternative dependent variables; first, we examine variation in all imports for further processing. This allows to see whether the mechanism we propose also explains variation in arm's length purchases by the affiliate, when the affiliates import certain outsourced services from unaffiliated parties. Second, we consider all imports of the affiliate, which is the broadest measure, including also imports that are not designed for further processing. Table 7 presents these results.

With only the linear trade cost variable, the results for all three dependent variables are quite similar. A common finding is that trade costs do not have a highly significant impact on the import share (lowest p-value of 6.7% for all imports). The inclusion of the Trade Cost-Complexity variable changes this finding (columns 4, 5, and 6), because the import share for complex products responds relatively little as trade cost increases. This indicates the importance of complexity for quantifying multinational substitution between exports from the parent and local production by the affiliate.

Table 7. Different Imports Measures

	(1) Process-ing from Parent	(2) All Pro-cessing	(3) All	(4) Process-ing from Parent	(5) All Pro-cessing	(6) All	(7) Process-ing from Parent	(8) All Pro-cessing	(9) All
Trade Costs	-1.280	-1.263	-1.730	-2.619	-2.729	-3.102	-3.544	-3.902	-4.091
	[0.128]	[0.174]	[0.067]	[0.007]	[0.008]	[0.004]	[0.000]	[0.000]	[0.000]
Trade Costs * Complexity				28.950	32.021	30.101	23.057	26.842	24.794
				[0.000]	[0.000]	[0.000]	[0.013]	[0.011]	[0.020]
Phone Call							0.334	0.409	0.468
							[0.000]	[0.000]	[0.000]
IPR Protection							-0.456	-0.418	-0.404
							[0.000]	[0.000]	[0.001]
GDP per capita							0.085	0.152	0.284
							[0.711]	[0.514]	[0.247]
Population							-0.151	-0.174	-0.165
							[0.001]	[0.000]	[0.001]
Tax Rate							0.779	0.857	0.848
							[0.003]	[0.004]	[0.005]
Common Language							0.237	0.343	0.423
							[0.015]	[0.001]	[0.000]
Human Capital							0.794	0.643	0.592
							[0.175]	[0.303]	[0.358]
Judicial Quality							-1.371	-1.895	-2.047
							[0.127]	[0.045]	[0.033]
R-squared	0.004	0.004	0.007	0.007	0.007	0.010	0.072	0.092	0.099
N	5,123	5,412	5,647	5,123	5,412	5,647	4,929	5,204	5,429

Notes: Dependent variable: Share of processing imports from parent in total sales in columns (1), (4), and (7); share of processing imports from all U.S. parties in total sales in (2), (5), and (8); and all U.S. imports to total sales in (3), (6), and (9). All variables are defined as deviations from the firm-year mean. Robust p-values allow for clustering by country-year and are shown in brackets.

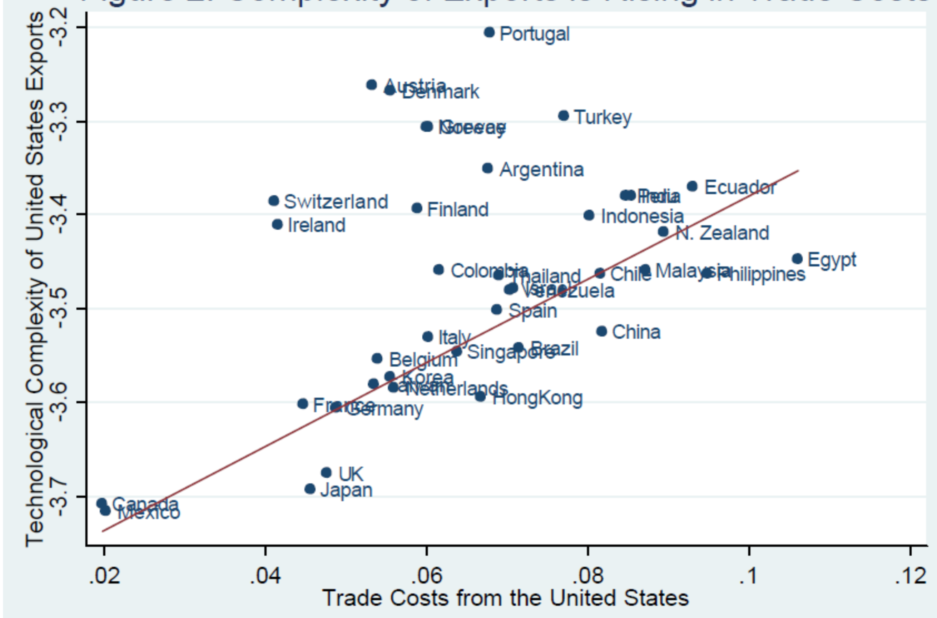
We also report results from specifications that include the extended set of regressors. For most determinants of the import share, the results are similar across all three measures of imports. Specifically, higher costs of telephone calls favor imports, consistent with the idea that local production requires more communication between multinational parent and affiliate than exports from the home country. Also, a higher measure of population in the host country favors FDI relative to imports, consistent with fixed costs of FDI. In contrast, for judicial quality there are some differences across the import measures. Judicial quality is not significant in determining the share of intra-firm processing imports, whereas it has a larger (and significant) impact on the import share when trade between unaffiliated parties is included (compare columns 7 and 8). It is plausible that judicial quality matters more for trade between unaffiliated parties, if only because courts will rarely have to adjudicate disputes that concern intra-firm trade.

For the most part the results for the different measures of imports are quite similar. Moreover, including the extended set of variables does not affect the qualitative findings on trade costs and complexity. Quantitatively, including additional variables raises somewhat the importance of trade costs relative to complexity; for the linear trade cost variable, the coefficient falls from about -2.8 to -3.8 while the Trade Cost-Complexity estimate falls from about 30 to 25. Taken together, technological complexity appears to be an important determinant of vertical production sharing of the multinational affiliates in our sample.

We now turn to examining the composition of intra-firm trade.

The Technological Complexity of Affiliate Imports The previous results demonstrate that trade costs interact with technological complexity in a clear and consistent way in determining the choice of imports versus local affiliate production, with import shares decreasing less rapidly if products are more complex. We now ask whether another prediction of the model is borne by the

Figure 2: Complexity of Exports is Rising in Trade Costs



data. Lemma 1 states that as trade costs increase, the composition of intra-firm trade shifts toward relatively more complex intermediates. To address this question, we can no longer rely on the data from the BEA because it does not address in detail the commodity composition of intra-firm trade. Instead we turn to related-party export data collected by the U.S. Census Bureau. We use this data to calculate the technological complexity, as measured by the average R&D intensity, of U.S. exports to related partners in other countries.

Figure 2 plots the technological complexity of exports against trade costs by country.[34]

The figure shows a strong positive relationship between complexity and the size of trade costs. This relationship provides support for our model: as trade costs rise, parents offshore the production of increasingly complex activities, and at the same time their exports become increasingly concen-

[34] The best-fit line corresponds to a weighted regression, with GDP as weights. The construction of the complexity of trade variable is detailed in the Appendix.

trated in goods requiring complex technologies. In the Appendix, we show that this relationship holds up to including a large set of other variables. This is an important confirmation of the model's prediction regarding intra-firm trade using detailed information on the technological content of trade.

The following section presents a number of concluding remarks.

6 Concluding Remarks

How well does technology transfer between production sites? The answer to this question is important to many fields of economics, and yet it has proven to be a hard question to address. We tackle it by developing a framework in which technology can be transferred either embodied in traded intermediates or in disembodied form through direct communication. Disembodied technology transfer costs vary in the complexity of the technology, but not in the distance of the transfer, while embodied technology transfer costs vary in the distance of the transfer but not in the complexity of the technology.

We show that it is the interaction between a product's technological complexity, on the one hand, and the distance between the buyer and the seller, on the other hand, that determines the size of the costs of selling products in international markets. In the context of a multinational enterprise, we derived three important implications. First, more distant markets will be served less than proximate markets, and the size of this effect is increasing in technological complexity. Second, if technology is complex, firms are constrained in their ability to shift production towards their affiliates; instead, a large part of the final good is produced by the multinational parent. Finally, the model also predicts that firms change systematically the composition of their international trade in terms of its technological complexity as trade costs change relative to technology transfer costs.

Employing extensive information on U.S. multinational firms, we find evidence for all three of these predictions. Moreover, the results are robust to incorporating a wide range of well-known other determinants of multinational activity. This gives not only support to the idea that international technology transfer costs matter, but we are also able to address a major puzzle, namely the fact that there is gravity for weightless goods.

Economists know little about the impact of relative cost changes for disembodied versus embodied technology transfer, even though both appear to be changing at a rapid pace. Communicating complex technology may become cheaper through video-conferencing compared to telephone calls, while at the same time the technology embodied in intermediate goods becomes more movable because trade barriers and transportation costs are falling. The present paper should be useful for future research on the mobility of technological knowledge.

We have presented our view of some key influences of international commerce in terms of a theory of multinational firms because arguably this is the perfect lens to do so. Multinational firms are central to the spread of technological knowledge across borders as the technology developed by the parent can be employed by its affiliates in other countries. The parent's development costs are fixed while technology is non-rival, leading to international increasing returns to scale. Further, in the context of the multinational firm, none of the well-known obstacles to international technology transfer emphasized in the existing literature are present.[35] And yet, we see that technology transfer costs strongly limit the benefits of these scale economies.

If such technology transfer frictions are even present within the multinational firm, this suggests that they also affect the way in which domestic firms are organized. How do technology transfer costs affect multi-plant operation, or the structure of hierarchies? What additional issues arise when

[35] There are, for example, no policy-induced costs of technology adoption (Parente and Prescott 2000), no costs of imitation (Barro and Sala-i-Martin 1997), or appropriate technology issues (Basu and Weil 1998).

transactions are carried out at arm's length? This last question is particularly important for two reasons.

First, because to the extent that the technology developed by one firm becomes available to unaffiliated firms, there are externalities, or technology spillovers, and the potential efficiency effects arising from fixed costs and non-rivalness are increased. While there is evidence that both international trade and foreign direct investment may be major channels for spillovers, the literature still lacks a suitable framework for thinking about these issues.[36] We believe that our framework can be used to make progress on this, not least because it determines which affiliates will employ relatively complex technologies.

Second, we think that adding arms-length transactions to the framework would give us a powerful tool to say more about the quantitative importance of international outsourcing at the aggregate level. Because outsourcing is by all accounts an increasingly important part of international commerce while at the same time we have very little hard data on it, progress in this area is very much needed.

[36] Keller (2009) discusses technology spillovers, putting them in the context of other factors that may affect a firm's productivity, such as changes in competition and pecuniary externalities.

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7 Appendix

In this model, firms offshore the production of the least complex tasks and export to their affiliates the intermediates embodying the most complex tasks. As shipping costs increase, the cutoff intermediate input rises so that the remaining exports become more technologically complex (see equation 7). This variation in the extensive margin implies that the average complexity of exports from U.S. parents to their affiliates should be systematically increasing in the size of trade costs. It is this relationship that we analyze in Figure 2 and in this Appendix.

Our measure of the technical complexity of U.S. intra-firm exports are constructed from data from the U.S. Census Bureau and the *Compustat* database. The Census Bureau reports all related party trade between U.S. entities and foreign intentities, where a related party is one in which there exists at least a 6 percent ownership share. This data set contains all related party exports by six-digit industrial classification for all countries in our BEA dataset. There are 500 NAICS six-digit manufacturing industries. While some of these exports are from U.S. affiliates of foreign parents to their foreign parents, the BEA data reveal that most of these exports are from U.S. parents to their foreign affiliates.[37] Our data are for the year 2002.

Let EX_{ik} be the value of related party exports in commodity i from the U.S. to country j. The total number of traded commodities between the U.S. and country k is

$$N_k = \sum_{i=1}^{500} \{1|EX_{ik} > 0\},$$

where $\{1|EX_{ik} > 0\}$ is an indicator variable that takes the value of one when there are positive exports

[37] In 1997, the aggregate shipments of U.S. parents to their foreign majoirty owned affiliates was $193 billion while the aggregate shipments of U.S. affiliates to their foreign parents was only $28 billion (source: BEA).

between the U.S. and country k in good i and zero otherwise. Let RD_i be the R&D intensity, R&D expenditures divided by sales, for all firms in the *Compustat* dataset for industry i. The average technological complexity of exports between the U.S. and country k is then

$$AC_k = \frac{1}{N_k} \sum_{i=1}^{500} RD_i \cdot \{1 | EX_{ik} > 0\}.$$

Variation in AC_k then reflects variation in the extensive margin of the complexity of traded intermediates. It is the logarithm of this measure that is plotted against trade costs from the U.S. in Figure 2.

We now show the results of regressing the logarithm of AC_k on a number of other variables (Table A).[38] The first column in Table A reports the simple bivariate relationship that is plotted in Figure 2. An increase in trade costs is associated with an increase in the average complexity of U.S. intra-firm trade. Indeed, this single regressor accounts for 44 percent of the variation as indicated by the R-squared.

[38] These are weighted least squares results, with GDP as the weight; the results are qualitatively similar when not weighted. Summary statistics of the variables are shown in Table B.

Table A. The Technological Complexity of Intra-Firm Trade

	(1)	(2)	(3)
Trade Costs	5.111	3.700	3.231
	[0.000]	[0.000]	[0.014]
Phone Call		0.008	0.015
		[0.755]	[0.539]
IPR Protection		0.076	0.131
		[0.603]	[0.378]
GDP per capita		-0.099	-0.095
		[0.058]	[0.083]
Population		-0.064	-0.070
		[0.000]	[0.000]
Tax Rate		0.071	0.093
		[0.166]	[0.055]
Common Language		-0.067	-0.021
		[0.086]	[0.669]
Human Capital		-0.154	-0.221
		[0.240]	[0.120]
Judicial Quality		0.245	0.152
		[0.192]	[0.417]
Weight-to-value			0.013
			[0.417]
R-squared	0.440	0.793	0.802
N	39	36	35

Notes: Dependent variable is the average complexity of U.S. related-party exports. All regressions have a constant (coefficient not reported); all variables except Common Language are in logarithms. Robust t-statistics shown in brackets.

In column 2, we add all of the other country variables employed in the text to the regression. We find that the coefficient on trade costs is still very large and statistically significant but is moderately smaller than in the bivariate case. We also find that the complexity of intra-firm trade is lower in large, developed countries in which English is spoken, as indicated by the negative coefficients on GDP per capita, population, and Common Language. These results could be consistent with an incentive to offshore the production of relatively complex intermediates when communications costs are relatively low or market size is relatively high (as would be the case if there were fixed costs to offshoring each individual task). None of the other coefficients are statistically significant.

One concern is that the relationship reflects trade costs that rise more slowly in distance for highly complex goods because these goods, to some extent intangibles, have lower weight to value ratios. To see if this is the case, we calculate the average weight to value ratio of goods traded between the U.S. and each host country and include that measure in the specification shown in column 3.[39] As the results indicate, the weight-to-value indicator is not statistically significant, while the coefficient on trade costs is only marginally affected, retaining its approximate magnitude and level of statistical significance. Thus using detailed information on the nature of intra-firm trade and controlling for other factors, we find supportive evidence of the model's prediction on how multinational firms change the technological content of their intra-firm trade.

[39] The country level value-to-weight measure is computed from detailed U.S. imports data of the U.S. Census Bureau. We add the values of air and vessel shipments by country, and divide by the sum of their weight.

Table B. Descriptive Statistics - Appendix

	Mean	Standard Deviation
Technological Complexity	-3.471	0.128
Trade Costs	0.065	0.019
Cost of Phone Call	0.582	0.619
IPR Protection	1.393	0.150
GDP per Capita	9.429	0.756
Population	16.138	1.424
Tax Rate	-1.093	0.516
Common Language	0.085	0.252
Human Capital	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.