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GLOBAL PRODUCTION AND TRADE IN THE KNOWLEDGE ECONOMY

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ABSTRACT

This paper presents and tests a new model of multinational firms to explain a rich array of multinational behavior. In contrast to most approaches, here the multinational faces costs to transferring its know-how that are increasing in technological complexity. Costly technology transfer gives rise to increasing marginal costs of serving foreign markets, which explains why multinational firms are often much more successful in their home market compared to foreign markets. The model has several key predictions. First, as transport costs between multinational parent and affiliate increase, firms with complex production technologies find it relatively difficult to substitute local production for imports from the parent, because complex technologies are relatively costly to transfer. Second, the activity of affiliates with complex technologies declines relatively strongly as transport costs from the home market increase, both at the intensive and the extensive margin. We also show that as transport costs from the home market increase, affiliates concentrate their imports from the parent on intermediates that are technologically more complex. We test these hypotheses by employing information on the activities of individual multinational firms, on the nature of intra-firm trade at the product level, and on the skills required for occupations with different complexity. The empirical analysis finds strong evidence in support of the model by confirming all four hypotheses. The analysis shows that accounting for costly technology transfer within multinational firms is important for explaining the structure of trade and multinational production.

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1 Introduction

Multinational firms are often seen as the quintessential global player. At the same time, they tend to be much more successful in their home market compared to foreign markets. The combined market share of the car makers General Motors and Ford in the United States, for example, is close to 40%, compared to only about 20% in Western Europe. National consumer preferences could play a role, but they can hardly explain why two German car makers, BMW and Volkswagen, have a market share in all countries of Western Europe that is more than six times their market share in the United States.[1] In this paper, we propose a different explanation.

We start from the premise that multinationals sell less abroad than at home because there are costs of transferring technology that lowers their productivity abroad. Consistent with this, the business press often reports that multinational affiliates operate with lower efficiency than their multinational parent plants. Even though multinational firms play an ever-larger role in the world economy—about half of foreign trade and 80% of manufacturing R&D in the US are conducted by US multinational firms–, this research is one of the few attempts to uncover the underlying factors.

In most analyses of the multinational firm, whether the motive for foreign production is mainly to save on factor costs or primarily to gain easy market access, multinational parents always fully transfer the firm-specific and non-rival intangible that defines the firm's technology to their affiliates (Helpman 1984, Markusen 1984).[2] Thus, firms make no inde-

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[1] BMW and Volkswagen's market shares in Western Europe (in the U.S.) in the year 2008 until September were 5.9% (2.0%) and 19.8% (2.0%), respectively; source: Ward's AutoInfoBank

[2] Some recent work focuses on rival firm know-how as it resides within managers while retaining the perfect

pendent choice on technology transfer.[3] In contrast, here the degree of technology transfer is endogenously determined by both the desire to save on factor and trade costs and by the difficulty of transferring technology within the multinational firm.[4] We propose that technology transfer costs are high in part because some technologies are relatively complex, and complex technologies require extensive problem-solving communication between parent and affiliate. Technology transfer costs to relatively poor countries are also higher than to richer countries because the former have a lower ability to adopt technological information than the latter.

Firms sell differentiated final goods produced with intermediate inputs that can be sourced from different countries. In our model, there are two Northern and one Southern country. The advantage of importing intermediate inputs from the South is low factor costs, while importing intermediates from the North is preferred relative to local production if the technology transfer required to produce is relatively costly. We show that optimal firm strategies often involve production sharing, where some intermediates are imported while others are locally produced. The least technologically complex intermediates are sourced from the South, while the most technologically complex intermediates are produced in the multinational parent. If a firm originating in a Northern country (East) opens a multinational affiliate in the other (West), the affiliate will import a greater range of intermediates

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transferability assumption (Burstein and Monge-Naranjo 2008).

[3]In these models, there is international transfer of technology, but it is only at the extensive margin: if an affiliate is established, there is full transfer, and if not, there is zero transfer.

[4]Along the lines of Dunning's (1977) **O**(wnership)**L**(ocation)**I**(nternalization) paradigm, our paper treats the O and L aspects simultaneously; in future work, we plan to extent the framework to address the internalization question as well. We expect that studying the technology transfer of multinational firms will also improve our understanding of when local firms benefit from FDI spillovers, which have recently been quantified in Keller and Yeaple (2008).

from the South than the multinational parent, because the affiliate receives the parent's technology only at a cost, and thus purchasing a greater range of inputs from the South becomes optimal.

As trade and transfer costs are changing, this framework yields major predictions for the level and the composition of international economic activity, both at the intensive and the extensive margin. Specifically, as trade costs from the South decline, sales of multinational affiliates will expand by more than sales of the parent (since affiliates rely more strongly on imports from the South). Affiliate sales in technologically complex industries are more affected by increasing trade costs than affiliate sales in less complex industries, because in the latter it is easier to substitute local production for intermediate imports from the parent. We also show that lower trade costs between East and West leads to the entry of new multinational affiliates at the same time that exit increases the productivity of the average multinational parent firm.

These results are obtained by combining our analysis of trade and transfer costs with a heterogeneous firm model in the spirit of Melitz (2003) and Helpman, Melitz, and Yeaple (2004). We then use information for individual U.S. multinational firms from the U.S. Bureau of Economic Analysis on the level of affiliate sales, affiliate imports from their parents, and the R&D of the parents as a measure of technological complexity to test our theory's predictions. Consistent with our model, there is strong evidence that affiliate sales decline in trade costs to the parent, and this effect is stronger for relatively complex technologies. At the same time, as trade costs increase, the share of intra-firm imports in affiliate sales falls less rapidly for complex technologies than for less complex technologies. This result also supports our

model, since for a given increase in trade costs, affiliates find it more difficult to substitute local production for imports from the multinational parent when technologies are complex. We also find evidence that not only the value of trade, but also the range of intermediate inputs that US parents are providing to their affiliates is declining in trade costs by using highly disaggregated data on U.S. exports. This provides direct evidence in favor of our prediction that as trade costs increase, more and more intermediates are produced locally by the affiliate as opposed to imported from the parent.

Our paper is not alone in highlighting the importance of intermediate inputs in international trade flows (Feenstra 1998, Hummels, Ishii, Yi 2001, Yi 2003). Particularly relevant for us is the work by Hanson, Mataloni, and Slaughter (2005) who show using data on U.S. multinational firms that vertical production sharing, where parents and affiliates each perform different tasks but are linked by trade in intermediate inputs, is an important feature of the data. In Hanson, Mataloni, Slaughter's (2005) framework, such production sharing is facilitated by both low intermediate trade costs and factor cost savings when activities differ in their factor intensity. We extend this analysis, first, by showing that the technological complexity of tasks is another important factor that shapes multinational production networks, both in relatively poor and in richer countries. Second, our analysis determines also the level of multinational activity in different countries, both at the intensive and the extensive margin, in addition to the composition of production inside the affiliates on which Hanson, Mataloni, and Slaughter (2005) focus.

An influential set of papers has recently examined offshoring, defined as the performance of tasks (or, intermediate goods) in a country different from where a firm's headquarters are

located (Grossman and Rossi-Hansberg 2006, 2008). Different factors have been emphasized in what makes certain tasks easy to offshore. Our analysis shares a resemblance with Levy and Murnane (2004) and Leamer and Storper (2001); the former argue that routine tasks are easier to offshore because information can be exchanged with fewer misunderstandings, while the latter stress that tasks requiring only non-tacit information exchange are relatively easy to offshore.[5] Our contribution in this respect is to provide explicit microfoundations, based on Arrow (1969), which are highly consistent with the arguments made by Levy and Murnane (2004) and Leamer and Storper (2001). Grossman and Rossi-Hansberg's (2008) paper differs in that heterogeneous offshoring costs are taken as given in a North-North framework while at the same time they interact with external economies of scale not present in our work. Moreover, while in our paper factor price differences affect offshoring decisions, as in Grossman and Rossi-Hansberg (2006), our model has nothing to say on the factor price effects of changes in offshoring costs, the main focus of Grossman and Rossi-Hansberg (2006). At the same time, by including both costs of offshoring tasks—here, the costs of transferring technology within the multinational—as well as the usual iceberg-type trade costs on intermediate and final goods, our framework allows for a richer set of predictions as these costs change relative to each other.

The theory of multinational firms tends to view multinationals either as the result of horizontal expansion (in which the affiliate replicates the production activities at home but saves on the trade costs of exporting) or vertical expansion (in which parent and affiliate

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[5]In Head and Ries' (2008) study of merger & acquisitions FDI, the authors propose the costs of corporate control vary with distance and cultural similarity; at the same time, such costs might also vary across intermediate stages of production.

specialize in different parts of production so as to take advantage of factor cost savings).

Correspondingly, the focus of recent empirical work is often on one of these motives. For example, Brainard (1997) and Irarrazabal, Moxnes, and Opromolla (2008) examine horizontal, whereas Hanson, Mataloni, and Slaughter (2001), Burstein and Monge-Naranjo (2008), and Garetto (2008) study vertical foreign direct investment (FDI).[6] Our theory of multinational firms combines horizontal and vertical motives. All FDI is vertical in the sense that multinational parents and affiliates specialize in different tasks.[7] At the same time, since our analysis incorporates both trade costs and factor cost differentials, it includes motives for horizontal and vertical expansion. Moreover, our empirical analysis confirms that both motives are explaining important parts of the overall pattern of multinational production.

Another set of papers has started to address the important question of how large the gains from openness are based 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); all authors except the influential work by Eaton and Kortum (2002) consider, as does this paper, both international trade and FDI. One contribution of this paper is that the optimal decision on intermediate input purchases, which determines the level of trade and FDI in this framework, is a smooth function of costs, whereas in existing work certain margins of choice exist, or do not, in a discrete way.[8] Finally, it is important to note that our analysis tests, and confirms, key elements of the

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[6]Some empirical studies address both horizontal and vertical FDI, including Carr, Markusen, and Maskus (2001), Blonigen et al. (2003), and Hanson, Mataloni, and Slaughter (2005).

[7]At a relatively fine level of disaggregation, it becomes apparent that multinational parents and affiliates specialize to a significant degree in different tasks (Alfaro and Charlton 2007).

[8]In Garetto (2008), for example, the costs for final goods producers to purchase the 'adaptable' technology used by potential input suppliers is infinity.

model by employing information on individual multinational enterprises. This includes data on the multinational firms' technology investments and their intra-firm trade, as well as information on multinational affiliate activity both at the extensive margin (entry) and the intensive margin (sales). This enables us to assess the performance of individual elements of our model relatively accurately. We believe that this is very useful in order to make progress on these important questions.

The remainder of the paper is as follows. The following section 2 describes the model, characterizes its equilibrium and derives the key empirical predictions of the model. Section 3 derives four central hypotheses that will be tested, describes the data that we have assembled to do so, and presents the empirical results. We conclude with section 4.

2   Theory

2.1   A Model of Costly Technology Transfer with Multinationals

Consider a world with three countries, E, W, and S that are each endowed with L units of labor. Countries E and W are identical Northern countries and S is the South. Preferences in the Northern countries are given by

$$U = \sum_i^I \frac{\chi_i}{\alpha} \ln \left[\int_{\omega \in \Omega^i} x_i(\omega)^\alpha d\omega \right] + \left(1 - \sum_i \chi_i \right) \ln Y, \tag{1}$$

where Y is a homogenous, freely-traded good, χ_i is the expenditure share of the differentiated final good i, $x_i(\omega)$ is the volume of variety ω of good i consumed, and Ω^i is the set of available

varieties of good i. The parameter $\alpha = 1 - 1/\sigma$, where $\sigma > 1$, is the elasticity of substitution across varieties. For simplicity, we assume that the South consumes only good Y.

All goods are produced using exclusively labor. Good Y is produced in every country by perfectly competitive firms. Cross-country variation in the efficiency of Y production induces differences in wages across countries. The wage in the North w_N exceeds the wage in the South w_S. In each Northern country, there is a continuum of potential entrants. Each potential entrant is endowed with the property rights over a unique variety associated with a particular good i.

Any variety of the differentiated good X is costlessly assembled in the country in which it is consumed from a continuum of variety-specific intermediates, which are indexed by their technical complexity, z. Industries differ in the mixture of intermediates that are used in their production. Specifically, in the industry producing good i the production function is Cobb-Douglas:

$$x_i(\omega) = \Psi_i \exp\left(\int_0^\infty \beta_i(z) \ln m(\omega, z) dz\right),\tag{2}$$

where $x_i(\omega)$ is the volume of output of variety ω, $\Psi_i = \exp\left(-\int_0^\infty \beta_i(z) \ln \beta_i(z) dz\right)$ is an industry-specific constant, $m(\omega, z)$ is the volume of intermediate input z that is specific to variety ω, and $\beta_i(z)$ is the cost share schedule for intermediate z in industry i. We assume that the cost share function in industry i is given by

$$\beta_i(z) = \phi_i \exp(-\phi_i z).\tag{3}$$

According to the formulation in (3), the average technical complexity for industry i is equal

to $1/\phi_i$: industries with lower values of ϕ_i are more technologically complex.

Firms differ in their technological capability (or productivity), φ. In order to produce its variety, a Northern firm must first incur an industry-specific fixed cost Φ_i. Upon entry, a firm draws its type φ from a known distribution G. The country in which the firm enters will henceforth be called the firm's home country, any productive facility in that country will be called the parent, and any other productive facility owned by that firm in another country will be called an affiliate.

A firm's productivity in producing intermediate inputs depends on its productivity and on the country in which the intermediate is being produced. If a firm produces a given intermediate z in its home country, then its labor productivity is given by its type φ: one unit of labor can produce φ units of any intermediate. If the firm produces an intermediate input z in any country other than its home country then its productivity at that location is reduced because of the existence of costs to international technology transfer. The size of this labor productivity loss depends on the technological complexity of the intermediate input z and on country characteristics. Such technology transfer costs due on international communication problems are stressed by Arrow (1969), who argued that there can be large efficiency losses when communication between teachers (here the multinationals' parents) and students (here the multinationals' affiliates) fails.[9]

To produce one unit of an intermediate input, suppose that a number of tasks, given by z, must be successfully completed. In the application of each task, problems arise that will,

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[9]Technological information is difficult to communicate because it is often not fully codified; Feldman and Lichtenberg (1998) demonstrate empirically that codifiability is associated with better transfer of information, and Teece (1977) shows that transfer costs account for a substantial portion of all costs of shifting production from multinational parent to affiliate.

if unsolved, result in the destruction of that unit. A plant's management must communicate 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. If the solution to any problem fails to be communicated, then the input that is produced is useless. When the plant and the headquarters are in the same country, we assume that there is no difficulty in communication, but when headquarters and the plant are in different countries, the probability of successful communication is $\widetilde{\lambda} \in (0,1)$. Assuming that the success rate of communication is independent across tasks, the probability of successful communication is $(\widetilde{\lambda})^z$. If a units of labor were committed to the production of one unit of an intermediate input, then $a(\widetilde{\lambda})^z$ is the "effective" labor input. A decrease in the communicability of technology thus results in a decrease in productivity for intermediate z equal to the inverse of $(\widetilde{\lambda})^z$:

$$
\begin{aligned}
1/(\widetilde{\lambda})^z &= \exp(-z \ln \widetilde{\lambda}) \\
&= \exp(\lambda z),
\end{aligned}
\tag{4}
$$

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, higher z are associated with higher technology transfer costs. We assume that labor in the North is better trained than Southern labor, and so the magnitude of technology transfer costs to the South are higher in the South than to the North: $\lambda_S > \lambda_N$. Hence, the effective productivity of a firm with home productivity level φ producing intermediate z is $\widetilde{\varphi}_j(\varphi, z)$ in a foreign country

$j \in \{N, S\}$ is

$$\widetilde{\varphi}_j(\varphi, z) = \varphi \exp(-\lambda_j z). \tag{5}$$

A firm that has learned its type must then decide in which countries to sell its variety. To sell its variety in a given country, the firm must incur fixed labor cost f to market and distribute its variety. There are no other fixed costs.

Final goods are assembled in the country in which they will be sold, but the source of any given intermediate input is chosen by the firm. Any given intermediate input could be produced in either of the Northern countries, or in the South, or in all three locations. This choice will depend on relative labor costs w_N/w_S, on the size of technology transfer costs λ_S and λ_N, and on transport costs. Any intermediate input or differentiated final good shipped between Northern countries incurs an iceberg-type transport cost $\tau_N > 1$. Any intermediate input or differentiated final good shipped from the South to the North incurs iceberg transport cost $\tau_S > 1$.

The timing of the model is as follows. First, firms incur entry costs. Second, firms choose which Northern market to set up an assembly plant and distribution networks to sell their products. Third, firms choose where to produce their intermediates. Finally, firms assemble their final product and sell output on the monopolistically competitive product market.

2.2   Equilbrium and Empirical Implications of the Model

We now develop the main empirical implications of our theory in a series of propositions. The equilibrium is described by, first, solving for the optimal intermediate input sourcing

decisions of firms conditional on their decision to sell their product in the home and foreign markets. Second, we examine how transport costs and technology transfer costs affect the international structure of multinationals' operations. It is shown that as transport costs between multinational parent and affiliate increase, the latter concentrate on intermediate imports from the parent that are technologically relatively complex. Moreover, this technological complexity also plays a key role in determining affiliate activity at both the extensive and intensive margins, as well as for the trade-off between imports from the parent versus local affiliate production. These central implications of our theory are examined empirically in section 4. The description of the model's equilibrium is completed in the appendix, which also derives additional predictions on the relative importance of North-North compared to North-South FDI as transport costs change.

Transport Costs and the Structure of Intra-Firm Trade We begin by deriving the optimal intermediate sourcing decisions of a firm of type φ whose parent is in one Northern country (e.g. E) and that owns an assembly affiliate in the other Northern country (e.g. W). First, consider the decision for the parent firm. Let the minimum cost of a parent firm of type φ of procuring intermediate z be $c^P(\varphi, z)$. For each intermediate input, the parent can either produce the intermediate itself or procure it from an affiliate in the South.[10] If the parent firm produces the intermediate z locally, it pays the northern wage w_N and its productivity is φ, so $c^P(\varphi, z) = w_N/\varphi$. If the intermediate is procured from an affiliate in the South, it pays the Southern wage w_S, incurs transport cost τ_S, and incurs technology costs transfer

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[10] This parent firm will never procure an intermediate from an affiliate in the other Northern country because doing so incurs transport and technology-transfer costs that it can avoid by producing locally.

costs that reduce its productivity to $\varphi \exp(-\lambda_S z)$. In this case, $c^P(\varphi, z) = w_S \tau_S \exp(\lambda_S z)/\varphi$.

The minimum cost of procuring intermediate z for assembly at the parent firm is thus

$$c^P(\varphi, z) = \frac{1}{\varphi} \min \{w_N, w_S \tau_S \exp(\lambda_S z)\}. \tag{6}$$

Assuming that $w_S \tau_S < w_N$, and noting that technology transfer costs are increasing in z, it follows that the least technologically complex intermediates are produced in the South while the most complex intermediates are produced by the parent. In particular, there exists a cutoff intermediate input

$$\widehat{z}_S^P = \frac{1}{\lambda_S} \ln \left(\frac{w_N}{w_S \tau_S} \right). \tag{7}$$

such that all intermediates $z < \widehat{z}_S^P$ are sourced from a Southern affiliate and all the remaining intermediates are produced in the home country by the parent.

Now consider the sourcing decision of the multinational's affiliate in the other Northern country. Let $c^A(\varphi, z)$ be the minimum cost to the affiliate of a firm of type φ to procure intermediate z. The firm has three options for procuring this intermediate. First, it can obtain the intermediate from its parent in which case the wage paid is w_N, the transport cost is τ_N, and the productivity is φ, so $c^A(\varphi, z) = w_N \tau_N/\varphi$. Second, the firm can obtain the intermediate from a Southern affiliate in which case the marginal cost of the Northern affiliate is the same as it would be for the parent: $c^A(\varphi, z) = w_S \tau_S \exp(\lambda_S z)/\varphi$. Finally, the affiliate can produce the intermediate input itself in which case it pays a wage of w_N, pays no transport costs, and produces with efficiency level $\varphi \exp(-\lambda_N z)$, so $c^A(\varphi, z) =$

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$w_N \exp(\lambda_N z)/\varphi$. The minimum cost of procuring intermediate z for assembly at a Northern affiliate is thus

$$c^A(\varphi, z) = \frac{1}{\varphi} \min \left\{ w_N \tau_N, w_S \tau_S \exp(\lambda_S z), w_N \exp(\lambda_N z) \right\}. \tag{8}$$

Given our assumption that foreign productivity is decreasing in z, it follows that the most technologically complex intermediates must be sourced from the parent. Our assumption that $w_S \tau_S < w_N$ implies that the least technologically complex intermediates will be sourced from a Southern affiliate. If λ_S is sufficiently large relative to λ_N, the intermediate inputs of a moderate technological complexity will be most cheaply produced locally. Assuming this is the case, intermediates $z < \widehat{z}_S^A$ will be sourced from a Southern affiliate, where

$$\widehat{z}_S^A = \frac{1}{\lambda_S - \lambda_N} \ln \left(\frac{w_N}{w_S \tau_S} \right). \tag{9}$$

Intermediates $z > \widehat{z}_N^A$, where

$$\widehat{z}_N^A = \frac{1}{\lambda_N} \ln \left(\tau_N \right), \tag{10}$$

are imported by the affiliate from its parent firm, and intermediates $z \in [\widehat{z}_S^A, \widehat{z}_N^A]$ are produced locally by the affiliate. We can now summarize two key results in the following propositions. First, comparing equations (7) and (9) establishes the first proposition.

Proposition 1 *Affiliates source a wider range of intermediate inputs from the South than their parents, i.e. $\widehat{z}_S^P < \widehat{z}_S^A$.*

This result on parent versus affiliate's import range from the South is the consequence

of costly technology transfer within the multinational enterprise. That increases the cost of producing each intermediate in a Northern affiliate relative to the cost of producing at the parent so that for the threshold intermediate $\widehat{z}_S^P$, the cost of production in the parent firm is the same as in the Southern affiliate but strictly higher for the affiliate in the other Northern country. Hence, the affiliate will strictly prefer to import that intermediate from a Southern affiliate rather than produce the intermediate itself.

Differentiating equation (10) establishes the second proposition.

Proposition 2 *An increase in the size of transport cost τ_N increases $\widehat{z}_N^A$ and so (i) reduces the range of intermediates imported from the parent and (ii) increases the average technical complexity of the intermediates it imports from the parent.*

According to this result, the commodity composition of affiliates' imports from their parent firms should become more concentrated in fewer categories that are more technologically complex as transport costs between affiliate and parent firm rise. The increase in transport costs from the parent means that the intermediate good with threshold technological complexity $\widehat{z}_N^A$ is now strictly cheaper obtained locally. As a consequence, the affiliate's imports from the parent will concentrate on intermediates that are more complex than the level $\widehat{z}_N^A$. In the limit as transport costs increase, parents export only the most technologically complex intermediate as headquarter service–all other inputs are locally produced by the affiliate.

The Structure of International Production   In this section, we show how technological complexity affects the trade-off between imports from the parent versus local affiliate production. Also, technology transfer costs that are increasing in complexity are shown to

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yield predictions for both the extensive and intensive margins of affiliate activity. We first calculate the cost share of intermediate inputs that foreign affiliates in Northern countries procure from their parent firms as a function of transport costs, and we show how this relationship can be used to infer cross-country and cross-industry variation in the marginal cost facing multinationals in serving foreign markets. We then derive the implications of this variation in marginal costs for affiliates' sales and the likelihood that a firm will open a foreign affiliate.

Let θ_i be the optimal share of imported intermediates in the total costs of a foreign affiliate of a firm in industry i. The Cobb-Douglas production technology combined with the observation that all intermediates with a technological complexity greater than $\widehat{z}_N^A$ are imported from the parent firm imply that this cost share is given by

$$\theta_i = \int_{\widehat{z}_N^A}^{\infty} \beta_i(z)dz, \tag{11}$$

where $\beta_i(z)$ is given by equation (3). Substituting out $\beta_i(z)$, integrating, substituting for $\widehat{z}_N^A$ using (10), and then taking logarithms of the resulting expression yields the following simple formula for this share of intermediates imported from the parent firm in total affiliate costs:

$$\ln \theta_i = -\frac{\phi_i}{\lambda_N} \ln \tau_N. \tag{12}$$

From this expression, the following important proposition is immediate:

Proposition 3 *The share of intermediates imported from the parent firm in total costs,*

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

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 hard to move offshore. In contrast, for non-complex intermediates it is easy to substitute local affiliate production for imports from the parent. This has important implications for the structure of marginal costs of affiliates across countries and across industries because industries featuring complex technologies will be more exposed to transport cost changes than less technologically complex industries.

To see this, we now calculate the marginal cost of an affiliate as a function of transport costs. Cost-minimization implies that the marginal cost of assembling the variety of a firm of type φ in industry i at the affiliate or parent (indicated by $k \in \{A, P\}$) is

$$C_i^k(\varphi) = \exp\left(\int_0^\infty \beta_i(z) \ln c^k(\varphi, z) dz\right). \tag{13}$$

To calculate the marginal cost facing the Northern affiliate of a firm of type φ in industry i, substitute for $c^A(\varphi, z)$ using (8) and the cutoffs (9) and (10), and then integrate by parts using (3). The resulting equation can be written

$$C_i^A(\varphi) = \frac{1}{\varphi} \exp(g^A(\lambda_S, \lambda_N, \tau_S, \tau_N, \phi_i)), \tag{14}$$

where

$$g^A(\lambda_S, \lambda_N, \tau_S, \tau_N, \phi_i) = \ln(w_S \tau_S) + \frac{\lambda_S}{\phi_i} - \frac{\lambda_S - \lambda_N}{\phi_i} \left(\frac{w_N}{w_S \tau_S}\right)^{-\frac{\phi_i}{\lambda_S - \lambda_N}} - \frac{\lambda_N}{\phi_i}(\tau_N)^{-\frac{\phi_i}{\lambda_N}}. \quad (15)$$

Here, $g^A(.)$ summarizes the effect of costly technology transfer, transport costs, and the factor cost differences on the marginal cost of serving the foreign market.

Now consider the effect on the marginal cost of the affiliate in industry i of an increase in τ_N, the size of transport costs between the parent and the affiliate. Differentiating equation (14) with respect to τ_N and rearranging, we obtain

$$\varepsilon_{\tau_N, i}^{C^A} \equiv \frac{\tau_N}{C_i^A} \frac{\partial C_i^A}{\partial \tau_N} = (\tau_N)^{-\frac{\phi_i}{\lambda_N}}. \quad (16)$$

The following lemma can be obtained by differentiating this equation.

Lemma 1 *The elasticity of the marginal cost of the affiliate with respect to τ_N $(\varepsilon_{\tau_N, i}^{C^A})$ is higher in technologically relatively complex (low ϕ) industries.*

It is useful to compare equation (16) which relates technology transfer costs λ_N, technological complexity ϕ_i, and transport costs τ_N, to the elasticity of marginal cost of the affiliate with respect to transport costs to the cost share of intermediates imported from the parent, given by equation (12). We observe that $\ln(\varepsilon_{\tau_N, i}^{C^A}) = \ln \theta_i$, so the logarithm of the cost share of imported intermediates is a sufficient statistic for the elasticity of marginal costs with respect to the size of transport costs between affiliate and parent. By estimating the relationship between technological complexity, transport costs, and $\ln \theta_i$, we can infer

the effect of these variables on affiliates' marginal costs.

We now derive the implications of Lemma 1 for other key variables: the structure of a firm's affiliate's sales conditional on opening a foreign affiliate in a given country and the likelihood that a given firm will open an affiliate in the first place. We begin our analysis of the structure of firms' international operations by deriving the optimal level of sales generated in each market conditional on entry.

The preferences given by (1) imply that the demand for the variety of a type φ firm in country $k \in \{E, W\}$ is

$$x_{ik}(\varphi) = \left(\frac{\chi_i L_k}{P^i} \right) \left(\frac{p_{ik}(\varphi)}{P^i} \right)^{-\sigma}, \tag{17}$$

where $p_{ik}(\varphi)$ is the price charged by the firm in industry i of type φ in country k, and P^i is the price index for good i in each of the Northern countries.

It is well known that a firm facing the iso-elastic demand curve (17) optimally charges a constant proportional mark-up over marginal costs ($1/\alpha > 1$). Substituting for the parent's marginal cost using (14), we find that the optimal revenue of generated by an affiliate of parent firm of type φ in industry i in a foreign market is

$$R_i^A(\varphi) = A_i C_i^A(\varphi)^{1-\sigma}, \tag{18}$$

where

$$A_i \equiv \chi_i \alpha^{\sigma-1} w_N L_N \left(P^i \right)^{\sigma-1}$$

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is the endogenous, mark-up adjusted demand level in a Northern country in industry i, and $C_i^A(\varphi)$ is given by equation (14). Totally differentiating (18) and holding fixed A_i, we find that the elasticity of affiliate sales can be written

$$\varepsilon_{\tau_N,i}^{R^A} \equiv \frac{\tau_N}{R_i^A(\varphi)} \frac{\partial R_i^A(\varphi)}{\partial \tau_N} = -(\sigma - 1)\varepsilon_{\tau_N,i}^{C^A}$$

This equation combined with Lemma 1 has the following implication.

Proposition 4 *Holding fixed the mark-up adjusted demand level, A_i, the value of affiliate revenues $R_i^A(\varphi)$ is decreasing in the transport costs τ_N, and the rate of this decrease is highest in technologically relatively complex (low ϕ) industries.*

This second observation follows from the fact that in technologically complex industries more of the global value added is in intermediates that are costly to offshore, and so marginal costs rise faster in transport costs.

Similarly, a firm will open an assembly affiliate in the other Northern country if gross profits are sufficient to cover fixed entry costs, or if

$$\pi_i^A(\varphi) \equiv \frac{R_i^A(\varphi)}{\sigma} - w_N f \geq 0. \tag{19}$$

Substituting (18) and (14) into this expression and rearranging yields the cutoff productivity level that a firm must have before it is profitable to serve the foreign market:

$$\widehat{\varphi}_i^A = \left(\frac{\sigma w_N f}{A_i}\right)^{\frac{1}{\sigma-1}} \exp(g^A(\lambda_S, \lambda_N, \tau_S, \tau_N, \phi_i)) \tag{20}$$

Differentiating equation (20) with respect to τ_N and using Lemma 1, we can establish the following important result.

Proposition 5 *Holding fixed a foreign country's mark-up adjusted demand level A_i, the probability that any given firm invests in that country is decreasing in transport costs between parent and affiliate (τ_N). Everything else equal, this rate of decrease is higher in technologically relatively complex (low ϕ) industries.*

This result is closely linked to our earlier results. An affiliate's marginal cost is higher when the transport cost between parent and affiliate is greater, and the rate at which marginal cost increases is faster in more complex industries (see Proposition 3). Therefore, holding all other country variables fixed, the threshold $\widehat{\varphi}_i^A$ rises faster in technologically complex industries and the likelihood that any given firms productivity exceeds this threshold is decreasing.

We now turn to testing these predictions.

3 Empirical Analysis

The model offers a rich set of predictions over the structure of intra-firm trade and the location and volume of multinational activity that will be examined in this section. We begin by summarizing the predictions for the case where transport costs between multinational parent and affiliate (τ_N) increase, relative to transport costs to the South and the costs of technology transfer. An increase in τ_N reduces the share of imports in total affiliate costs relatively less in technologically complex industries (Hypothesis 1). An increase in

Northern transport costs lowers affiliate sales particularly strongly in technologically complex industries (Hypothesis 2). And an increase in τ_N reduces the probability that a firm invests particularly strongly in technologically complex industries (Hypothesis 3). We will refer to these as, respectively, the hypotheses on the mix of imports versus local production, on the intensive margin, and on the extensive margin of multinational activity.[11]

Note that if intermediates are technologically complex, this *moderates* the substitution from imports to local production while at the same time it *exacerbates* the response of affiliate activity to an increase in transport costs both at the intensive and the extensive margin. The data most suitable to testing this powerful distinction is the confidential firm-level information from the BEA on the structure of U.S. multinationals' global operations. This is because one can directly observe the total cost share of intermediates imported by the affiliates from their parent firms and the location and host country sales of these affiliates. Below we derive the corresponding estimation equations, provide additional information on the BEA dataset, and conduct this empirical analysis.

Another prediction of our theory to be tested is that as τ_N increases, multinational affiliates concentrate on intermediate imports from their parents that are technologically more complex (Hypothesis 4).[12] The changing nature of U.S. intra-firm trade is captured best by U.S. Census information on related-party trade which varies by country and six-digit industry classification.[13] Below we show how the related-party trade data can be used together with information on the importance of complex problem solving skills from the U.S.

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[11] These three hypotheses are based on Proposition 3, Proposition 4, and Proposition 5, respectively.

[12] See Proposition 2 above.

[13] There is no firm-level data on the technological complexity of intra-firm trade that we are aware of.

Department of Labor's *Occupational Information Network* to shed light on how U.S. exports vary across destination countries in their technological complexity.

The following two sections describe how Hypothesis 1 to 4 are tested with these data.

The Structure of U.S. Multinationals' Global Operations   The BEA data allows us to observe many features of the international operations of U.S. multinational firms. Chief among these features are the cost share of intermediate inputs obtained by the affiliates of U.S. multinationals, the sales of these affiliates in their host countries, and the location decisions of these affiliates. Consider first the share of intermediate inputs imported by an affiliate from its parent firm j in an affiliate's total cost. In the model, this variable is the firm-level analog to equation (12), or

$$\ln \theta_i(\widehat{z}_N^A) = -\frac{\phi_i}{\lambda_N} \ln \tau_N.$$

Hypothesis 1 says that while generally the import cost share is declining in τ_N, this is less so the case when intermediates are technologically complex (low ϕ_i). In terms of observables, let M_{jk} be the value of goods imported by an affiliate of firm j located in country k from its parent firm, and let TC_{jk} be the total costs of that same affiliate. Further, let FC_k be the size of transport costs between the parent firm (in our data located in the United States) and the affiliate in country k. The analog to $\theta_i(\widehat{z}_N^A)$ in the data is then

$$\ln \frac{M_{jk}}{TC_{jk}} = -\frac{\phi_j}{\lambda_N} \ln FC_k.$$

The transfer cost (λ_N) and technological complexity (ϕ_j) parameters are not observed. We address this by, first, assuming that technology transfer costs are the same across countries in which firms sell their good to final customers. Second, we parametrize the technological complexity of firm j by the parent's R&D intensity (R&D expenditures over sales). To the extent that technology transfer costs are problem solving communication costs, as in equation (4), it is reasonable to assume that they are higher, the higher is the firm's R&D intensity. Thus we assume that the technological complexity of firm j is

$$\phi_j = \delta_0 + \delta_1 RD_j,$$

where RD_j is the R&D intensity of firm j in industry i, and δ_0 and δ_1 are parameters. Now, allowing for (unmodelled) observed country characteristics that influence the ability of a country to absorb technology X_k, firm fixed effects γ_j, and idiosyncratic unobserved firm-country characteristics ε_{jk}, we obtain the following estimating equation:

$$\ln \frac{M_{jk}}{TC_{jk}} = \gamma_j + \kappa \ln X_k + \left(\frac{\delta_0}{\lambda_N} + \frac{\delta_1}{\lambda_N} RD_j \right) \ln FC_k + \varepsilon_{jk} \tag{21}$$

where κ is a vector of unknown coefficients. We assume that ε_{jk} is well-behaved in the sense that it is uncorrelated with observed country characteristics so that we may estimate equation (21) via ordinary least squares. Hypothesis 1 is that the coefficient $\frac{\delta_0}{\lambda_N} < 0$ and that the coefficient estimate $\frac{\delta_1}{\lambda_N} > 0$. As transport costs increase, firms substitute local production for imports of intermediates from the parent, but this substitution is more costly in technologically relatively complex industries with hard to transfer technologies.

Now consider the intensive margin of affiliate activity. The relationship between the revenue generated by an affiliate from sales in its host country and the magnitude of transport costs between the parent and the affiliate is given by equation (18). Taking the logarithm of equation (18), we have

$$\ln R^A(\varphi) = \ln A_i + (\sigma - 1)\ln(\varphi) - (\sigma - 1)g^A(\lambda_S, \lambda_N, \tau_S, \tau_N, \phi_i),$$

where $g^A(.)$ is given by equation (15). Holding fixed the mark-up adjusted demand level A_i, the size of an affiliate's revenue should be increasing in the firm's productivity φ and decreasing in the size of transport costs between the affiliate and its parent firm. As shown above, the size of the effect of transport costs should be larger (decreasing faster) in technologically relatively complex industries because technology is more difficult to transfer in those industries. We consider the following linearized version of this equation that relates the sales revenue of the affiliate of firm j in country k, R_{jk}, to transport costs FC_k and other country characteristics:

$$\ln R_{jk} = \eta_j + \rho \ln X_k + (\varsigma_0 + \varsigma_1 RD_j)\ln FC_k + \upsilon_{jk}, \tag{22}$$

where η_j is a firm-fixed effect that absorbs firm j's productivity, X_k is the same vector of controls as in equation (21) and ρ is the corresponding coefficient, υ_{jk} is a well-behaved error term. Our Hypothesis 2 is that $\varsigma_0 < 0$ and $\varsigma_1 < 0$: affiliate sales in technologically relatively complex sectors (high RD_j) are more sensitive to variation in transport costs FC_k. The difference in the predicted sign on the interaction between RD_j and FC_k in equations (21)

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and (22) has strong empirical bite.

Finally, on the extensive margin of affiliate activity, Hypothesis 3 states that the probability of individual firms to enter individual foreign markets should be decreasing in the size of transport costs between the parent firm and the prospective host country and that the size of this decrease should be more pronounced in technologically relatively complex industries. This relationship is driven by the foreign entry condition that a firm should enter if

$$\frac{R^A(\varphi)}{\sigma} - w_N f \geq 0.$$

Letting Y_{jk} equal one if firm j owns an affiliate in country k and zero otherwise, we assume that a firm will invest if the latent variable $Y_{jk}^* > 0$, with

$$Y_{jk}^* = \ln R_{jk} + \chi_{jk}, \tag{23}$$

where χ_{jk} is a random error term associated with the fixed cost of investment facing firm j when investing in country k (if fixed costs are the same across countries than they will be absorbed into the fixed effects). Because the same country characteristics that make the optimal volume of sales larger in a given country also increase the probability to enter the market in the first place, everything else equal, the independent variables for the entry estimation equation (23) are the same as in the revenue equation (22).

The data for testing Hypotheses 1, 2, and 3 come from the BEA which collects confidential enterprise-level data on U.S. foreign direct investment.[14] Our data is extracted from the

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[14]The BEA conducts annual surveys of U.S. Direct Investment Abroad where U.S. direct investment is

1994 Benchmark Survey results for U.S. affiliates abroad that are majority-owned by U.S. manufacturing parent firms. We calculate the technical complexity of each firm j, RD_j, as the ratio of the parent firm's R&D spending to the parent firm's total sales. Each affiliate in each country k is linked to a unique parent firm, allowing us to construct the variable $ENTRY_{jk}$, which is equal to one if parent firm j owns an affiliate in country k and is zero otherwise; this is the dependent variable for estimation equation (23). The local sales variable R_{jk} in estimation equation (22) is constructed by aggregating the sales to local customers of all the affiliates in country k owned by firm j. The cost share of intermediate inputs imported from the parent of firm j by its affiliates in country k, M_{jk}/TC_{jk} (see equation 21), is constructed by dividing total imports of all affiliates from their parent by the total cost of goods sold.[15]

The Scope and Technological Complexity of Exports by U.S. Parents to their Affiliates Hypothesis 4 posits that affiliates' imports from their parent firms should become more concentrated in technologically complex intermediates as trade cost increase. This

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defined as the direct or indirect ownership or control by a single U.S. legal entity of at least 10 percent of the voting securities of an incorporated foreign business enterprise or an equivalent interest in an unicorporated business enterprise. A U.S. multinational entity (MNE) 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. The International Investment and Trade in Services Survey Act requires that firms file detailed financial and operating items for the parent firm and each affiliate.

[15] For robustness, we also constructed several alternative measures using different measures of intermediate imports. One concern is that FDI is sometimes associated with wholesale distribution activities, as opposed to production and assembly. To ensure that imports are actually intermediates, we used a variable defined as intended "for further manufacture." Results obtained using this narrower measure are very similar to our primary measure and are reported in Table A1 of the Appendix.

hypothesis follows from equation (10):

$$\widehat{z}_N^A = \frac{1}{\lambda_N} \ln \tau_N,$$

which gives a positive relationship between the technical complexity of the cutoff interme-diate ($\widehat{z}_N^A$) and the size of shipping costs (τ_N). An increase in $\widehat{z}_N^A$ implies that the set of intermediate inputs that are imported decreases and that the average technical complexity of the intermediate inputs in that set increases. Note that this hypothesis does not involve any cross-industry or cross-firm variation, only variation across countries.

To test Hypothesis 4, we define two country-level variables: $SCOPE_k$, which is the number of products exported from U.S. parents to their foreign affiliates in country k, and $TCPX_k$, which is the average technical complexity of exports from U.S. parents to their for-eign affiliates in country k. We then regress each of these variables on the size of transport costs to country k, FC_k. According to Hypothesis 4, the coefficient on FC_k should be *nega-tive* when $SCOPE_k$ is the dependent variable and *positive* when $TCPX_k$ is the dependent variable. To control for countries' ability to absorb technology, we include the set of country controls X_k in each of these regressions.

Our measures of the scope and technological complexity of U.S. intra-firm exports are constructed from data from the U.S. Census Bureau and the U.S. Department of Labor.[16] The Census Bureau reports 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. This

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[16]The related-party export data were downloaded from the following Census Bureau website: http://sasweb.ssd.census.gov/relatedparty/.

dataset contains all related party exports by six-digit NAICS industrial classification for all the 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, in the aggregate at least, most of these exports are from U.S. parents to their foreign affiliates.[17] 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 k. We measure the scope of U.S. related party trade across country as follows

$$SCOPE_k = \frac{1}{500} \sum_{i=1}^{500} \{1|Ex_{ik} > 0\}, \tag{24}$$

where $\{1|Ex_{ik} > 0\}$ is an indicator function equal to one if exports of commodity i to country k is positive. We measure the average technical complexity of U.S. related party exports to country k as follows

$$TCPX_k = \frac{1}{SCOPE_k} \sum_{i=1}^{500} TCP_i \cdot \{1|Ex_{ik} > 0\}, \tag{25}$$

where TCP_i is the complexity of the technology for commodity i. For robustness, we consider two alternative measures of TCP_i. The first is based on the average complexity of occupations used in the manufacture of these commodities. The second is the skill intensity of each commodity.

The occupations data is less familiar, so we provide more details on it (our construction

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[17]The BEA data report that in 1997, the aggregate shipments of U.S. parents to their foreign majority owned affiliates was $193 billion while the aggregate shipments of U.S. affiliates to their foreign parents was only $28 billion.

broadly follows Costinot et al. 2008). From the U.S. Department of Labor's Occupational Information Network (O^*NET) we obtained an index of the importance of complex problem solving skills for each of 809 occupations as defined in the Standard Occupational Classification (SOC) system. Importance is measured on a scale of 0 to 100, and "complex problem solving skills" is described as the need to "identify complex problems and reviewing related information to develop and evaluate options and implement solutions." To faciliate matching these occupational measures to industrial data, we first aggregated occupational complexity data to 22 two-digit occupations, using the share of each 6-digit occupation category and nationwide employment weights. The resulting measures of occupational complexity were then merged with data from the Bureau of Labor Statistics' *Occupational Employment Statistics* for 2006, which provides employment information on each occupation by 4-digit NAICS industry categories. Using occupational employment shares by industry, we calculated TCP_i in each of 86 4-digit NAICs manufacturing industries.[18] For the skill-intensity based measure of TCP_i, we compute each commodity's skill intensity as the ratio of non-production workers to production workers in each 6-digit NAICS industry from employment data reported in the 2002 Census of Manufacturing.[19]

Finally, for each country we obtain measures of the size of transport costs FC_k between the U.S. and country k and a set of country variables X_k to control for unobserved variation in factor costs, market size, and other factors. We follow Brainard (1997) in constructing

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[18]Our concordance is not perfect because technical complexity is measured at the four digit level while the trade data is at the 6-digit data. To avoid losing important variation in the extensive margin of trade, we apply each measure of commodity technical complexity to several 6-digit commodities.

[19]We also experimented with trade share based weights rather than simple averages. While the coefficients on some of the controls were different, the coefficient on FC_k was very similar.

an ad-valorem measure of transport costs derived from U.S. import data. Our measure FC_k is the ad-valorem measure of c.i.f imports divided by f.o.b. imports into the United States by country and by industry. To create a single measure of country-level transport costs, we demeaned the data by industry and kept only country-specific averages obtained from this demeaned data.[20]

To control for variation across countries in the mark-up adjusted demand level and for a country's ability to absorb foreign technology, we include in many specifications the logarithm of a country's GDP per capita, $GDPPC$, and the logarithm of its population, POP. Both measures are for the year 1994 and were taken from the Penn World Tables. Because intra-firm trade can be used to shift profits in response to variation in country taxes rates, we also include the logarithm of each country's maximum corporate tax rate, TAX, which was taken from the University of Michigan database. The means and standard deviations of each dependent and independent variable for each dataset are shown in the Table 1. The descriptive statistics for the firm-level multinational dataset is reported in the upper portion of Table 1. It contains information on the activities of over 5,400 affiliates of 1,055 parent firms located in 40 countries. The lower part of Table 1 shows summary statistics for the scope and technological complexity of U.S. related party trade and the other country-level variables.

The next section presents our empirical results.

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[20] Anderson and Van Wincoop (2004) discuss the measurement of trade costs in great detail. They suggest a number of imperfect measures of trade costs and the issues associated with aggregation. In future work, we plan to explore the importance of additional measures of trade costs, including measures that incorporate trade policy related barriers such as tariffs and non-tariff barriers.

Empirical Results We first examine the trade-off between imports and local production as transport costs change (Hypothesis 1). The results for estimating equation (21) using the firm-level BEA data are reported in columns (1) and (2) of Table 2. In column (1) coefficient estimates are reported which correspond to the specification that excludes country controls, while they are included in column (2). All regressions include firm-level fixed effects, and the standard errors, reported in parentheses, are robust to heteroskedasticity. We see that as predicted by the model, the coefficients on transport cost, FC, in both columns (1) and (2) are negative and statistically significant, while the coefficients on the interaction between R&D intensity and transport cost, $RD * FC$, in both columns are positive and statistically significant. The cost share of intermediates imported from the parent firm is declining in the size of transport costs, but the rate of this decline is slower for firms that trade in technologically relatively complex intermediates. The coefficients on the control variables in column (2) indicate that other country characteristics influence the cost share of intermediates imported from their parent firm. The negative coefficient on $GDPPC$ indicates that affiliates in less developed countries rely more on imported inputs than affiliates in developed countries. This result suggests that affiliates in developing countries face more serious technology transfer costs than in developed countries.

These results are robust to a number of specification changes. First, instead of exploiting only variation within a given multinational firm, implied by the inclusion of firm fixed effects, we have repeated the analysis by exploiting within-industry variation. Table A1 in the appendix shows that this leads to similar results (columns (1) and (2)). Second, we employ a narrower definition of affiliates' imported intermediates, imports of goods intended for

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further manufacture. This will exclude wholesale distributors from our sample, for which our model arguably applies to a lesser extent. Using this imports measure generates almost identical results (see columns (3) and (4) of Table A1). In addition, we have experimented with using data on affiliate imports from the multinational parent *and* all other U.S. entities to see whether outsourcing of intermediate production is a serious concern for our inferences. However, the results using this import data were virtually identical to those obtained using our preferred measure. To sum up, we find strong evidence for Hypothesis 1: technological complexity affects the trade-off between affiliate imports and local affiliate production in the way the model predicts.

Next we provide evidence on the influence of costly technology transfer on the intensive margin of affiliate operations (Hypothesis 2). Results for the estimating equation (22) are shown in columns (3) and (4) of Table 2. In both columns, the coefficients on FC are negative and statistically significant, and the coefficients on $RD * FC$ are also negative and statistically significant. This confirms our Hypothesis 2: we find that, holding fixed the firm, affiliates in countries where transport costs are high are smaller and hence they sell less, and this effect is more pronounced for firms with relatively complex technologies. These effects are robust to controlling GDP per capita and country size as shown in column (4). The results suggest that after controlling for a country's level of development and size, the marginal cost of production is rising in transport costs, and that holds particularly for firms' that sell technologically relatively complex products. Moreover, these results are confirmed in specifications employing industry- instead of firm fixed effects (see columns (5) and (6) in Table A1).

The analysis so far confirms two central implications of our model of costly technology transfer. On the one hand, because costly transfer raises affiliates' marginal costs, they reduce sales particularly strongly when they have most bite–which is for technologically complex products. On the other hand, the impact of an increase in transport costs between parent and affiliate is not as large for technologically complex products as it is for less complex products. This is because for an affiliate to reduce its reliance on imported intermediates from its parent, it would have to be able to produce them locally, and that is relatively costly when products are technologically complex. Our results provide strong evidence on both channels through which costly technology transfer within the multinational firm affects its operations.

We now turn to Hypothesis 3, which concerns the extensive margin of affiliate activity: high transport costs and complex technology reduce, everything else equal, the probability that a firm will establish a multinational affiliate in a foreign country (see equation 23). The fifth and sixth columns of Table 2 report the coefficient estimates for a linear probability model of multinational affiliate entry. The coefficients on FC are negative and statistically significant, and the coefficients on $RD * FC$ are also negative and statistically significant. These results confirm Hypothesis 3 and support the idea that while affiliates' marginal costs generally are increasing in transport cost, this rate of increase is particularly fast for firms with complex technologies.

These results indicate that multinationals' marginal costs are rising in the transport cost to their host country and that the rate of increase is fastest for firms using complex technologies. There is also evidence that the technological complexity of some products explains

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why some firms can substitute local production for intermediates imported from their parent better than other firms. We can bring to bear additional evidence on this by analyzing direct measures of the scope and the technological complexity of U.S. multinational parent exports to their affiliates. According to Hypothesis 4, the scope of multinational affiliate imports from their parents falls as the transport costs between parent and affiliate rise, because it becomes optimal to locally produce a larger set of intermediates. In addition, this also raises the average technological complexity of affiliate imports, because the newly locally produced intermediates are less technologically complex compared to those that continue to be imported from the parent.

In Table 3, we present results from employing our $SCOPE$ and technological complexity (TCP) variables that support this hypothesis. Columns (1) and (2) of Table 3 report the scope regression results. Columns (3) and (4) report the coefficient estimates for the technological complexity of export regressions where technological complexity is measured from occupational data. Columns (5) and (6) report the coefficient estimates for the technical complexity of export regressions where technical complexity is measured using skill intensity. Standard errors robust for heteroskedasticity are reported in parentheses. For each set of results, we report regressions with and without country controls.

The statistically significant coefficients on FC in columns (1) and (2) indicate that affiliates in countries with high transport costs import a narrower range of intermediates from their parents. The coefficient estimate is not sensitive to controlling for a country's GDP per capita, the size of its population, or the corporate tax rate. We next turn our attention to how the technological complexity of U.S. related party trade varies with the

size of transport costs. Consider columns (3) and (4), which correspond to specifications in which complexity is measured using the occupational composition of commodities. In both columns, the coefficient on FC is positive and statistically significant indicating that as the range of commodities imported by affiliates becomes narrower, the composition of this trade is systematically shifting toward more technologically complex commodities. This conclusion is reinforced by the results reported in columns (5) and (6), where complexity is measured using the ratio of non-production to production workers. As transport costs increase, the average skill intensity of U.S. related party trade is increasing. These results strikingly support the mechanism present in our model: because technology transfer costs make technologically complex intermediates hard to offshore, intra-firm trade in these intermediates is less sensitive to increases in transport costs than intra-firm trade in less complex intermediates.[21]

Overall, the empirical analysis provides strong evidence in favor of the model. When analyzing central hypotheses of our theory of costly technology transfer within multinationals, we obtain precisely estimated parameter estimates in line with the model using data both on individual multinational firms as well as disaggregated information on the trade between multinational parents and their affiliates.

We conclude with the following section.

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[21]Additional results corresponding to specifications in which the dependent variable is in logarithms are reported in the appendix, Table A2; they confirm the results of Table 3.

4 Conclusions

Economists increasingly recognize that multinational firms are the cornerstone of international trade and technology diffusion. These firms intermediate much of trade flows between developed countries and are widely believed to be important conduits for knowledge flows between nations. It should be of great concern to economists, therefore, that the geographical reach of most multinationals is actually quite modest, particularly given that the traditional treatment of the multinational firm is built on the premise that firms can perfectly replicate their technologies abroad and so geography should play little role in the structure of multinational activities.

In this paper, we introduce a model of multinationals that demonstrates that explains a rich array of multinational behavior by the interaction between physical transport costs and technology transfer costs. As in much of the recent international literature, our model considers physical transport costs and the ability of firms to fragment their production technology into tradeable components. One key assumption is added: there also exist technology transfer costs that are increasing in the complexity of components in the production process. We show that the role of technology transfer costs manifests itself in the interaction between transport costs across countries and the technological complexity of firms' production technologies: as transport costs increase, firms have an incentive to replicate increasingly complex (and therefore hard to transfer) activities abroad. This gives rise to increasing marginal costs of serving foreign markets as the size of transport costs increase. This is our explanation of why multinational firms tend to be much more successful in their home

market compared to foreign markets.

This simple mechanism gives rise to a set of important hypotheses that we can test. First, the cost of intermediates imported from the parent in total affiliate costs should be decreasing in transport costs between multinational parent and affiliate, and the rate of decrease should be slower for firms with relatively complex production technologies. Importantly, we show that variation in this ratio is a sufficient statistic for variation in the marginal cost of production facing foreign affiliates abroad. Second, because the rate of increase in marginal costs is increasing in the complexity of a firm's production technology, the size of affiliate sales such be decreasing in the size of transport costs but at a faster rate for firms using relatively complex production technologies. Third, the probability that a given multinational opens an affiliate in a given foreign location should be decreasing in transport costs and the rate of decrease should be faster for firms using technically complex production technologies. The fourth hypothesis is over the commodity composition of affiliate exports: as transport costs increase, affiliates should concentrate their purchases of intermediates from their parent in intermediates that are technologically more complex.

To evaluate these hypotheses empirically, we show that the model's central predictions can be tested using rather simple estimating equations. Moreover, we employ information on the activity of individual U.S. multinational firms from the BEA, highly disaggregated Census data on U.S. intra-firm trade, as well as Department of Labor data on the problem solving skills required for different occupations, among other data, to give the theory a certain empirical content. The resulting data base is richer than what is typically employed in empirical analyses of the structure of trade and multinational production, and arguably

it is the best data that exists to address questions in this area.

The empirical analysis provides strong evidence in favor of the model. For all four hypotheses we obtain precisely estimated parameter estimates that confirm the predictions of the model. We find that when technologies are relatively complex, affiliates have less opportunity to substitute for imports from their parent with local production. Moreover, both the extensive and intensive margins of affiliate activity contract as transport costs rise, and this is most strongly the case for firms with relatively complex production technologies. The range of imported inputs of affiliates also becomes more concentrated in technologically complex intermediates as transport costs increase.

There are a number of directions that we intend to work on in the future. First, the empirical analysis in this paper has been based primarily on outward FDI, here the activity of U.S.-owned affiliates in foreign countries. At the same time, the interplay of transport costs, technology transfer costs, and factor price differences can lead to important differences in the activities of multinational parents compared to affiliates, as we show with Proposition 1 above. These effects can be investigated by comparing the activities of U.S. multinational parents and foreign-owned affiliates that are located in the United States. Second, we will study the economic importance of technology transfer costs in an aggregative model that builds on the framework developed here.

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Table 1: Descriptive Statistics

BEA FDI Sample		
Variable	Mean	Std. Dev.
MC	-2.71	1.93
LR	10.4	1.30
FC	0.058	0.018
RD	0.051	0.058
RD*FC	0.0023	0.0028
GDPPC	9.69	0.51
POP	10.4	1.08
TAX	3.45	0.207

Census Trade Sample		
	Mean	Std. Dev.
Scope	0.56	0.15
Complexity	49.2	0.47
Skill Intensity	0.54	0.035
FC	0.065	0.018
GDPPC	9.42	0.76
POP	16.1	1.42
TAX	3.41	0.24

All variables except RD, Scope, Complexity, and Skill Intensity are in natural logarithms.

Table 2: Transport Costs and the Structure of Affiliate Operations of U.S. Multinational Firms

	Hypothesis 1: Imports vs. local production		Hypothesis 2: Intensive margin of affiliate operations		Hypothesis 3: Extensive margin of affiliate operations	
	Dependent variable: Import Cost Share		Dependent variable: Local Sales		Dependent variable: Local Affiliate	
	(1)	(2)	(3)	(4)	(5)	(6)
FC	-19.6	-30.3	-19.6	-8.06	-2.48	-0.969
	(2.41)	(2.34)	(1.29)	(1.17)	(0.041)	(0.060)
RD*FC	111	79.5	-61.0	-37.3	-3.00	-3.00
	(29.9)	(24.4)	(16.9)	(13.1)	(0.485)	(0.472)
GDPPC		-0.798		0.903		0.062
		(0.065)		(0.034)		(0.002)
POP		-0.197		0.495		0.027
		(0.028)		(0.015)		(0.001)
TAX		-0.301		-0.172		0.035
		(0.124)		(0.064)		(0.030)
N	4,001	4,001	5,394	5,394	112,860	112,860
R-squared	0.024	0.065	0.128	0.344	0.054	0.075

All variables in all specifications are demeaned by firm. The variables FC, GDP, POP, and TAX are in logarithms and RD is in levels. Robust standard errors are in parentheses below the corresponding coefficient estimates. In columns (1) and (2), the dependent variable is the logarithm of the ratio of the value of affiliate imports from their parent firms to cost of goods sold. In columns (3) and (4), the dependent variable is the logarithm of total affiliate sales to local customers. In columns (5) and (6), the dependent variable that is equal to one if the firm owns an affiliate and equal to zero otherwise.

Table 3: The Scope and Technological Complexity of U.S. Intra-firm Exports

	Hypothesis 4: Scope and complexity of multinational parent exports					
	Scope		Average Technological Complexity			
	Dependent variable: Scope		Dependent variable: Occupation-based Complexity		Dependent variable: Skill-intensity based Complexity	
	(1)	(2)	(3)	(4)	(5)	(6)
FC	-3.86	-3.65	9.51	11.08	0.73	0.75
	(1.03)	(1.38)	(3.14)	(4.00)	(0.20)	(0.26)
GDPPC		0.03		-0.01		-0.01
		(0.03)		(0.11)		(0.01)
POP		0.05		-0.13		-0.01
		(0.01)		(0.05)		(0.003)
TAX		-0.07		0.48		0.04
		(0.06)		(0.18)		(0.02)
N	39	39	39	39	39	39
R-sq.	0.227	0.405	0.153	0.323	0.147	0.359

Notes: All standard errors (shown in parentheses) are robust to heteroskedasticity. Scope is defined as the share of NAICS 6-digit product categories exported in the total number of possible categories. Average Complexity is the occupation based measure of the average technical complexity of exports. Average Skill Intensity is the average ratio of nonproduction workers to production workers of the product categories exported; details can be found in the text.

Appendix: Additional Equilibrium Conditions and Results

Here we provide additional results concerning parent firms, close the model, and provide a fundamental comparative static result. We begin by deriving the marginal cost of the parent firm, the sales revenue and profit directly generated by the parent firm.

Consider first the marginal cost of the parent. Substituting for $c^P(\varphi, z)$ using (6), the cutoff (7), and integrating by parts using (3), the parent's marginal cost can be written

$$C_i^P(\varphi) = \frac{1}{\varphi} \exp(g^P(\lambda_S, \tau_S, \phi_i)), \tag{26}$$

where

$$g^P(\lambda_S, \tau_S, \phi_i) = \ln(w_S \tau_S) + \frac{\lambda_S}{\phi_i} \left[1 - \left(\frac{w_N}{w_S \tau_S} \right)^{-\frac{\phi_i}{\lambda_S}} \right] \tag{27}$$

summarizes the effects of technology transfer costs and physical shipping costs on parent marginal cost. Because the parent firm does not directly face technology transfer costs or shipping costs it follows that $C_i^A(\varphi) > C_i^P(\varphi)$. Differentiating equations (26) and (14), we obtain the elasticities of the marginal costs of the parent firm and its foreign affiliate in industry i with respect to shipping costs between the north and the south:

$$\begin{aligned} \varepsilon_{\tau_S, i}^{C^P} &\equiv \frac{\tau_S}{C_i^P} \frac{\partial C_i^P}{\partial \tau_S} = 1 - \left(\frac{w_S \tau_S}{w_N} \right)^{\frac{\phi_i}{\lambda_S}}, \\ \varepsilon_{\tau_S, i}^{C^A} &\equiv \frac{\tau_S}{C_i^A} \frac{\partial C_i^A}{\partial \tau_S} = 1 - \left(\frac{w_S \tau_S}{w_N} \right)^{\frac{\phi_i}{\lambda_S - \lambda_N}}. \end{aligned} \tag{28}$$

An increase in τ_S is associated with an increase in the marginal cost of both parent and

affiliate. There are two additional implication of (28). First, we have $\varepsilon_{\tau_S,i}^{C^A} > \varepsilon_{\tau_S,i}^{C^P}$ because affiliates rely more heavily on imported intermediates than their parents. Second, the elasticity of marginal cost with respect to τ_S is higher in relatively low-tech industries (high ϕ) because lower-tech industries rely more heavily on intermediates imported from the South. We summarize this result in the following lemma:

Lemma 2: *The elasticity of marginal cost of the parent firm with respect to τ_S given by $\varepsilon_{\tau_S}^{C^P}$ is strictly less than the elasticity of the marginal cost of north affiliate with respect to τ_S, given by $\varepsilon_{\tau_S}^{C^A}$.*

Following the arguments in the text, it is straightforward to show that the revenue generated by the parent firm of type φ in industry i is given by

$$R_i^P(\varphi) = A_i C_i^P(\varphi)^{1-\sigma}.$$

Because the parent firm's marginal cost is less than that of its affiliate, the parent firm should have larger sales than the affiliate and the profits associated with these sales, which are given by

$$\pi_i^P(\varphi) \equiv \frac{A_i C_i^P(\varphi)^{1-\sigma}}{\sigma} - w_N f \geq 0, \tag{29}$$

should be greater. Substituting (26) into this expression and rearranging yields the cutoff productivity level that a firm must have before it is profitable to serve its home market:

$$\widehat{\varphi}_i^P = \left(\frac{\sigma w_N f}{A_i}\right)^{\frac{1}{\sigma-1}} \exp(g^P(\lambda_S, \tau_S, \phi_i)). \tag{30}$$

It should be clear from the fact that the marginal cost of the parent is less than the marginal cost of the affiliate that $\widehat{\varphi}_i^P < \widehat{\varphi}_i^A$, which is a feature of most heterogeneous firm models.

The model is closed by the zero profit condition, which is

$$\int_{\widehat{\varphi}_i^P}^{\infty} \pi_i^P(\varphi) dG(\varphi) + \int_{\widehat{\varphi}_i^A}^{\infty} \pi_i^A(\varphi) dG(\varphi) - w_N \Phi_i = 0, \tag{31}$$

where $\pi_i^P(\varphi)$ is given by (29) and $\pi_i^A(\varphi)$ is given by (19). Having closed the model, we can generate the following result concerning the effect on changes in international shipping costs:

Proposition 6 *A decrease in either τ_S or τ_N results in a decrease in $\widehat{\varphi}^A$ and an increase in $\widehat{\varphi}^P$*

Because the proposition does not consider variation across industries, we suppress the industry subscript. First, consider the effect of a reduction in the size of τ_S, the cost of transporting intermediates from the south to the north. Totally differentiating (30) and rearranging gives us

$$\frac{d\widehat{\varphi}^P}{\widehat{\varphi}^P} = -\frac{1}{\sigma - 1}\frac{dA}{A} + \frac{\tau_S \partial g^P}{\partial \tau_S}\frac{d\tau_S}{\tau_S}.$$

Note that we have suppressed the arguments in g^P for more compact notation.28), this expression can be rewritten:

$$\frac{d\widehat{\varphi}^P}{\widehat{\varphi}^P} = -\frac{1}{\sigma - 1}\frac{dA}{A} + \varepsilon_{\tau_S}^{CP}\frac{d\tau_S}{\tau_S}. \tag{32}$$

Repeating the same procedure for the affiliate cutoff $\widehat{\varphi}_i^A$ yields

$$\frac{d\widehat{\varphi}^A}{\widehat{\varphi}^A} = -\frac{1}{\sigma - 1}\frac{dA}{A} + \varepsilon_{\tau_S}^{CA}\frac{d\tau_S}{\tau_S}. \tag{33}$$

To calculate the size of dA_i/A_i, we use the free entry condition. Substituting for the profit functions and revenue functions, the zero profit condition can be written

$$A\left\{\exp((1-\sigma)g^P)V(\widehat{\varphi}^P) + \exp((1-\sigma)g^A)V(\widehat{\varphi}^A)\right\} \tag{34}$$

$$- \left[\left(1 - G(\widehat{\varphi}^P)\right) + \left(1 - G(\widehat{\varphi}^P)\right)\right]w_N f - w_N \Phi$$

$$= 0,$$

where

$$V(a) = \int_a^\infty \varphi^{\sigma-1}dG(\varphi).$$

Note that we have suppressed the arguments in g^P for more compact notation. Also notice the fact that the two countries are identical and has been used in writing this expression. Entering firms drive down the industry price index, causing the mark-up adjusted demand level to shift until expected variable costs equal expected fixed costs.

Totally differentiating (34), substituting using (30) and (28), and rearranging results in the following expression:

$$\frac{dA}{A} = (\sigma - 1)\frac{\varepsilon_{\tau_S}^{CP}\exp((1-\sigma)g^P)V(\widehat{\varphi}^P) + \varepsilon_{\tau_S}^{CA}\exp((1-\sigma)g^A)V(\widehat{\varphi}^A)}{\exp((1-\sigma)g^P)V(\widehat{\varphi}^P) + \exp((1-\sigma)g^A)V(\widehat{\varphi}^A)}\frac{d\tau_S}{\tau_S} > 0.$$

This expression shows that the change in the mark-up adjusted demand level is proportional to a weighted average of the elasticities of marginal costs with respect to the southern transport costs for the parents and the affiliates and so $dA/d\tau_S > 0$. Substituting this expression into (32) and rearranging yields

$$\frac{d\widehat{\varphi}^P}{\widehat{\varphi}^P} = \left(\frac{\left(\varepsilon_{\tau_S}^{C^P} - \varepsilon_{\tau_S}^{C^A}\right)\exp((1-\sigma)g^A)V(\widehat{\varphi}^A)}{\exp((1-\sigma)g^P)V(\widehat{\varphi}^P) + \exp((1-\sigma)g^A)V(\widehat{\varphi}^A)} \right) \frac{d\tau_S}{\tau_S}.$$

Because $\varepsilon_{\tau_S}^{C^A} > \varepsilon_{\tau_S}^{C^P}$, it follows that $d\widehat{\varphi}^P/d\tau_S < 0$. An increase in Southern trade costs reduces the cutoff productivity for parent firms. Repeating this series of operations for $\widehat{\varphi}^A$ yields

$$\frac{d\widehat{\varphi}^A}{\widehat{\varphi}^A} = \left(\frac{\left(\varepsilon_{\tau_S}^{C^A} - \varepsilon_{\tau_S}^{C^P}\right)\exp((1-\sigma)g^P)V(\widehat{\varphi}^P)}{\exp((1-\sigma)g^P)V(\widehat{\varphi}^P) + \exp((1-\sigma)g^A)V(\widehat{\varphi}^A)} \right) \frac{d\tau_S}{\tau_S}.$$

By Lemma 2, we have $\varepsilon_{\tau_S}^{C^A} > \varepsilon_{\tau_S}^{C^P}$, it follows that $d\widehat{\varphi}^A/d\tau_S > 0$. An increase in the Southern trade cost increases the cutoff productivity for foreign affiliates.

Now consider the effect of a change in northern trade costs τ_N. Totally differentiating (30) yields

$$\frac{d\widehat{\varphi}^P}{\widehat{\varphi}^P} = -\frac{1}{\sigma - 1}\frac{dA}{A}. \tag{35}$$

The parent cutoff is not directly affected by Northern trade costs. Repeating the procedure for $\widehat{\varphi}^A$ yields

$$\frac{d\widehat{\varphi}^A}{\widehat{\varphi}^A} = -\frac{1}{\sigma - 1}\frac{dA}{A} + \varepsilon_{\tau_N}^{C^A}\frac{d\tau_N}{\tau_N}. \tag{36}$$

Finally, totally differentiating the free entry condition, we obtain

$$\frac{dA}{A} = (\sigma - 1) \frac{\varepsilon_{\tau_N}^{C^A} \exp((1-\sigma)g^A)V(\widehat{\varphi}^A)}{\exp((1-\sigma)g^P)V(\widehat{\varphi}^P) + \exp((1-\sigma)g^A)V(\widehat{\varphi}^A)} \frac{d\tau_N}{\tau_N} > 0.$$

Combining this expression with (35) and (36), it follows immediately that $d\widehat{\varphi}^P/d\tau_N < 0$ and $d\widehat{\varphi}^A/d\tau_N > 0$.

Appendix

Table A1: Alternative specifications of the Effect of Trade Costs on the Structure of Affiliate Operations of U.S. Multinational Firms

	Hypothesis 1: Import vs. local production				Hypothesis 2: Intensive margin of affiliate operations	
	Dependent variable: Import Cost Share				Dependent variable: Local Sales	
	All Imports	All Imports	Imports for further manufacture	Imports for further manufacture		
	(1)	(2)	(3)	(4)	(5)	(6)
PSALE					0.459 (0.028)	0.508 (0.024)
RD	-0.482 (1.69)	0.558 (1.07)	-2.58 (1.76)		2.82 (1.02)	2.10 (0.729)
FC	-24.3 (10.2)	-33.0 (2.31)	-36.4 (10.6)	-30.3 (9.74)	-15.2 (3.06)	-6.25 (2.59)
RD*FC	108 (37.4)	84.7 (23.9)	140 (38.6)	92.3 (34.9)	-61.7 (21.2)	-43.3 (17.2)
GDPPC		-0.581 (0.065)	-0.912 (0.226)	-0.945 (0.189)		0.703 (0.077)
POP		-0.112 (0.139)	-0.259 (0.108)	-0.263 (0.079)		0.406 (0.035)
TAX		-0.262 (0.139)	0.052 (0.402)	0.027 (0.361)		-0.188 (0.194)
Fixed Effects	Industry	Industry	Industry	Firm	Industry	Industry
N	4,001	4,001	2,401	2,401	5,394	5,394
R-squared	0.020	0.165	0.156	0.086	0.380	0.473

Coefficients on industry indicator variables are suppressed. The variables FC, GDP, POP, and TAX are in logarithms and RD is in levels. Robust standard errors are in parentheses below the corresponding coefficient estimates. The Import Cost Share columns (1) and (2) correspond to specifications in which the dependent variable is the logarithm of the ratio of the value of total affiliate imports from their parent firms to cost of goods sold. The Import Cost Share columns (3) and (4) correspond to specifications in which the dependent variable is the logarithm of the ratio of the value of affiliate imports of goods intended for further manufacture to cost of goods sold. The Local Sales columns (5) and (6) correspond to specifications in which the dependent variable is the logarithm of total affiliate sales to local customers.

Table A2: The Scope and Composition of U.S. Intra-firm Exports – Log Specifications

	Hypothesis 4: Scope and complexity of multinational parent exports		
	Log Scope	Log Average Occupation-based Complexity	Log Average Skill-intensity-based Complexity
FC	-5.67	0.23	1.42
	(2.32)	(0.08)	(0.49)
GDPPC	0.05	0.00	-0.01
	(0.06)	(0.002)	(0.01)
POP	0.09	-0.003	-0.02
	(0.03)	(0.001)	(0.01)
TAX	-0.16	0.01	0.08
	(0.11)	(0.003)	(0.03)
N	39	39	39
R-sq.	0.322	0.326	0.378

The dependent variables in these three specification are in logarithms. All standard errors (shown in parentheses) are robust to heteroskedasticity. Scope is defined as the share of NAIC 6-digit product categories exported in the total number of possible categories. Average Complexity is the occupation based measure of the average technical complexity of exports. Average Skill Intensity is the average ratio of nonproduction workers to production workers of the product categories exported