

Global Production and Trade in the Knowledge Economy*

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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 and estimate their significance for economic welfare.

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-

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

²Some 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

transferability assumption (Burstein and Monge-Naranjo 2008).

³In 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.

⁴Along 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 extend 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 US multinational firms from the BEA 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 is also consistent with 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 today's 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

⁵In 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 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

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

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

⁸In 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 two introduces the model, while section three characterizes its equilibrium and derives a number of key predictions of the model. Section four gives an overview of the empirical work, which consists of analyzing the structure of global production (section 5) as well as related-party trade (section 6). The paper concludes with section 7.

2 A Model of Technology Transfer with Multinationals

We now present our analytical framework in which multinational firms face a trade off between technology transfer costs and physical shipping costs. Consider a world with three countries, E , W , and S . Countries E and W are identical Northern countries and S is the South. Each country is endowed with L units of labor. Preferences in the northern countries are given by

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

where Y is a homogenous, freely-traded good, χ_i is the expenditure share of type i final goods, $x_i(\omega)$ 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 productivity in good Y 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 differentiated good i . There are no potential entrants in the Southern country.

Any variety of the differentiated good X is costlessly assembled in the country in which they are 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:

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

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

$$\beta_i(z) = \phi_i \exp(-\phi_i z). \quad (3)$$

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 technically complex.

Firms differ in their technological capability (or productivity), φ . In order to be able 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 non-degenerate distribution G that is known by all potential entrants prior to entry. The country in which the firm enters will henceforth be known as the firm's home country and 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

⁹Technological 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.

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 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 $\tilde{\lambda} \in (0, 1)$. Assuming that the success rate of communication is independent across tasks, the probability of successful communication is $(\tilde{\lambda})^z$. If a units of labor were committed to the production of one unit of an intermediate input, then $a(\tilde{\lambda})^z$ 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 $(\tilde{\lambda})^z$:

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

where the parameter $\lambda \equiv -\ln \tilde{\lambda} > 0$ 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 $\tilde{\varphi}_j(\varphi, z)$ in a foreign country $j \in \{N, S\}$ is

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

A firm that has learned its type must then decide in which countries to sell its variety. To sell its variety in a given northern country, the firm must incur fixed marketing and distribution network costs. This fixed cost, f , is in terms of labor. There are no other fixed costs.

Final goods are assembled in the country in which they will be sold. A key decision for a firm is how to supply its assembly plants with intermediate inputs. 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 shipping 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.

3 Solving for the Model's Equilibrium

In this section, we characterize the equilibrium of the model. Our focus is on the foreign investment and intermediate sourcing decisions of individual firms. We first consider the intermediate sourcing decisions of firms conditional on their decision to sell their product in the home and foreign markets. We then solve for the minimum level of marginal costs of serving the home and foreign country and explore how this marginal cost varies with parameters of the model. We then solve for the FDI decisions of individual multinational firms, consider comparative statics, and finally map the model's structure into an empirical strategy for testing its predictions and for estimating its structural equations.

3.1 The Sourcing of Intermediate Inputs

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). Henceforth, we refer to a firm by its type φ rather than its index ω . First, consider the optimal sourcing decision for intermediates for the parent firm. Let the minimum cost to the parent of a firm of type φ of procuring intermediate z be $c^P(\varphi, z)$. For each intermediate input, the parent can either procure the intermediate from an affiliate in the South, or it can produce it locally. 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 the intermediate locally. If the parent firm produces the intermediate z locally it pays the going wage in the North w_N

and its productivity is φ . In this case, $c^P(\varphi, z) = w_N/\varphi$. If instead 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 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

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

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 by the affiliate located in the south while the most complex intermediates are produced by the parent firm. In particular, there exists a cutoff intermediate input

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

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 firm.

Now consider the intermediate 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 if procuring intermediate z . The firm has three viable options for procuring this intermediate. First, it can obtain the intermediate from its parent firm, in which case the wage paid is w_N , the shipping costs incurred are τ_N , and the productivity is φ . In this case, $c^A(\varphi, z) = w_N \tau_N/\varphi$. Second, the firm could obtain the intermediate from a southern

affiliate in which case the marginal cost is the same as it would be for the parent. In this case, $c^A(\varphi, z) = w_S \tau_S \exp(\lambda_S z) / \varphi$. Finally, the affiliate could produce the intermediate input itself, in which case it pays a wage of w_N , pays no shipping costs, and produces with productivity $\varphi \exp(-\lambda_N z)$. In this last case, $c^A(\varphi, z) = w_N \exp(\lambda_N z) / \varphi$. The minimum cost of procuring intermediate z for assembly at a Northern affiliate is thus

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

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 , it also follows that the intermediate inputs of a moderate technological complexity will be most cheaply produced locally. Assuming this to be case, intermediates $z < \widehat{z}_S^A$ will be sourced from a Southern affiliate, where

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

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

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

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 empirically relevant results in the following propositions. First, comparing equations (7) and (9) establishes the first proposi-

tion.

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 is very intuitive. Technology transfer costs increase the cost of producing each intermediate in a northern affiliate relative to the cost of producing each intermediate at the parent so that for intermediate \widehat{z}_S^P the cost of production is the same in the parent firm as in the Southern affiliate but strictly higher at 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 *The range of intermediates imported from the parent $z > \widehat{z}_N^A$, decreases in the size of transport cost τ_N .*

According to this result, the commodity composition of affiliates' imports from their parent firms should become more concentrated in fewer categories as trade costs between affiliate and parent firm rises.

3.2 The Geography of Production Costs

Having derived the optimal intermediate input sourcing decisions of parent firms and their foreign affiliates, we can solve for their marginal costs of production. Because goods are costlessly assembled from intermediate inputs, a firm's marginal cost of serving consumers

in any given country depends only on the cost of providing these intermediates to assembly plants located in that country. 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

$$C_i^k(\varphi) = \exp \left(\int_0^\infty \beta_i(z) \ln c^k(\varphi, z) dz \right). \quad (11)$$

Consider first the marginal cost of the parent. Substituting for $c^P(\varphi, z)$ using (6) and using the cutoff (7), the marginal cost of the parent of a firm of type φ can be written

$$C_i^P(\varphi) = \frac{1}{\varphi} (\Gamma_i(0, \widehat{z}_S^P : S) w_S \tau_S)^{\theta_i(\widehat{z}_S^P)} (w_N)^{1-\theta_i(\widehat{z}_S^P)}$$

where

$$\theta_i(b) = \int_0^b \beta_i(z) dz \quad (12)$$

and

$$\Gamma_i(a, b : j) = \exp \left(\lambda_j \int_a^b z \frac{\beta_i(z)}{\int_a^b \beta_i(z) dz} dz \right). \quad (13)$$

This cost function shows that the marginal cost of the parent is a weighted average of “effective” Southern and Northern wages, where the weights $\theta(\widehat{z}_S^P)$ are endogenous, and a productivity term $\Gamma_i(0, \widehat{z}_S^P : S)$ that captures the average technology transfer cost incurred by a firm in industry i of sourcing intermediates $[0, \widehat{z}_S^P]$ from a Southern affiliate. Increasing \widehat{z}_S^P allows the use of cheaper southern labor but comes at the cost of increasing technology

transfer costs. Using the cutoffs (7), and integrating by parts using (3), we can rewrite the parent's marginal cost as

$$C_i^P(\varphi) = \frac{1}{\varphi} \exp(g^P(\lambda_S, \tau_S, \phi_i)), \quad (14)$$

where

$$g^P(\lambda_S, \tau_S, \phi_i) = \ln(w_S \tau_S) + \frac{\lambda_S}{\phi_i} \left[1 - \left(\frac{w_N}{w_S \tau_S} \right)^{-\frac{\phi_i}{\lambda_S}} \right] \quad (15)$$

summarizes the effects of technology transfer costs and physical shipping costs on parent marginal cost.

Now consider the marginal cost for the Northern affiliate of a firm of type φ in industry i . Substituting for $c^A(\varphi, z)$ using (8) and using the cutoffs (9) and (10), the marginal cost of the parent of a firm of type φ can be written

$$C_i^A(\varphi) = \frac{1}{\varphi} (\Gamma_i(0, \widehat{z}_S^A : S) w_S \tau_S)^{\theta_i(\widehat{z}_S^A)} (\Gamma(\widehat{z}_S^A, \widehat{z}_N^A : N) w_N)^{\theta_i(\widehat{z}_N^A) - \theta_i(\widehat{z}_S^A)} (w_N \tau_N)^{1 - \theta_i(\widehat{z}_N^A)}$$

where $\theta(\cdot)$ is given by equation (12), and $\Gamma(\cdot, \cdot : j)$ $j \in \{N, S\}$ is given by equation (13).

The marginal cost facing the affiliate reflects average technology transfer costs $\Gamma(0, \widehat{z}_S^A : S)$ incurred by producing intermediates $[0, \widehat{z}_S^A]$ in the South and the average technology transfer costs $\Gamma(\widehat{z}_S^A, \widehat{z}_N^A : N)$ incurred by producing intermediates $[\widehat{z}_S^A, \widehat{z}_N^A]$ locally. Using the cutoffs (9) and (10), and integrating by parts using (3), we can rewrite the parent's marginal cost as

$$C_i^A(\varphi) = \frac{1}{\varphi} \exp(g^A(\lambda_S, \lambda_N, \tau_S, \tau_N, \phi_i)), \quad (16)$$

where

$$g^A(\lambda_S, \lambda_N, \tau_S, \tau_N, \phi_i) = \ln(w_S \tau_S) + \frac{\lambda_S}{\phi_i} - \frac{\lambda_S - \lambda_N}{\phi_i} \left(\frac{w_N}{w_S \tau_S} \right)^{-\frac{\phi_i}{\lambda_S - \lambda_N}} - \frac{\lambda_N}{\phi_i} (\tau_N)^{-\frac{\phi_i}{\lambda_N}} \quad (17)$$

summarizes the effect of technology transfer costs and shipping costs on marginal cost of serving the foreign market.

Before concluding our discussion of the geography of marginal costs, we summarize how changes in transport costs τ_S and τ_N affect the relative marginal costs of parents and their affiliates. Consider first the effect of changes in τ_S . Differentiating equations (14) and (16), 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:

$$\begin{aligned} \varepsilon_{\tau_S, i}^{C^P} &\equiv \frac{\tau_S}{C_i^P} \frac{\partial C_i^P}{\partial \tau_S} = 1 - \left(\frac{w_S \tau_S}{w_N} \right)^{\frac{\phi_i}{\lambda_S}}, \\ \varepsilon_{\tau_S, i}^{C^A} &\equiv \frac{\tau_S}{C_i^A} \frac{\partial C_i^A}{\partial \tau_S} = 1 - \left(\frac{w_S \tau_S}{w_N} \right)^{\frac{\phi_i}{\lambda_S - \lambda_N}}. \end{aligned} \quad (18)$$

Not surprisingly, an increase in τ_S is associated with an increase in the marginal cost of both parent and affiliate. There are two additional implications of (18). 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.

Now consider the effect on the marginal cost of the affiliate in industry i of an increase in τ_N , the size of shipping costs between the parent and the affiliate. Differentiating equation (16) with respect to τ_N and rearranging, we obtain

$$\varepsilon_{\tau_N, i}^{CA} \equiv \frac{\tau_N}{C_i^A} \frac{\partial C_i^A}{\partial \tau_N} = (\tau_N)^{-\frac{\phi_i}{\lambda_N}}. \quad (19)$$

The following empirical relevant result can be obtained by differentiating this equation.

Proposition 3 *The elasticity of the marginal cost of the affiliate with respect to τ_N ($\varepsilon_{\tau_N, i}^{CA}$) is higher in relatively high-tech (low ϕ) industries.*

The result follows from the fact that affiliates in technologically complex industries rely more heavily on intermediates that are sourced from their parent firm.

3.3 The Structure of International Production

Whether a firm will serve its home market and that of the other Northern country will depend on the marginal cost of domestic and foreign production and on the size of its sales conditional on entering those markets. 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 $j \in \{E, W\}$ is

$$x_{ij}(\varphi) = \left(\frac{\chi_i L_j}{P^i} \right) \left(\frac{p_j(\varphi)}{P^i} \right)^{-\sigma}, \quad (20)$$

where $p_j(\omega)$ is the price charged by the firm ω_i , and P^i is the price index for good i in each of the two, symmetric Northern countries.

As is well known, a firm that faces the iso-elastic demand curve (20) optimally charges a constant proportional mark-up over marginal costs ($1/\alpha > 1$), and substituting for the parent's marginal cost using (14), we find that the optimal revenue of generated by a parent firm of type φ in industry i in its home market is

$$R_i^P(\varphi) = A_i C_i^P(\varphi)^{1-\sigma}, \quad (21)$$

where $C_i^P(\varphi)$ is given by equation (14) and

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

is the endogenous, mark-up adjusted demand level in a Northern country in industry i . The revenue earned by a Northern affiliate of a firm of type φ in industry i is

$$R_i^A(\varphi) = A_i C_i^A(\varphi)^{1-\sigma}, \quad (22)$$

where $C_i^A(\varphi)$ is given by equation (16). Totally differentiating (22) 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 proposition 3 has the following implication.

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

This second observation follows from the fact that in high-tech industries more of the global value added is in intermediates that are costly to offshore, and so marginal costs rise faster in shipping costs. This is an implication that we will test below.

Given the iso-elastic demand curve (20), a firm of type φ in industry i will earn gross profit in Northern country k equal to $R_i^k(\varphi)/\sigma$, $k = \{E, W\}$. A firm will enter a given market if the gross profits are sufficiently large to cover the fixed costs. This yields the following entry condition for a firm's home country:

$$\pi_i^P(\varphi) \equiv \frac{R_i^P(\varphi)}{\sigma} - w_N f \geq 0. \quad (23)$$

Substituting (21) and (14) into this expression and rearranging yields the cutoff productivity level that a firm must have before it is profitable to serve its home market:

$$\widehat{\varphi}_i^P = \left(\frac{\sigma w_N f}{A_i} \right)^{\frac{1}{\sigma-1}} \exp(g^P(\lambda_S, \tau_S, \phi_i)). \quad (24)$$

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

$$\pi_i^A(\varphi) \equiv \frac{R_i^A(\varphi)}{\sigma} - w_N f \geq 0. \quad (25)$$

Substituting (22) and (16) into this expression and rearranging yields the cutoff productivity level that a firm must have before it is profitable to serve the foreign market:

$$\widehat{\varphi}_i^A = \left(\frac{\sigma w_N f}{A_i} \right)^{\frac{1}{\sigma-1}} \exp(g^A(\lambda_S, \lambda_N, \tau_S, \tau_N, \phi_i)) \quad (26)$$

Because $g^A > g^P$, we have that $\widehat{\varphi}_i^A > \widehat{\varphi}_i^P$. This is the usual sorting result saying that only the largest, most productive firms sell their product abroad. Differentiating equation (26) with respect to τ_N and using proposition 3, 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 τ_N . Everything else equal, this rate of decrease is higher in high-tech (low ϕ) industries.*

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

Finally, we consider the firm entry condition which requires that the expected profit of entry must be zero:

$$\int_{\widehat{\varphi}_i^P}^{\infty} \pi_i^P(\varphi) dG(\varphi) + \int_{\widehat{\varphi}_i^A}^{\infty} \pi_i^A(\varphi) dG(\varphi) - w_N \Phi_i = 0, \quad (27)$$

where $\pi_i^P(\varphi)$ is given by (23) and $\pi_i^A(\varphi)$ is given by (25). Having closed the model, we can generate the following general equilibrium result concerning 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 $\widehat{\varphi}^P$.*

Proof. *See the appendix.* ■

Because the marginal costs of affiliates are more sensitive to physical trading costs than are the marginal costs of their parents, a reduction in either type of trade cost tends to expand the share of firms that become multinational. The result on the effect of southern trade costs is interesting because it shows that an opening of developing countries to international trade can lead to increased North-North foreign direct investment. This result is similar to that in Yeaple (2003) but occurs here for a different reason: the relatively heavy reliance of affiliates on imported intermediates.

4 Empirical Strategy

The model presented in the previous section offers a rich set of predictions over the structure of intra-firm trade and the location and volume of multinational activity at the firm level. We draw on two distinct datasets to test propositions 2 through 5 and to estimate key structural parameters. The first data set, which is discussed in greater detail below, draws from confidential firm-level information from the Bureau of Economic Analysis on the structure of U.S. multinationals' global operations, and it allows us to 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. Propositions 3, 4, and 5 can be tested and the relevant magnitudes assessed using this data alone. What these firm-level data lack, however, is detailed information on the industrial composition of intermediates. Therefore, in order to test the proposition 2, which states that the composition of a parent firm’s exports to its affiliates becomes more concentrated as the magnitude of shipping costs between the parent firm and its affiliate grows, we rely on detailed, industry-country level data on related party trade from the Census Bureau. In the following two sections, we present two complementary analyses.

5 The Structure of U.S. Multinationals’ Global Operations

Our firm level data will allow us to observe many features of the international operations of U.S. multinationals. 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 model’s structure regarding the share of intermediate inputs imported by an affiliate from its parent firm in an affiliate’s total cost. In the model, this variable corresponds to $1 - \theta_j(\widehat{z}_N^A)$. Using equations (12) and (10) and taking logarithms, we find

$$\ln(1 - \theta_i(\widehat{z}_N^A)) = -\frac{\phi_i}{\lambda_N} \ln \tau_N.$$

This expression suggests that the co-variation in the share of firms' costs due to imported intermediates and the magnitude of shipping costs across countries can be used to identify ϕ_i/λ_N , a key structural parameter that can be used to calculate variation across countries and industries in the marginal costs of affiliates.

We will use firm-level data to estimate this relationship. 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. 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

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

To make this relationship empirically operational, we assume that the technology transfer cost parameter λ_N is the same across countries in which firms sell their good to final customers and that the variation across firms in their technical complexity ϕ_j , 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:

$$\ln \frac{M_{jk}}{TC_{jk}} = \gamma_j + \kappa \ln X_k + \left(\frac{\delta_0}{\lambda_N} + \frac{\delta_1}{\lambda_N} RD_j \right) \ln FC_k + \varepsilon_{jk} \quad (28)$$

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 (28) via ordinary least squares. We will estimate several variants of this equation below. Our model predicts that the coefficient $\frac{\delta_0}{\lambda_N} < 0$ and that the coefficient estimate $\frac{\delta_1}{\lambda_N} > 0$. As shipping costs increase, firms substitute local production for imports of intermediates from the parent, but this substitution is more costly in high-tech industries with hard to transfer technologies.

Now consider the relationship between the revenue generated by an affiliate from sales in its host country and the magnitude of shipping costs between the parent and the affiliate, which is given by equation (22). Taking the logarithm of equation (22), we have

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

Holding fixed the mark-up adjusted demand level A_i , the size of affiliate's revenue should be increasing in the firm's productivity φ and decreasing in the size of shipping costs between the affiliate and its parent firm τ_N . As pointed out in proposition 4, the size of the effect of transport costs should be larger (decreasing faster) in high-tech 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

shipping costs FC_k and other country characteristics:

$$\ln R_{jk} = \eta_j + \rho \ln X_k + (\varsigma_0 + \varsigma_1 RD_j) \ln FC_k + v_{jk}, \quad (29)$$

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 (28) and ρ is the corresponding coefficient, v_{jk} is a well-behaved error term. Proposition 4 has the implication that $\varsigma_0 < 0$ and $\varsigma_1 < 0$: affiliate sales in high-tech sectors (high RD_j) are more sensitive to variation in freight costs FC_k . The difference in the predicted sign on the interaction between RD_j and FC_k in equations (28) and (29) have strong empirical bite.

Finally, we consider the predictions of proposition 5, which states that the propensity of individual firms to enter individual foreign markets should be decreasing in the size of shipping costs between the parent firm and the prospective host country and that the size of this decrease should be more pronounced in high-tech 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 $Y_{jk}^* > 0$, where

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

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, the specification of Y_{jk}^* is the same as it is for (29).

5.1 Data

We use the confidential enterprise-level data collected by the Bureau of Economic Analysis (BEA) to conduct the bulk of our analyses. The BEA conducts annual surveys of U.S. Direct Investment Abroad where U.S. direct investment is 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 unincorporated 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. Our data is extracted from the results of the 1994 Benchmark Survey. Benchmark surveys are conducted every five years and provide greater coverage than annual surveys.

>From the BEA's database, we extracted data for all majority-owned U.S. affiliates that report local sales in their host country markets that were owned by U.S. parent firms whose main line of business is a manufacturing industry. For each affiliate, we observe the country

in which that affiliate is located, the total value of sales reported by that affiliate, the total value of sales made to customers in the host country, the total cost of producing these goods (cost of goods sold), the total value of the affiliate’s imports from its parent firm, and the total value of imports from the U.S. parent firm that were classified as intended for further processing.¹⁰ For each affiliate, we also observe the identity of the parent firm, and for each parent firm, we observe the main line of business of the parent firm, the total value of its sales in the United States, the total value of its sales, and the total value of R&D expenditures reported by the parent firm. All affiliates owned by an individual parent firm in a given country were aggregated to form a single firm-country observation.¹¹

Our measure of the cost share of imported intermediates M_{jk}/TC_{jk} was calculated in several ways to ensure robustness. According to our first measure, the total value of imports from the parent firm divided by the total cost of goods sold. Our second measure includes only imports intended for further processing. We also considered an alternate denominator: the total value of a firm’s sales.¹² In order to calculate a firm’s R&D intensity, RD_j , we divided the parent firm’s R&D spending by total parent firm sales.

There are many possible ways to measure transport costs, none of which are perfect. Rather than infer transport costs indirectly from the effects of distance, we follow Brainard

¹⁰In alternate specifications, we also included imports by foreign affiliates from the U.S. that were not from the parent firm. This alternate measure would allow for some outsourcing of intermediate parts to U.S. based producers. Because most of affiliate imports are from their parent firms, and because the results were almost identical, these results are not reported below.

¹¹Unfortunately, U.S. affiliates abroad do not report imported intermediates from sources other than the United States, so that we can not analyze outsourcing from the South. The survey on inward FDI into the United States does ask affiliates of foreign countries to report all imports from all countries. We plan to add an analysis of U.S. inward FDI in future versions of the paper.

¹²Because the results generated using this measure are very close to those presented below, we do not report them in this paper.

(1997) in constructing an ad-valorem measure of shipping 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 shipping costs, we demeaned the data by industry and kept only country-specific averages obtained from this demeaned data.¹³

To control for variation across countries in the mark-up adjusted demand level and for a country's ability to absorb foreign technology, we included in many specifications the logarithm of a country's GDP per capita, $GDPPC$, and the logarithm of its population, POP . Both measures correspond to 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 included 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 are shown in the Table 1. The complete dataset contains information on the activities of over 5,400 affiliates of 1,055 parent firms located in 44 countries.

5.2 Empirical Results

The main results of estimating equations (28) and (29) are shown in Table 2. All of these coefficient estimates were obtained using data that has been demeaned by firm, so that all of the remaining variation is between affiliates of individual U.S. multinationals. To facilitate

¹³Anderson 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 drafts, we plan to explore a number of different direct measure of trade costs, including measures that incorporate trade policy related barriers such as tariffs and NTBs.

comparison between the results for the logarithm of the ratio of affiliate imports from their parent firm to total costs (MC) and the logarithm of local revenue (LR), the results for each specification are reported in adjacent columns.

To make the point that the correlation between freight and shipping costs and the logarithm of MC and LR is strong, the first specifications restrict all the coefficients on all variables, except the logarithm of freight and shipping costs (FC), to zero. In both equations, an increase in the shipping costs is associated with a statistically significant and economically substantial reduction in both the cost share of imported intermediates and the size of local sales. The coefficient estimate of -13.2 reported in column one corresponds to ϕ/λ if all industries were to have the same technological intensity. Using equation (19), we can calculate the effect of trade costs on the marginal cost of the affiliate. Evaluating (19) at the mean level of transport costs, we find that a one percent increase in transport costs is associated with a 0.6% increase in the marginal cost of the affiliate. The coefficient of 22.7 on FC in the LR equation implies that a one percent increase in transport costs is associated with a 22 percent decrease in the value of sales to local customers.

Next, we allow for the interaction between a firm's R&D intensity and a country's shipping cost, while restricting the coefficients on the other country variables to be zero. The results are shown in columns 3 and 4 for MC and LR respectively. The coefficient on FC in column 3 is negative and the coefficient on the interaction between RD and FC is positive, while in column 4 the coefficient on FC is negative and the coefficient on the interaction between RD and FC is negative. All four coefficients are statistically significant.

These two sets of results provide strong support for the key predictions of the model.

First, the share of imports in total costs for an affiliate is decreasing in shipping costs for all firms, but the rate of decrease is less for high-tech firms. The model offers the following interpretation: high-tech firms have greater difficulty substituting local production for technologically complex intermediates. This interpretation also explains the negative coefficient on the interaction term in the LR regressions: because it is expensive to substitute local production for imports, affiliates in these industries must import a larger share of intermediates from the parent, and this makes their marginal costs rise faster in the size of shipping costs. Higher marginal costs result in reduced revenues on sales to local customers.

In columns 5 and 6 of Table 2, we report the unrestricted results corresponding to equations (28) and (29). Consider first the MC results in column 5. The coefficient estimates on FC and $FC * RD$ are still of the same sign and statistically significant, but their magnitudes have changed somewhat. After controlling for country size and level of development, the ratio of the value of imports from the parent to total costs falls at a faster rate in shipping costs than before. One possible explanation is suggested by the negative coefficient on GDP , which is both economically large and statistically significant. Technology may be more easily transferred to highly developed economies. Note that these results are consistent with Hanson, Mataloni, and Slaughter (2005) who show that imported intermediate usage tends to be higher in relatively less developed countries.

The results for R shown in column 6 are consistent with the interpretation of the results for MC in column 5. Controlling for country size and development dampens the magnitude of the rate of decrease of local affiliate sales in shipping costs, but the effect of shipping costs is still statistically significant and maintains the expected sign. The positive and

statistically significant sign on $GDPPC$ is also consistent with marginal costs that are lower in developed countries, perhaps because of the ease in which technology is transferred from parent to affiliate.

We now turn to additional robustness checks. In Table 3, we report results in which fixed effects are allowed at the level of the industry of the parent firm rather than the level of the firm. Because a firm's productivity is no longer absorbed by a firm-level fixed effect, we proxy for firm-level productivity in the LR regressions using the logarithm of the parent firm's sales to U.S. customers ($PSALE$) and the R&D intensity of the parent RD . Columns 1 and 3 of Table 2 correspond to specification in which the coefficients on country controls are restricted to zero, while columns 3 and 4 reports the coefficient estimates obtained when these controls are included.

The first important observation is that the coefficient estimates on the variables FC and $FC * RD$ are not sensitive to replacing firm fixed effects with industry fixed effects. The second important observation is that the coefficient on $PSALE$ is positive and statistically significant. This result, which has been pointed out before in Yeaple (2008), demonstrates that whatever characteristics that the parent firm has that gives it a large market share in the United States appear to transfer, at least in part, to its foreign affiliates. Note also, that the coefficient on RD is also positive in the LR regressions, which is also consistent with at least partial international technology transfer. The effect of parent R&D on the affiliate size is decreasing in the magnitude of shipping cost between U.S. parent and foreign affiliate as indicated by the negative coefficient on $RD * FC$.

In Table 4, we repeat our analysis using a slightly different definition of the MC dependent

variable. Rather than use the value of all imports by affiliates from their parent firm, we use a direct measure of the imported intermediates, which is defined in the BEA survey as goods imported for further processing. One disadvantage of using this variable is that fewer firms provided the BEA with data on this variable so the number of observation drops substantially. Column 1 of Table 4 is estimated using industry fixed effects (dummy variables) while column 2 of Table 4 shows the coefficient estimates obtained from a within-firm regression (demeaned by firm). The results are highly consistent with those shown in Tables 2 and 3, differing only in the magnitude of the coefficient estimate on $FC * RD$, which is slightly larger in absolute value. In summary, the predictions of proposition 4 receive strong support in the data.

We now turn to the location decision predictions of proposition 5. According to this proposition, the propensity of firms to open an affiliate in a given prospective host country should be decreasing in the size of transport cost between the host country and the parent firm, and the effect should be larger in high-tech industries. To explore this possibility, we estimate a linear probability model in which the same set of explanatory variables are used as in the MC and LR regressions. We allow for firm-level fixed effects as before.

The results are shown in Table 5. The results shown in column 1 correspond to a stripped down specification in which the other country-level controls are excluded, while column two corresponds to the full specification. In both columns, the coefficients on FC are negative, indicating that an increase in freight costs is associated with a reduced propensity of firms to open foreign affiliates. Most importantly, the effect of shipping costs is largest for the most technologically intensive firms as indicated by the negative coefficient on the interaction term $FC * RD$. These results are consistent with the prediction of proposition 5.

5.2.1 The Implied Cost Differences between Parents and Affiliates

According to the model, the affiliates of U.S. parent firms tend to be smaller than their parents because they face higher marginal costs that reflect the interaction between physical shipping costs and technology transfer costs. If we abstract away from intermediates obtained from Southern affiliates, our estimates on the effect of freight costs and their interaction with parent firm technological intensity can be interpreted as structural parameters that can be used to estimate the cost disadvantage of the affiliate relative to their parent. To see this, note that under the assumption that there are no Southern affiliates, the marginal cost of the affiliate relative to the parent becomes

$$\frac{C^A(\varphi)}{C^P(\varphi)} = \exp\left(\frac{\lambda_N}{\phi_i} \left[1 - (\tau_N)^{-\frac{\phi_i}{\lambda_N}}\right]\right). \quad (30)$$

Note that we have used (16) and (17) to derive this expression. Under our parameterization of ϕ_i , we can use the coefficient estimates on FC and on $FC * RD$ combined with the data on transport costs to infer these costs.

In Table 6, we calculate (30) for various values of FC and RD using the coefficient estimates from column (3) of Table 2. The columns of Table 6 correspond to RD evaluated at 1 standard deviation below the mean, the mean, and one standard deviation above the mean. The rows of Table 6 corresponds to one standard deviation below the mean, the mean, one standard deviation above the mean, and a row corresponding to the situation in which no trade is possible. The calculated costs are then displayed as a matrix. The calculations imply that the affiliate located at the mean level of trade costs (5.8%) from its parent with

the mean R&D intensity of 5.1% the marginal cost of the affiliate is 4% higher than its parent firm. Were the parent simply to ship the entire final good to the affiliate, its marginal cost of serving the foreign market would be 5.8% higher than the cost of serving the home market. The marginal cost disadvantage of an affiliate is higher for high R&D firms: for a parent with R&D intensity one standard deviation above the mean, the marginal cost of the affiliate is 4.7% higher than its parent firm compared to the 5.8% cost differential were the parent firm to ship the final good directly to the foreign country.

6 The Composition of Related Party Trade

The analyses of the previous section provide a consistent set of results on the structure of U.S. multinational activity that are consistent with the predictions of the model summarized in propositions 3, 4, and 5. Because the BEA data do not provide a breakdown of the commodity composition of trade, however, they do not allow a direct test of proposition 2, which states that the range of intermediates inputs imported by affiliates from their parent firms should be decreasing in the size of shipping costs between parent and affiliate. In this section, we specify an econometric test of this proposition, describe a publically available dataset that allows us to test this proposition, and report the results of that test.

Equation (10) relates the cutoff intermediate input to the interaction between trade costs and technology transfer costs:

$$\widehat{z}_N^A = \frac{1}{\lambda_N} \ln(\tau_N).$$

The greater the magnitude of shipping costs τ_N between the parent firm and the affiliate, the larger the fraction of intermediates that should be produced locally and the smaller the fraction of inputs that are sourced from the parent firm. Since the BEA does not allow us to address this issue, we have obtained other data to test the hypothesis that the range of intermediates imported by the affiliate becomes narrower as transport costs rise.

To assess this prediction, we draw on data on publically available sources on the commodity composition of U.S. intra-firm trade. 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 dataset contains all related party exports by six-digit NAICS industrial classification for all the countries in our BEA dataset. While it is possible that some of these exports are exports from U.S. affiliates to their foreign parents, the BEA data reveal that, in the aggregate at least, the bulk of these exports are from U.S. parents to their foreign affiliates.

To obtain a measure related to \hat{z}_N^A that varies by country, we simply count the total number of product categories out of a total of 607 possible product categories in which positive levels of exports are reported and divide by 607. The resulting measure, $scope_k$, is a proxy for \hat{z}_N^A : an increase in $scope_k$ is equivalent to a decrease in the threshold intermediate as a wider range of intermediates are imported. We then regress various transformations of $scope_k$ on the same set of country characteristics as in the previous section. That is, we estimate

$$scope_k = \Theta \ln X_k + \Omega \ln FC_k + e_k, \quad (31)$$

where X_k is the $GDPPC$, POP , and TAX , and FC is the measure of freight and shipping costs. Descriptive statistics for all five variables are shown in Table 6.

The results obtained by estimating equation (31) using the Census, related-party data are shown in Table 7. The results shown in the first column correspond to a specification in which the coefficients Θ on the controls are constrained to be zero. As predicted by the theory laid out above, an increase in trade costs is associated with a reduction in the range of the intermediate that are imported by the affiliates of U.S. multinationals from their parent companies. The coefficient is statistically significant at standard levels. Column 2 reports the results in which the coefficients on the controls are not constrained. The coefficient on FC is essentially unchanged from the estimate in column 1 and it retains a high level of statistical significance. Of the controls, only the logarithm of a country's population (POP) is statistically significant, providing some evidence that country size matters: larger countries import a wider range of intermediates than smaller countries.

Because the variable $scope$ is constrained to be between zero and one by construction, we investigate the robustness of our findings by replacing this variable with its logarithm. The results are reported in columns 3 and 4. The pattern of coefficient signs and their statistical significance is unaffected by the transformation of the dependent variable. We conclude that intra-firm trade becomes increasingly concentrated in fewer product categories as shipping costs between parent firm and affiliate rise, precisely as predicted by the model.

We conclude with the following observations.

7 Conclusions

In this paper we analyze a model in which multinationals face both physical shipping costs and costs related to technology transfer. In their effort to minimize the cost of serving foreign markets, firms produce the most technically complex intermediates at their parent firm and ship them to affiliates, purchase the least technically complex intermediates from low wage countries, and produce moderately complex intermediates in their northern affiliates. A key result is that the marginal cost of foreign affiliates is rising in the magnitude of shipping costs between affiliate and parent and that the rate of increase is faster in technology intensive industries. The implied geography of production costs then maps into a geography of multinational entry and the optimal level of affiliate sales.

In the empirical part of the paper, we show that the main predictions of the model are consistent with the actual behavior of U.S. multinationals. High trade costs reduce the likelihood that U.S. affiliates are opened and the resulting sales when they are, and this effect is indeed strongest for R&D intensive firms. Further, we use the structural equation of the model to directly infer the geography of marginal costs implied by the interaction between physical shipping costs and firm technological intensity. Technology transfer costs appear to be quite large in that the marginal cost savings associated with avoiding shipping costs are relatively modest once technology transfer costs are taken into account.

In future work we plan to extend our analyses in a number of directions. First, we plan to use data on the parent firm sourcing intermediate sourcing decisions to quantify the effect of transport costs and technology transfer costs on offshoring intermediate inputs to low wage

countries. Second, we will compare the intermediate sourcing decisions of the U.S. affiliates of foreign multinationals to the sourcing decisions of U.S. parent firms to test a number of other predictions of the model that are derived above. Finally, we intend to use the full structure of the model to estimate the entire range of structural equations, covering sourcing decisions, location decisions, and optimal output levels, as a complete model in order to generate more precise estimates of the key structural relationships.

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Appendix: Proof of Proposition 6

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 (24) 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.18), this expression can be rewritten:

$$\frac{d\widehat{\varphi}^P}{\widehat{\varphi}^P} = -\frac{1}{\sigma-1} \frac{dA}{A} + \varepsilon_{\tau_S}^{C^P} \frac{d\tau_S}{\tau_S}. \quad (32)$$

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

$$\frac{d\widehat{\varphi}^A}{\widehat{\varphi}^A} = -\frac{1}{\sigma-1} \frac{dA}{A} + \varepsilon_{\tau_S}^{C^A} \frac{d\tau_S}{\tau_S}. \quad (33)$$

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

$$\begin{aligned} & A \{ \exp((1-\sigma)g^P)V(\widehat{\varphi}^P) + \exp((1-\sigma)g^A)V(\widehat{\varphi}^A) \} \\ & - [(1-G(\widehat{\varphi}^P)) + (1-G(\widehat{\varphi}^A))] w_N f - w_N \Phi \\ & = 0, \end{aligned} \quad (34)$$

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 (24) and (18), and rearranging results in the following expression:

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

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

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

Because $\varepsilon_{\tau_S}^{C^A} > \varepsilon_{\tau_S}^{C^P}$, 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 (24) yields

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

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

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

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 $d\widehat{\varphi}^A/d\tau_N > 0$.

Table 1: Descriptive Statistics

| | 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 |
| GDP | 9.69 | 0.51 |
| POP | 10.4 | 1.08 |
| TAX | 3.45 | 0.207 |

All variables except RD are in natural logarithms.

Table 2: The Within Firm Effect of Trade Costs on the Structure of Affiliate Operations of U.S. Multinational Firms

| | (1) | (2) | (3) | (4) | (5) | (6) |
|----------|-----------------------------|-----------------------|-----------------------------|-----------------------|-----------------------------|-----------------------|
| | Import Cost Share, MC | Local Sales, LR | Import Cost Share, MC | Local Sales, LR | Import Cost Share, MC | Local Sales, LR |
| FC | -13.2 (1.68) | -22.7 (0.915) | -19.6 (2.41) | -19.6 (1.29) | -30.3 (2.34) | -8.06 (1.17) |
| RD*FC | | | 111 (29.9) | -61.0 (16.9) | 79.5 (24.4) | -37.3 (13.1) |
| GDPPC | | | | | -0.798 (0.065) | 0.903 (0.034) |
| POP | | | | | -0.197 (0.028) | 0.495 (0.015) |
| TAX | | | | | -0.301 (0.124) | -0.172 (0.064) |
| N | 4,001 | 5,394 | 4,001 | 5,394 | 4,001 | 5,394 |
| R-square | 0.020 | 0.064 | 0.024 | 0.128 | 0.065 | 0.344 |

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. The Import Cost Share columns correspond to specifications in which the dependent variable is the logarithm of the ratio of the value of affiliate imports from their parent firms to cost of goods sold. The Local Sales columns correspond to specifications in which the dependent variable is the logarithm of total affiliate sales to local customers.

Table 3: The Within Industry Effect of Trade Costs on the Structure of Affiliate Operations of U.S. Multinational Firms

| | (1) | (2) | (3) | (4) |
|----------|-----------------------------|-----------------------|-----------------------------|-----------------------|
| | Import Cost Share, MC | Local Sales, LR | Import Cost Share, MC | Local Sales, LR |
| PSALE | | 0.459 (0.028) | | 0.508 (0.024) |
| RD | -0.482 (1.69) | 2.82 (1.02) | 0.558 (1.07) | 2.10 (0.729) |
| FC | -24.3 (10.2) | -15.2 (3.06) | -33.0 (2.31) | -6.25 (2.59) |
| RD*FC | 108 (37.4) | -61.7 (21.2) | 84.7 (23.9) | -43.3 (17.2) |
| GDPPC | | | -0.581 (0.065) | 0.703 (0.077) |
| POP | | | -0.112 (0.139) | 0.406 (0.035) |
| TAX | | | -0.262 (0.139) | -0.188 (0.194) |
| N | 4,001 | 5,394 | 4,001 | 5,394 |
| R-square | 0.020 | 0.380 | 0.165 | 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 correspond to specifications in which the dependent variable is the logarithm of the ratio of the value of affiliate imports from their parent firms to cost of goods sold. The Local Sales columns correspond to specifications in which the dependent variable is the logarithm of total affiliate sales to local customers.

Table 4: Imports Classified for Further Reprocessing in Total Costs

| | (1) | (2) |
|-----------------|-----------------------------|-----------------------------|
| | Import Cost Share, MC | Import Cost Share, MC |
| RD | -2.58 (1.76) | |
| FC | -36.4 (10.6) | -30.3 (9.74) |
| RD*FC | 140 (38.6) | 92.3 (34.9) |
| GDPPC | -0.912 (0.226) | -0.945 (0.189) |
| POP | -0.259 (0.108) | -0.263 (0.079) |
| TAX | 0.052 (0.402) | 0.027 (0.361) |
| Fixed Effect | Industry | Firm |
| N | 2,401 | 2,401 |
| R-square | 0.156 | 0.086 |

Coefficients on industry indicator variables are suppressed in the column 1 specification. All variables in all firm fixed effect specification are demeaned by firm. 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. The dependent variable is the logarithm of the ratio of the value of affiliate imports of goods intended for further reprocessing from their parent firms to the affiliate's cost of goods sold.

Table 5: Linear Probability of Entry

| | (1) | (2) |
|----------|------------------|-------------------|
| FC | -2.48 (0.041) | -0.969 (0.060) |
| RD*FC | -3.00 (0.485) | -3.00 (0.472) |
| GDPPC | | 0.062 (0.002) |
| POP | | 0.027 (0.001) |
| TAX | | 0.035 (0.030) |
| N | 112,860 | 112,860 |
| R-square | 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.

Table 6: Estimated Cost Disadvantage of Affiliate relative to its Parent

| | R&D Intensity | | | |
|-------------------|---------------------|---------------|-------|----------------|
| | | Std Dev Below | Mean | Std Dev. Above |
| Trade Cost | Std Dev Below | 1.028 | 1.031 | 1.035 |
| | Mean | 1.035 | 1.040 | 1.047 |
| | Std. Dev Above | 1.040 | 1.047 | 1.058 |
| | Infinite Trade Cost | 1.052 | 1.074 | 1.143 |

This table shows the estimated ratio of the marginal cost of the affiliate to the marginal cost of its US parent as a function of the parent's R&D intensity and the size of the trade cost between parent and affiliate assuming no sourcing of inputs from the south is possible. To conserve space, the cost function is evaluated at the mean of R&D and Trade cost and one standard deviation above and below this mean. The mean level of trade cost is 1.058 and the mean level of R&D intensity is 0.051.

Table 7: Descriptive Statics, U.S. Related Party Exports

| | Mean | Std Dev |
|------------|--------|---------|
| Scope | 0.459 | 0.123 |
| Log(scope) | -0.817 | 0.284 |
| GDPPC | 9.401 | 0.757 |
| POP | 16.11 | 1.406 |
| TAX | -1.09 | 0.516 |
| FC | 0.605 | 0.019 |

Table 8: The Effect of Trade Costs on Import Scope

| | (1) scope | (2) scope | (3) Log(scope) | (4) Log(scope) |
|----------|------------------|------------------|-------------------|-------------------|
| FC | -3.05 (0.809) | -2.77 (1.09) | -5.75 (2.64) | -5.06 (2.21) |
| GDPPC | | 0.013 (0.028) | | 0.033 (0.060) |
| POP | | 0.037 (0.011) | | 0.081 (0.025) |
| TAX | | 0.001 (0.030) | | -0.039 (0.077) |
| N | 44 | 44 | 44 | 44 |
| R-square | 0.227 | 0.373 | 0.152 | 0.286 |

Robust standard errors are shown in parentheses. The variable, scope, is measured as the share of NAICs 6-digit industries that are positive for the country and so varies from zero to one.