The Extensive Margin of Intrafirm Trade

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This Draft: October 2010

Abstract

The firm-level approach to intra-industry trade reveals that the variation in the number of exporters or exported varieties (extensive margin) accounts for a greater share of the changes in aggregate trade than the variation in the average exports per firm-variety (intensive margin). Using Bureau of Economic Analysis' U.S. Multinational Company data of 2007, this paper shows vertical intrafirm trade follows a similar pattern. Like Antràs (2003), the share of intrafirm imports in total U.S. imports is found to be higher, the higher the headquarters intensity of the exporting affiliates in foreign countries. This paper further demonstrates this increase in imports is mainly due to the establishment of a large number of foreign affiliates. In addition, lower trade barriers and a better investment environment in a country attract greater amounts of U.S. direct investment, and this attraction materializes mostly in terms of new affiliates than in terms of more sales per existing affiliate. The endogenous choice of optimal number of affiliates can be rationalized in a theoretical framework that combines three ingredients—a multiproduct setup, Antràs' property-rights model, and Melitz's heterogeneity view on productivity applied to affiliates. Therefore, the paper's key contribution lies in identifying the extensive margin of intrafirm trade—headquarters-intensive firms tend to integrate larger numbers of productive suppliers as affiliates, and will redraw their boundaries under trade liberalization.

Keywords: Extensive margin, intrafirm trade, multiple affiliates, FDI.

JEL Classification: F14, F23.

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1 Introduction

Recent firm-level approach reveals that fluctuations in intra-industry trade are dominated by extensive margin. Specifically, the variation in the number of exporters and the scope of exported varieties (extensive margin) account for a greater share of the changes in aggregate trade than the variation in the average exports per firm-variety (intensive margin).[1] Does intrafirm trade follow a similar pattern? This paper defines intrafirm trade as domestic headquarters' (henceforth HQ) imports of manufactured parts from foreign upstream affiliates within a firm's boundaries. Like previous literature,[2] the share of intrafirm imports as total U.S. imports is found to be higher, the higher the HQ-services-input intensity of the industry of foreign affiliates in a cross-industry dataset. The novel finding is that this increase in intrafirm imports is mainly due to the acquisition of a large number of *productive* foreign affiliates. In a cross-country dataset, on the one hand, lower export costs attracts more manufactured-part suppliers to enter the export marketplace, and on the other hand, lower wages and better contract enforcement attract greater amounts of U.S. direct investment in a country. The paper demonstrates these attractions materialize mostly in terms of larger numbers of export affiliates than in terms of more cross-border sales per affiliate.

Firm's endogenous choice of affiliate number can be rationalized in a theoretical framework that combines three ingredients—Antràs' property-rights model of vertically fragmented production, Melitz's view of productivity heterogeneity applied to exporting affiliates, and a multiproduct setup widely used in the industrial organization literature. Deviated from the seminal work of Antràs (2003), where a single-product firm decides whether to integrate or outsource from its sole supplier, this paper studies the organizational choice of a single-brand multiproduct firm consisting of one HQ and a spectrum of suppliers. Each variety is distinct, thus requires two specially designed intermediate inputs—manufactured parts made by a supplier and paired HQ services provided by the HQ. Contract incompleteness leads to ex-ante underinvestment in intermediate inputs. Ex post, all suppliers under the same brand name unite to bargain with the HQ over allocation of sales revenue. There is a trade-off in integrating many suppliers, as it strengthens HQ's bargaining power but discouraging investment in manufactured parts. Intensive demands on HQ services in all product lines motivate a firm to integrate more suppliers as affiliate. Different suppliers bring different productivity draws into final-good production. In the presence of fixed integration costs, only affiliates with higher productivity will be integrated. The HQ can thus attain the optimal bargaining result by internaliz-

[1] See, for example, Bernard, Jensen, Redding, and Schott (2009).

[2] See, for example, Antràs (2003), and Nunn and Trefler (2008).

ing the fewest number of suppliers. In an open economy, manufactured parts are traded across borders, but final varieties are nontradable. The coexistence of beachhead costs and heterogeneity in productivity implies endogenous selection of exporters in a foreign country. Export suppliers not only have higher productivity than domestic suppliers on average but also lead to the invention of new varieties. With access to exporters, domestic HQ redraws boundaries—a fraction of *domestic* affiliates with relatively lower productivity ranks are rearranged as stand-alone outsiders to make some spaces for competent newcomers from the foreign country.

Related Literature. This paper is related to several branches of literature. First and foremost, the paper builds on nascent works that consider firm boundary as a mechanism to reduce bargaining inefficiency in an incomplete contract. This growing body of literature stems from Antràs (2003), where a plant providing labor intensive inputs is internalized by the HQ if final-variety production involves more capital-intensive inputs. Trade happens because countries differ in factor endowment. In a more recent paper, Antràs (2005) applies this idea to study product's life cycle in a North-South trade model, in which the South endures incomplete contracts, whereas the North is endowed with well-established contracting institutions. Antràs and Helpman (2004) develop a property-rights theory of transnational firm that allows for intra-industry heterogeneity in HQ's productivity as in Melitz (2003) combined with the organizational structure as in Antràs (2003). Their main result is that high productivity parent firm in HQ-intensive sectors are more likely to choose integration strategies, whereas in component-intensive sectors outsourcing is pervasive. Antràs and Helpman (2008) generalize this framework. In addition to assuming different contractibility across countries, they accommodate varying degrees of contractual frictions across input investments. HQ and its plants undertake a continuum of relation-specific investments, with a fraction of these investments contractible as in Acemoglu, Antràs, and Helpman (2007), to produce an intermediate input used in the production of final variety. They find that improvements in the contractibility in a country lead to an increase in the prevalence of foreign direct investment and related-party trade. The empirical evidence for the main predictions in Antràs (2003) and Antràs and Helpman (2004, 2008) is provided by Nunn and Trefler (2008). Secondly, this paper applies the firm-level heterogeneity by Melitz (2003) to plant-level, since on one hand, manufacturing plants are the exporters in this model and, on the other hand, HQ can still differ in overall productivity derived from a combination of all its affiliates' productivities. Thirdly, the multiproduct setup allows this paper to introduce multiple affiliates within a firm/brand and, more importantly, to generate the rationalization of affiliate scope after trade opening to intermediate inputs, which is similar to the variety scope adjustments under trade shocks as in Ma (2008). Finally, multiple affiliates can be modeled through alternative ways. Schwarz (2009) studies single product requiring multiple inputs besides HQ services, with each input supplied by an individual plant either as a subsidiary or an arm's-length partner. His formulation leads to the prediction that plants producing complex inputs that are proximate to the final-variety are more likely to be integrated within the boundaries. Since plants are exogenously different by definition of production function, there is no dynamics of sorting into different organizational forms, which is of critical importance to generate the extensive margin of intrafirm trade.

The rest of the paper is organized as follows. The paper begins with analysis of a closed economy in section 2. Section 3 studies a two-country open economy and discuss the impact of trade liberalization on structural reorganization. The paper then investigates the main predictions using data on U.S. multinational companies in section 4. Section 5 concludes, followed by a technical appendix A including all derivations.

2 Closed Economy Equilibrium

Consider the home country in autarky.

Demand. A representative consumer has CES preference over a continuum of different brands, $i \in [0, 1]$,

$$Q = \left(\int_{i=0}^{1} q(i)^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}}, \ \theta > 1.$$

The brand output, $q(i)$, represents the aggregated quantity of a basket of final varieties, $j \in \Omega$,[3]

$$q(i) = \left(\int_{j \in \Omega} q_j(i)^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}}, \ \sigma > 1, \tag{1}$$

where $q_j(i)$ is the variety output for j under brand i. One can think of this commodity hierarchy as capturing an industry (e.g., portable consumer electronics in the U.S.) consisting of many brands (e.g., Microsoft, Apple, Google, Sony, Amazon), under which the HQ of each brand supplies a line of varieties (e.g., laptop, smart phone, MP3 player, eBook reader, tablet) to local customers.

The price index for consumption composite, Q, is denoted as

$$P = \left(\int_{i=0}^{1} p(i)^{1-\theta} di \right)^{\frac{1}{1-\theta}},$$

where $p(i)$ is the price index for $q(i)$,

$$p(i) = \left(\int_{j \in \Omega} p_j(i)^{1-\sigma} dj \right)^{\frac{1}{1-\sigma}},$$

[3] Ω is the set of goods available to consumers in the home country. Though fixed in a closed economy, its size will be endogenously determined after opening to trade of intermediate inputs.

and $p_j(i)$ is the unit price of $q_j(i)$.

Take the consumption composite and two tiers of price indices as given, the demand functions for brand output and variety output are, respectively,

$$q(i) = QP^{\theta} p(i)^{-\theta}, \ \forall i,$$

and

$$q_j(i) = QP^{\theta} p(i)^{\sigma-\theta} p_j(i)^{-\sigma}, \ \forall i, \ j.$$

The total revenue generated by sales of brand output is

$$\begin{aligned} R(i) &= p(i)q(i) \\ &= Q^{\frac{1}{\theta}} P q(i)^{\frac{\theta-1}{\theta}}. \end{aligned} \tag{2}$$

Alternatively, this revenue can be viewed as the summation of all variety revenues under the same brand,

$$R(i) = \int_{j\in\Omega} R_j(i)dj,$$

where variety revenue is defined similarly below,

$$\begin{aligned} R_j(i) &= p_j(i)q_j(i) \\ &= Q^{\frac{1}{\sigma}} P^{\frac{\theta}{\sigma}} p(i)^{\frac{\sigma-\theta}{\sigma}} q_j(i)^{\frac{\sigma-1}{\sigma}}. \end{aligned} \tag{3}$$

Moreover, the fraction of brand revenue that is contributed by sales of variety j is proportional to variety output as a fraction of brand output,

$$\frac{R_j(i)}{R(i)} = \left[\frac{q_j(i)}{q(i)}\right]^{\frac{\sigma-1}{\sigma}}. \tag{4}$$

Production. The production of any variety j involves two parties—one HQ denoted by H, who owns the brand, and one manufacturing plant denoted as M_j.[4] The technology is a Cobb-Douglas assembly of two variety-specific intermediate inputs: HQ services, h_j, and manufactured parts, m_j.

$$q_j = z_j \left(\frac{h_j}{\eta_h}\right)^{\eta_h} \left(\frac{m_j}{\eta_m}\right)^{\eta_m}, \ \eta_h \in [0,1], \ \eta_m = 1-\eta_h, \tag{5}$$

where z_j is the productivity parameter, whereas η_h and η_m are, respectively, the intensity parameters for h_j and m_j. Intensity parameters are the characteristics associated with the brand, hence, the same across different varieties managed by that brand. HQ services can be produced only by H with a variable cost c_h

[4] Since brands are symmetric, the paper will focus on one brand from now on, and drop i in the brackets to avoid clutter.

per unit of h_j, and manufactured parts can be produced only by M_j with a variable cost c_m per unit of m_j.[5] By definition, H must hire a M_j in order to produce variety j at some productivity level z_j, which is drawn by M_j from a known distribution $G(z)$ with support $[z_{\min}, z_{\max}]$. Productivity parameters are asymmetric across varieties within one brand. Each M_j realizes its own productivity upon the establishment of cooperation agreements with the HQ.

It is assumed that both intermediate inputs for one variety are specially designed for its use, therefore worthless for other varieties. As a result, there exists two-way hold-up problem given contracts are incomplete.[6] After investments in inputs have been made, H and a coalition of all manufacturing plants, denoted as M, play a generalized Nash bargaining game to determine the allocation of brand revenue R: H gains $\beta_h \in [0, 1]$ fraction, and M gains $\beta_m = 1 - \beta_h$ fraction. Since β_h will depend solely upon bargaining powers ex post, ex-ante investments are inefficient. To provide investment incentives, H builds up the optimal balance of bargaining powers between itself and M.

The hiring relationship between H and a single M_j can either take the form of vertical integration or outsourcing. With vertical integration, H pays a fixed fee to acquire M_j as one of its subsidiaries; hence, obtain the right to seize a fraction of M_j's output when bargaining breaks down. Anticipating this loss of ex-post bargaining power and a corresponding decrease in revenue share, M_j will further decrease investment. With outsourcing, H buys manufactured parts from an outsider, M_j; thus, exposes to the threat of cutting supply. A raise in M_j's ex-post bargaining power increases β_m but encourages investment.

An organizational form, denoted by $\gamma \in \Gamma$, is defined as a spectrum of binary hiring choices for all plants M_j, $j \in \Omega$. There is a one-to-one mapping between the set of organizational forms, Γ, and the share of brand revenue flows to the HQ, β_h. In other words, choosing Γ is equivalent to choosing its corresponding β_h. For example, consider two elements in the set of an organizational form, γ_k and $\gamma_l \in \Gamma$. Without loss of generality, suppose γ_k represents integrating M_j's with $j \leq k$, while γ_l represents integrating M_j's with $j \geq l$. Although they have different integration strategies, both lead to the same pattern of brand revenue allocation.

To sum up, the HQ faces the trade-off that an integration oriented Γ reduces R and increases β_h, while an outsourcing oriented Γ sacrifices β_h to improve R. The optimal set, Γ, relies on the intensity of HQ services,

[5] In an open economy, this assumption prohibits HQ from building manufactured plants in a foreign country from scratch (the so-called Greenfield). Therefore, the only way to set up a foreign affiliate is by acquiring existing export suppliers.

[6] Incomplete contract in this paper means that the share of brand revenue apportioned to the HQ is the only item can be contracted upon.

η_h, and the final choice of element, γ, relies on the distribution of productivity draws, z_j, over all varieties under the brand of H.

Timing. The timing of events is as follows.

1. $\forall j$, H enters into a cooperation agreement with any one plant among a large number of *identical* candidates, and refers to the selected as M_j.

2. A Ω set of M_j find out their productivity draws separately, and found M to fight for a more favorable bargaining result.

3. H chooses Γ to set up according bargaining powers.

4. H chooses γ from Γ to minimize the integration costs.

5. H and M simultaneously choose their optimal investments in intermediate inputs $\{h_j\}_{j\in\Omega}$ and $\{m_j\}_{j\in\Omega}$, respectively.

6. Bargain over the incoming R begins, H proposes a revenue dividing scheme which keeps β_h fraction to itself, and offers the rest to M.

7. If M rejects, M gets nothing while H seizes a fraction of q_j from each integrated M_j defined in γ.

8. If M accepts the offer, then M transports $\{m_j\}_{j\in\Omega}$ to H, where q_j amount of variety j is assembled, $\forall j$.

9. Revenue R is collected, then divided in proportions specified in the offer.

10. M distributes its share of profit, $\beta_m R$, to all M_j in a pro rata share of their contributions—$\beta_m R_j$ to plant M_j, $\forall j$.

Profit Maximization. The profit maximization problem is solved using backward induction.

At step 5, the optimal Γ, or equivalently, β_h is known. Given $\{m_j\}_{j\in\Omega}$, H maximizes its share of profit by choosing various investments in HQ services.

$$\max_{\{h_j\}_{j\in\Omega}} \beta_h R - c_h \int_{j\in\Omega} h_j dj,$$

subject to brand output (1), the definition of brand revenue (2), and variety production functions (5). Similarly, M maximizes its profit given $\{h_j\}_{j\in\Omega}$.

$$\max_{\{m_j\}_{j\in\Omega}} \beta_m R - c_m \int_{j\in\Omega} m_j dj,$$

subject to Eqs. (1), (2) and (5). Combine the first order conditions with Eq. (4), this noncooperative game yields:

$$\begin{cases} h_j = \left(\frac{\beta_h \eta_h}{c_h}\right) \frac{\theta-1}{\theta} R_j; \\ m_j = \left(\frac{\beta_m \eta_m}{c_m}\right) \frac{\theta-1}{\theta} R_j, \end{cases} \tag{6}$$

for all $j \in \Omega$.

At step 3, H observes all the productivity draws in its manufacturing facilities, and chooses β_h to maximize ex-ante total profit.

$$\pi \equiv \max_{\beta_h} \int_{j\in\Omega} R_j dj - c_h \int_{j\in\Omega} h_j dj - c_m \int_{j\in\Omega} m_j dj, \tag{7}$$

subject to Eqs. (3) and (5), and incentive compatibility constraints (6) from step 5. Substitute all the constraints into the objective function to obtain an alternative maximization problem,[7]

$$\pi = \max_{\beta_h} ZA,$$

where Z is some measure of overall brand productivity,

$$Z \equiv \left(\int_{j\in\Omega} z_j^{\sigma-1} dj\right)^{\frac{1-\theta}{1-\sigma}},$$

the constant component in A reflects the impacts of consumer demands as well as variable costs of input investment on profit, and the variant component in A represents the trade-off between revenue pie and HQ's slice,

$$\begin{aligned} A \equiv & \underbrace{QP^{\theta}\left(\frac{\theta-1}{\theta}\right)^{\theta-1} c_h^{-\eta_h(\theta-1)} c_m^{-\eta_m(\theta-1)}}_{\text{Constant Component}} \\ & \times \underbrace{\left[1-\left(\frac{\theta-1}{\theta}\right)(\eta_h\beta_h+\eta_m\beta_m)\right]\beta_h^{\eta_h(\theta-1)}\beta_m^{\eta_m(\theta-1)}}_{\text{Variant Component}}. \end{aligned}$$

To find the optimum, it is sufficient to maximize the variant component in A subject to $\beta_m = 1-\beta_h$ and $\eta_m = 1-\eta_h$. If H can choose β_h freely from the $[0,1]$ interval, then there is an unique analytical expression for the optimal share of revenue,

$$\beta_h^*(\eta_h) = \frac{\eta_h\left[1+(\theta-1)\eta_h\right]-\sqrt{\eta_h(1-\eta_h)\left[\theta-(\theta-1)\eta_h\right]\left[1+(\theta-1)\eta_h\right]}}{\theta(2\eta_h-1)},\ \eta_h \neq \frac{1}{2},$$

with $\beta_h^*\left(\frac{1}{2}\right) = \frac{1}{2}$.[8] Note $\beta_h^*(0) = 0$, $\beta_h^*(1) = 1$, $\beta_h^{*\prime}(\eta_h) > 0$, $\beta_h^{*\prime\prime}(\eta_h) > 0$ when $\eta_h > \frac{1}{2}$ and $\beta_h^{*\prime\prime}(\eta_h) < 0$ when $\eta_h < \frac{1}{2}$.

[7] See the derivation in Appendix A.1.

[8] See the derivation in Appendix A.2.

Proposition 1 *Brands with high intensity in HQ services tend to acquire strong bargaining power against a group of collusive upstream plants.*

Choices of Organizational Form. More notations are needed to discuss the optimal organizational form γ. Consider a generalized Nash bargaining game, where two players bargain over a certain amount. Assume the results are always the same such that β fraction is distributed to one party (without loss of generality, say, the HQ) and the rest to another party (the suppliers' union). Let δ be the fraction of q_j that can still be produced when bargain fails and, consequently, H seizes some manufactured parts from M_j if M_j is an integrated affiliate.

What H chooses in the original problem (7) is the set of organizational forms, Γ, which is lower bounded by a singleton, Γ_O, where H outsources from all M_j, and upper bounded by another singleton, Γ_I, where all plants are integrated by H. These boundaries restrict H to choose β_h from a subset of $[0,1]$, namely, $\left[\beta, \beta+(1-\beta)\delta^{\frac{\theta-1}{\theta}}\right]$. If H chooses Γ_O, then bargain breakdown leaves 0 residual to both H and M. Since the amount to bargain over is the brand revenue R, H gains βR, while M gains $(1-\beta)R$. If H chooses Γ_I, then the outside option for M is again 0 when M rejects the offer, but H will be able to produce δ fraction of q_j for all variety $j \in \Omega$. According to Eq. (1), δq quantity of brand output are sold, and further translated into a sales revenue of $\delta^{\frac{\theta-1}{\theta}} R$. The amount that is subject to bargaining becomes $\left(1-\delta^{\frac{\theta-1}{\theta}}\right) R$. Therefore, H gains

$$\left[\beta+(1-\beta)\delta^{\frac{\theta-1}{\theta}}\right] R = \underbrace{\delta^{\frac{\theta-1}{\theta}} R}_{\text{Outside Option}} + \underbrace{\beta\left(1-\delta^{\frac{\theta-1}{\theta}}\right) R}_{\text{Bargain Share}},$$

and leaves the rest, $(1-\beta)\left(1-\delta^{\frac{\theta-1}{\theta}}\right) R$, to M. If H chooses an off-boundary set, denoted by Γ_{Mix}, then some plants in M are integrated subsidiaries while others are outsiders. However, it is still unclear which plants to integrate, since Γ_{Mix} is no longer a singleton. To find out the answer, an additional problem has to be solved.

At step 4, taking Γ_{Mix} as given, H picks out the element that minimizes the total costs incurred in integration.

$$\min_{\gamma \in \Gamma_{Mix}} f_I \times \text{number of integrated plants in } \gamma,$$

where f_I denotes the the fixed fee to integrate any one manufacturing plant. There is however no such costs for outsourcing, $f_O = 0$. Rank all plants under the same brand from high to low according to their productivity draws, i.e., $z_j \geq z_k$, $\forall j < k$ and $j, k \in \Omega$. To attain the desired revenue share with the smallest number of subsidiaries, H starts integration from M_0, who possesses the highest productivity technology, and continues to do so towards the other end. Suppose H arrives at β_h^* after acquiring M_k with a cutoff productivity, z_k. Put it another way, all M_j with $z_j \geq z_k$ are integrated facilities, and others with $z_j < z_k$ are outsiders. When two parties fail to reach an agreement, M gains nothing as usual, while H now produce ε_k fraction of q. Define $\varepsilon_k \in [0, \delta]$ as

$$\varepsilon_k \equiv \frac{\left(\int_{j \leq k} \delta q_j^{\frac{\sigma-1}{\sigma}} dj\right)^{\frac{\sigma}{\sigma-1}}}{q}.$$

Using Eqs. (1), (5), (6), and (A.1)[9], this fraction degenerates to

$$\begin{aligned} \varepsilon_k &= \delta \left(\frac{\int_{j \leq k} z_j^{\frac{(\sigma-1)^2+(\sigma-1)}{\sigma}} dj}{\int_{j \in \Omega} z_j^{\frac{(\sigma-1)^2+(\sigma-1)}{\sigma}} dj} \right)^{\frac{\sigma}{\sigma-1}} \\ &= \delta \left(\frac{\int_{j \leq k} z_j^{\sigma-1} dj}{\int_{j \in \Omega} z_j^{\sigma-1} dj} \right)^{\frac{\sigma}{\sigma-1}} \\ &= \delta Z^{\frac{\sigma}{1-\theta}} \left(\int_{j \leq k} z_j^{\sigma-1} dj \right)^{\frac{\sigma}{\sigma-1}}. \end{aligned} \quad (8)$$

Therefore, H gains $\left[\beta + (1-\beta)\varepsilon_k^{\frac{\theta-1}{\theta}}\right] R$, and leaves the rest, $(1-\beta)\left(1-\varepsilon_k^{\frac{\theta-1}{\theta}}\right) R$, to M.[10][11]

Let η_h^L and η_h^H denote, respectively, the HQ services intensities lead to lower and upper boundaries. They are implicitly defined by

$$\begin{cases} \beta_h^*\left(\eta_h^L\right) = \beta; \\ \beta_h^*\left(\eta_h^H\right) = \left[\beta + (1-\beta)\delta^{\frac{\theta-1}{\theta}}\right]. \end{cases}$$

Proposition 2 *In a closed economy, if all manufacturing plants under brand* i, $M_j(i)$, *are ranked by their productivity draws* z_j *in a descending order, then the HQ of this brand,* $H(i)$, *will adopt the organizational form depending upon its intensity parameter of HQ services. Specifically,* $H(i)$ *adopts*

1. Γ_O *if* $\eta_h(i) \in \left[0, \eta_h^L(i)\right]$;

[9] Essentially as for the integration over j is concerned, one can treat R_j as $K\ z_j^{\sigma-1}$, and K can be taken outside the intergration.

[10] Notice $\varepsilon_k = 0$ implies that Γ_{Mix} shrinks to Γ_O, and $\varepsilon_k = \delta$ takes one back to Γ_I.

[11] If all plants are ranked from low to high instead, then H stops the process of integration at M_l. The fraction ε_k will be defined as,

$$\varepsilon_k \equiv \delta \left(\frac{\int_{j \leqslant l} z_j^{\sigma-1} dj}{\int_{j \in \Omega}^{\infty} z_j^{\sigma-1} dj} \right)^{\frac{\sigma}{\sigma-1}}.$$

To attain the same value of ε_k, a larger number of affiliates ($l > k$) is required in this alternative ranking method, which is less preferred.

2. Γ_I *if* $\eta_h(i) \in \left[\eta_h^H(i), 1\right]$;

3. $\gamma_{k(i)} \in \Gamma_{Mix}$ *if* $\eta_h(i) \in \left(\eta_h^L(i), \eta_h^H(i)\right)$, *where* $\gamma_{k(i)}$ *means integrates* $M_j(i)$ *with* $j \leq k(i)$ *and outsources from* $M_j(i)$ *with* $j > k(i)$, $\forall j \in \Omega$.

In conclusion, the optimal set of organizational forms, Γ, is mapped one-to-one to $\beta_h^*(\eta_h)$. Hence, Γ depends solely upon the intensity parameter of the HQ services, η_h. The optimal element, $\gamma \in \Gamma$, is mapped one-to-one to k after all plants are ranked. Figure 1 gives an illustration. Brands differ in organizational forms: greater HQ services intensity, $\eta_h(i)$, results in an integration oriented strategy—a larger $k(i)$ number of affiliates.

3 Open Economy and The Impact of Trade Liberalization

The world consists of two countries—home and foreign. Assume only manufactured parts are traded across borders, whereas varieties are nontradable. To be consistent with the previous example of portable electronics industry, one can think of the following stylized fact—most parts of iPod shuffle are made in factories outside the U.S., however, the primary target of sales is the U.S. market.

Using an apostrophe, the foreign brand that corresponds to home brand i is denoted by i'. Foreign plants under brand i' can only serve the corresponding home brand i. A new domestic variety under brand i with its manufactured parts supplied by a foreign plant is denoted as $j' \in \Omega'$. The manufactured parts for variety j' are produced by a foreign plant, $M_{j'}$, with a variable cost $c'_m < c_m$ per unit of $m_{j'}$. For simplicity, the fixed fee of acquiring a foreign plant is the same as integrating a domestic plant. It is also assumed that the domestic HQ can only collaborate with exporting foreign manufacturing plants. Foreign plants face two types of costs when ship their manufactured parts to the home country—a fixed cost to start exporting, f, and a unit export cost, τ. It is only after the realization of productivity draws that foreign manufacturers decide whether to export based on the below free entry condition:

$$\beta_m R_{j'} - (\tau + c'_m) m_{j'} \geq f, \tag{9}$$

where foreign plant j''s export revenue $R_{j'}$ and cross-border sales $m_{j'}$ are defined similarly as in Eq. (3) and (6), respectively. The export profit in the left hand side is strictly increasing in $z_{j'}$.[12] This condition implies that only foreign plants with productivity level, $z_{j'} \geqslant \overline{z}$, will export and make positive profit out

[12] See the derivation in Appendix A.3.

of intrafirm trade. Assume $\max\{z_{j'} : z_{j'} \geqslant \overline{z}\} > z_k$ to capture the idea that foreign entrance indeed affect the organizational choice of domestic HQ.[13] Home and foreign are identical except for labor cost and the distribution of affiliate productivity levels. Note that, although all foreign plants draw productivity from the same distribution, $G(\cdot)$, as their domestic counterparties, actual exporting foreign plants form a different conditional distribution.

In an open economy, the revenue share apportioned to H stays unchanged.

$$\beta_h^* = \left[\beta + (1-\beta)\varepsilon_k^{\frac{\theta-1}{\theta}}\right] = \left[\beta + (1-\beta)\varepsilon_{k'}^{\frac{\theta-1}{\theta}}\right] \Rightarrow \varepsilon_k = \varepsilon_{k'}.$$

With foreign subsidiaries involved, the fraction of brand output that can be captured by the HQ, $\varepsilon_{k'}$, is now defined as

$$\varepsilon_{k'} = \delta Z'^{\frac{\sigma}{1-\theta}} \left[\left(\int_{j\leq k} z_j^{\sigma-1} dj\right)^{\frac{\sigma}{\sigma-1}} + \left(\int_{z_{j'}>\overline{z}} z_{j'}^{\sigma-1} dj'\right)^{\frac{\sigma}{\sigma-1}}\right],$$

where Z' is the new measure of overall brand productivity with foreign participation. Recall the definition of ε_k in Eq. (8),

$$\delta Z^{\frac{\sigma}{1-\theta}} \left(\int_{j\leq k} z_j^{\sigma-1} dj\right)^{\frac{\sigma}{\sigma-1}} = \delta\left(Z'\right)^{\frac{\sigma}{1-\theta}} \left[\left(\int_{j\leq k'} z_j^{\sigma-1} dj\right)^{\frac{\sigma}{\sigma-1}} + \left(\int_{z_{j'}>\overline{z}} z_{j'}^{\sigma-1} dj'\right)^{\frac{\sigma}{\sigma-1}}\right].$$

As there are more plants/productivity draws under the same brand, the new overall productivity measure $Z' > Z$. Therefore, we must have $k' < k$ in order to make the above equation satisfied.

International trade is beneficial since, on the one hand, domestic consumers have access to new varieties invented with foreign suppliers' participation (the basket of domestic consumption becomes $\Omega \cup \Omega'$), and on the other hand, domestic HQ improve profitability by operating at a high aggregate productivity Z' and low investment costs c'_m.[14]

Proposition 3 *When the market of intermediate inputs in the home country is open to imports of foreign manufactured parts, brand manager in the home country tends to*

1. *expand the range of varieties with new varieties invented by the participation of foreign manufactured parts;*

[13] Conversely, $\max\{z_{j'} : z_{j'} \geqslant \overline{z}\} \leqslant z_k$ suggests that all exporting foreign plants will become outside suppliers. Let $z_k = z_{\max}$ when Γ_O is the right organizational form, and $z_k = z_{\min}$ when Γ_I is chosen.

[14] Figure 2 lays out the vertical structure in an open economy. This paper ignores the market-seeking purpose of setting up foreign subsidiaries, which is more common in horizontal FDI than vertical FDI. Instead the paper focuses on the factor-seeking purpose. For example, in the portable electronics industry, standardized parts are offshored to cheaper and more efficient factories in a foreign country. In addition, the manufactured parts in electronics devices are high value to weight. This saves transportation costs, thus, makes vertical FDI more attractive.

2. *rationalize on its organizational form, through substituting a number of domestic affiliates with fewer foreign affiliates;*

3. *integrate a larger scope of foreign affiliates when the brand's HQ services intensity is higher.*

Since the total number of integrated plants is shrinking through substituting one high productive foreign affiliate for several relatively low productive domestic affiliates, the HQ lowers expenditures on merger and acquisition, but at the same time maintains its desired bargaining power.

Proposition 4 *When there is trade liberalization in an open economy, specifically, a decrease in exporting costs τ and/or entry fee f raises the total amount of intrafirm imports through increasing the number of foreign affiliates.*

The intuition is that when τ and/or f reduce(s) more foreign plants are qualified to export according to Eq. (9), as a result, the domestic HQ has access to a larger pool of potential M&A targets and integrate more of them. One can expect to observe an increasing volume of manufactured parts transported across borders.

4 Empirical Analysis

The empirical part investigates, separately, the impact of industry characteristics and trade barriers on the number of foreign affiliates as well as their shipments to parent firms, in a cross-sectional dataset of the year 2007 for multinational companies headquartered in the United States.

Hypothesis 1 ***"The extensive margin"*** *of FDI and intrafirm trade*

Parent companies in a high HQ-intensity industry (or brand as in this paper) tend to integrate a large number of foreign affiliates with high productivity draws. This increase in extensive margin contributes to the large volume of intrafirm imports, even though high η_h can exert a negative impact on imports per affiliate via lowering intensive margin.[15]

At the NAICS 4-digit classification by industry of affiliate, Hypothesis 1 is tested in Eq. (10) with 114 observations on the number of majority-owned nonbank foreign affiliates and their financial and operating data in an industry, using Bureau of Economic Analysis (BEA) dataset on U.S. multinational companies' direct investment abroad. Eq. (11) considers the overall impacts of extensive and intensive margin on

[15] According to Eq. (6), the output of manufactured parts per affiliate, m_j, is decreasing in HQ-intensity, $\eta_h = 1 - \eta_m$.

intrafirm imports. In particular, the paper considers the cross-industry regressions with:[16]

$$\ln(\text{No. of Affiliates}_i) = \alpha_0 + \alpha_1 \ln(\frac{K_i}{L_i}) + \alpha_2 \ln(\frac{M_i}{L_i}) + \alpha_3 \ln(\frac{RD_i}{L_i}) + \alpha_4 \ln(\frac{Q_i}{L_i}) + \epsilon_i, \tag{10}$$

and

$$\ln(\text{Intrafirm Imports}_i) = \rho_0 + \rho_1 \ln(\frac{K_i}{L_i}) + \rho_2 \ln(\frac{M_i}{L_i}) + \rho_3 \ln(\frac{RD_i}{L_i}) + \rho_4 \ln(\frac{Q_i}{L_i}) + u_i, \tag{11}$$

where $\ln(\text{No. of Affiliates}_i)$ is log of the number of foreign affiliates owned by U.S. HQ in industry i, and $\ln(\text{intrafirm trade}_i)$ is log of the intrafirm U.S. imports shipped by foreign affiliates to their U.S. parent firms as a share of total U.S. imports in industry i; $\ln(\frac{K_i}{L_i})$ is log of capital expenditures divided by compensation of employees, and $\ln(\frac{RD_i}{L_i})$ is log of the research and development expenditures divided by wages;[17] $\ln(\frac{M_i}{L_i})$ is the log of expenses on materials such as property, plant, and equipment divided by wages; the log of affiliate sales divided by wages, $\ln(\frac{Q_i}{L_i})$, measures the average affiliate's productivity in industry i; ϵ_i and u_i are unobserved industry-specific errors. Capital intensity, $\ln(\frac{K_i}{L_i})$, and R&D intensity, $\ln(\frac{RD_i}{L_i})$, capture the HQ services intensity. On the contrary, material intensity, $\ln(\frac{M_i}{L_i})$, is created to measure the input that is *not* likely provided by the HQ.

The results are shown in Table 1. In all specifications for Eq. (10), the coefficients for HQ services intensity are positive and significant, whereas the estimated coefficient for manufactured parts intensity is negative and significant. Higher average affiliate productivity entices parent firms to acquire larger scope of integration. Since standardized coefficients are reported, one can easily assess and compare their magnitudes. Take column [10-III] for example. Controlling for all other explanatory variables, an increase of 1 standard percentage of capital intensity and material intensity results in, respectively, a 0.676 deviation increase and a 0.839 deviation decrease in the percentage of affiliate numbers. The estimated coefficient for R&D intensity is however much smaller at 0.262. In all specifications for Eq. (11), this paper concludes that no statistically significant relationship exists in coefficients for capital and material intensity, probably due to the small sample size. The second part of Hypothesis 1 is verified indirectly. In industry i, define

$$\text{Average Imports per Affiliates}_i = \frac{\text{Intrafirm Imports}_i}{\text{No. of Affiliates}_i}.$$

Compare column [11-III] and [10-III], an increase of 1 standard unit of capital intensity causes the overall intrafirm trade to increase by $\rho_1 \times$ Intrafirm Imports_i, which is smaller than the increase in aggregate intrafirm

[16] Log transformation is used since there is evidence that data are skewed to the right.

[17] Since R&D expenditures in Eq. (10) includes several zeros, the paper adapts log transformation by adding a constant 0.5 to each data value.

trade contributed by the newly established affiliates alone, $\alpha_1\times$ No. of Affiliates$_i\times$ Average Imports per Affiliates$_i$. This difference must come from the negative impacts from a decrease in the sales per affiliate.

Hypothesis 2 ***"The effects of trade liberalization"***

A reduction in either the exporting costs τ or the entry fee f leads to a expansion in the range of exporting foreign affiliates and a resulting increase in total intrafirm trade.

This prediction is estimated by the following regressions that look across 109 countries:

$$\ln(\text{No. of Affiliates}_c) = \alpha'_0 + \alpha'_1 \ln(\tau_c) + \alpha'_2 \ln(f_c) + \alpha'_3 \ln(Enf_c) + \alpha'_4 \ln(\frac{L_c}{K_c}) + \epsilon'_c, \tag{12}$$

and

$$\ln(\text{Related Party Imports}_c) = \rho'_0 + \rho'_1 \ln(\tau_c) + \rho'_2 \ln(f_c) + \rho'_3 \ln(Enf_c) + \rho'_4 \ln(\frac{L_c}{K_c}) + u'_c, \tag{13}$$

where ln(No. of Affiliates$_c$) is log of the overall number of foreign affiliates operating in country c owned by U.S. HQ, and ln(Related Party Imports$_c$) is log of the related party imports as percentage shares of total imports from all foreign affiliates in country c to their parent firms in the U.S.;[18] $\ln(\tau_c)$ is log of exporting costs per standard container shipped out of country c (Doing Business Data: Trading Across Borders); $\ln(f_c)$ is the log of expenses to start a business in country c (Doing Business Data: Starting a business), used to proxy the fixed fee of entering into exporting marketplace; $\ln(Enf_c)$ is log of contract enforcement costs in country c (Doing Business Data: Enforcing Contracts); $\ln(\frac{L_c}{K_c})$ is log of foreign affiliate's compensation on employees divided by capital expenditures; ϵ'_i and u'_i are unobserved errors for country-specific characteristics. This paper utilizes the last two independent variables to control for the differences in contract incompleteness and labor costs across countries. Cheaper enforcement and lower wage indicates a favorable FDI environment. Estimates of Eqs. (13) and (12) are summarized in Table 2. All varieties of costs have negative impacts on the multinational activities. Statistically significant coefficients are found for entry fee f in specifications of both equations. However, the estimated coefficients for exporting costs τ have *no* statistically important impacts on intrafirm trade in all specifications of Eq. (13). For trade policy makers, this implies that a reduction in entry fee may be more efficient than a reduction in unit exporting costs.

[18] Related party imports are defined as trade with an entity located outside the U.S. in which the importer holds at least a 6% equity interest in the exporter. Using Intrafirm Imports$_c$ as independent variable creates problems since definitions and government policies on fully-owned affiliates differ across countries.

5 Concluding Remarks

The distinction between extensive and intensive margins identified in recent theoretical research in international trade also plays an important role in multinational activities, which are considered as complements to trade. For the U.S., 32% of imports in 2007 were intrafirm shipments to multinational parents from their majority-owned affiliates as a result of FDI, let alone the shares of arm's-length trade between multinationals and unaffiliated suppliers from all over the world. The establishment of a new affiliate can contribute up to 2% of intrafirm trade on average. This paper addresses the questions of how many input suppliers should be selected as affiliates within the boundaries of a transnational firm, and how the optimal number of affiliates vary across firms and countries, and in response to movements of trade barriers. Additional empirical examination of firms' characteristics and their investment environment that shape the respective contributions of the extensive and intensive margins, e.g., investigating a more disaggregated (6-digit NAICS) and detailed (with FDI origins and destinations) firm-level panel, would be helpful.

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A Appendix

A.1 The Derivation of Alternative Objective Function

Use Eqs. (5) and (6) to expand the variety revenue.

$$\begin{aligned}
R_j &= Q^{\frac{1}{\sigma}} P^{\frac{\theta}{\sigma}} p^{\frac{\sigma-\theta}{\sigma}} q_j^{\frac{\sigma-1}{\sigma}} \\
&= Q^{\frac{1}{\sigma}} P^{\frac{\theta}{\sigma}} p^{\frac{\sigma-\theta}{\sigma}} \left[z_j \left(\frac{\beta_h}{c_h}\right)^{\eta_h} \left(\frac{\beta_m}{c_m}\right)^{\eta_m} \frac{\theta-1}{\theta} R_j \right]^{\frac{\sigma-1}{\sigma}} \\
&= \underbrace{QP^{\theta} p^{\sigma-\theta} \left(\frac{\theta-1}{\theta}\right)^{\sigma-1} c_h^{-\eta_h(\sigma-1)} c_m^{-\eta_m(\sigma-1)} \beta_h^{\eta_h(\sigma-1)} \beta_m^{\eta_m(\sigma-1)}}_{K:\quad \text{Factor constant for integration over } j} z_j^{\sigma-1}. \qquad \text{(A.1)}
\end{aligned}$$

The total brand revenue has two equivalent definitions.

$$R = \begin{cases} pq; \\ \int_{j\in\Omega} R_j dj. \end{cases}$$

This equivalence generates an expression for the price index of brand output.

$$\begin{aligned}
QP^{\theta} p^{1-\theta} &= QP^{\theta} p^{\sigma-\theta} \left(\frac{\theta-1}{\theta}\right)^{\sigma-1} c_h^{-\eta_h(\sigma-1)} c_m^{-\eta_m(\sigma-1)} \beta_h^{\eta_h(\sigma-1)} \beta_m^{\eta_m(\sigma-1)} \int_{j\in\Omega} z_j^{\sigma-1} dj. \\
&\Rightarrow \ p = \left(\frac{\theta-1}{\theta}\right)^{-1} c_h^{\eta_h} c_m^{\eta_m} \beta_h^{-\eta_h} \beta_m^{-\eta_m} \left(\int_{j\in\Omega} z_j^{\sigma-1} dj\right)^{\frac{1}{(1-\sigma)}}.
\end{aligned}$$

Substitute this expression into the final profit function.

$$\begin{aligned}
& \int_{j\in\Omega} R_j dj - c_h \int_{j\in\Omega} h_j dj - c_m \int_{j\in\Omega} m_j dj \\
= & \int_{j\in\Omega} R_j \left(1 - \eta_h \beta_h \frac{\theta-1}{\theta} - \eta_m \beta_m \frac{\theta-1}{\theta}\right) dj \\
= & \int_{j\in\Omega} z_j^{\sigma-1} dj \times QP^{\theta} p^{\sigma-\theta} \left(\frac{\theta-1}{\theta}\right)^{\sigma-1} c_h^{-\eta_h(\sigma-1)} c_m^{-\eta_m(\sigma-1)} \\
& \times \left[1 - \left(\frac{\theta-1}{\theta}\right)(\eta_h\beta_h + \eta_m\beta_m)\right] \beta_h^{\eta_h(\sigma-1)} \beta_m^{\eta_m(\sigma-1)} \\
= & \left(\int_{j\in\Omega} z_j^{\sigma-1} dj\right)^{\frac{1-\theta}{1-\sigma}} \times QP^{\theta} \left(\frac{\theta-1}{\theta}\right)^{\theta-1} c_h^{-\eta_h(\theta-1)} c_m^{-\eta_m(\theta-1)} \\
& \times \left[1 - \left(\frac{\theta-1}{\theta}\right)(\eta_h\beta_h + \eta_m\beta_m)\right] \beta_h^{\eta_h(\theta-1)} \beta_m^{\eta_m(\theta-1)} \\
= & ZA
\end{aligned}$$

A.2 The Derivation of $\beta_h^*(\eta_h)$

Given the consumption composite Q and its corresponding price index P, one can maximize the following function to find the optimum,

$$\max_{\beta_h} \left[1 - \left(\frac{\theta - 1}{\theta}\right)(\eta_h \beta_h + (1 - \eta_h)(1 - \beta_h))\right] \beta_h^{\eta_h(\theta-1)} (1 - \beta_h)^{(1-\eta_h)(\theta-1)},$$

with $\beta_h, \eta_h \in [0, 1]$.

First order condition is

$$\theta (2\eta_h - 1) \beta_h^2 - 2\eta_h [1 + \eta_h (\theta - 1)] \beta_h + \eta_h [1 + \eta_h (\theta - 1)] = 0.$$

If $\eta_h = \frac{1}{2}$, then it degenerates to a linear equation and $\beta_h^* = \frac{1}{2}$. Otherwise, there are two possible solutions to this quadratic function,

$$\beta_h^{\pm}(\eta_h) = \frac{\eta_h [1 + (\theta - 1)\eta_h] \pm \sqrt{\eta_h [1 + (\theta - 1)\eta_h](1 - \eta_h)[\theta - (\theta - 1)\eta_h]}}{\theta (2\eta_h - 1)}.$$

It is required that $\beta_h^*(\eta_h)$ must lie within the $[0, 1]$ interval, since it is the fraction of profit distributed to the HQ. $\beta_h^+(\eta_h)$ is ruled out because it becomes negative if the HQ services intensity, η_h, is strictly smaller than $\frac{1}{2}$. Thus, there is one unique and continuous solution,

$$\beta_h^*(\eta_h) = \begin{cases} \frac{1}{2}, \text{ if } \eta_h = \frac{1}{2}; \\ \beta_h^-(\eta_h), \text{ otherwise.} \end{cases}$$

A.3 Increasing in Productivity

The left hand side of free entry condition can be written as

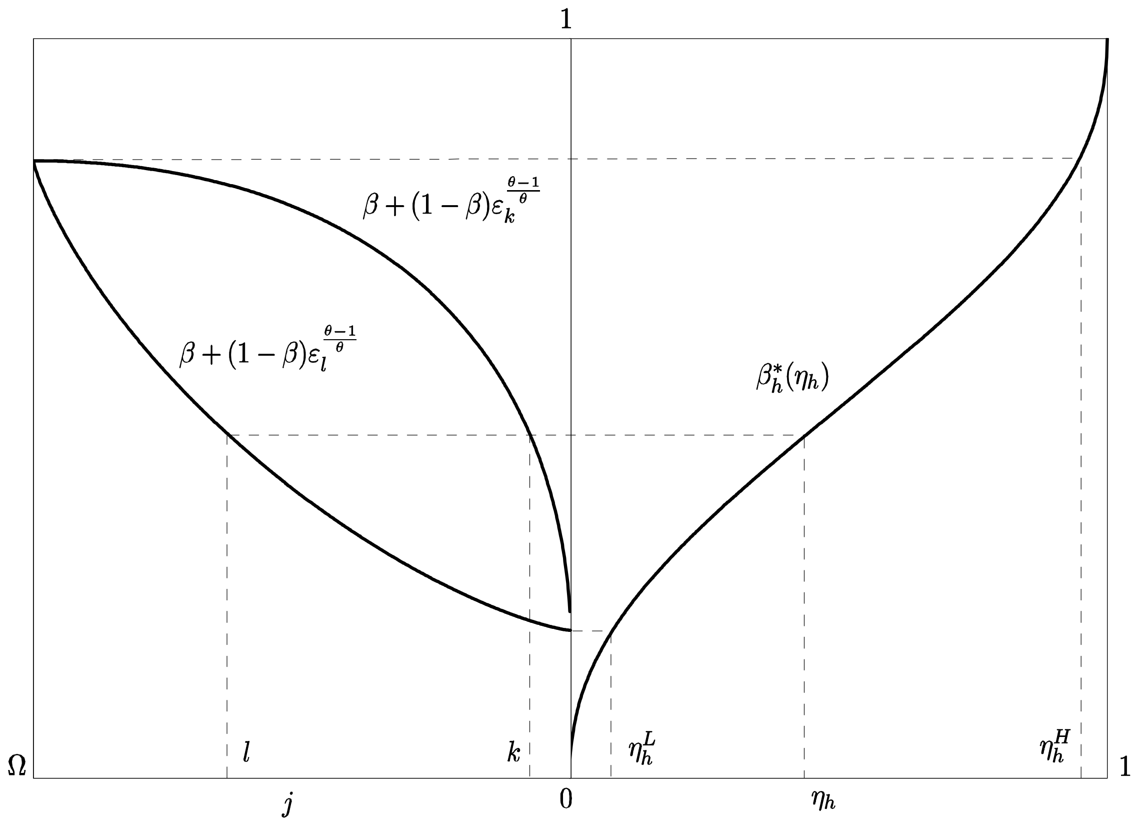
$$\beta_m R_{j'}(i) - (\tau + c'_m) m_{j'} = \beta_m R_{j'}(i) \left[1 - \frac{(\tau + c'_m)\eta_m}{c'_m} \frac{\theta - 1}{\theta}\right].$$

For the open economy problem to be interesting, assume positive profit from exports before the entry fee is paid.

$$1 - \frac{(\tau + c'_m)\eta_m}{c'_m} \frac{\theta - 1}{\theta} > 0 \Rightarrow c'_m > \frac{\tau}{\left[\frac{\theta}{(\theta-1)\eta_m} - 1\right]}.$$

Given that variable costs in a foreign country greater than the above threshold, foreign plant j''s export profit increases in its productivity draw, $z_{j'}(i)$.

Figure 1: Choices of Organizational Form



Notes: The curve in the right panel is the function of optimal revenue allocation to the HQ given the intensity parameter. The concave function in the left panel represents revenue shares generated through ordering suppliers on the $[0, \Omega]$ interval from high to low by their productivities, whereas the convex function below represents a low to high ranking.

Figure 2: Trade in Manufactured Parts

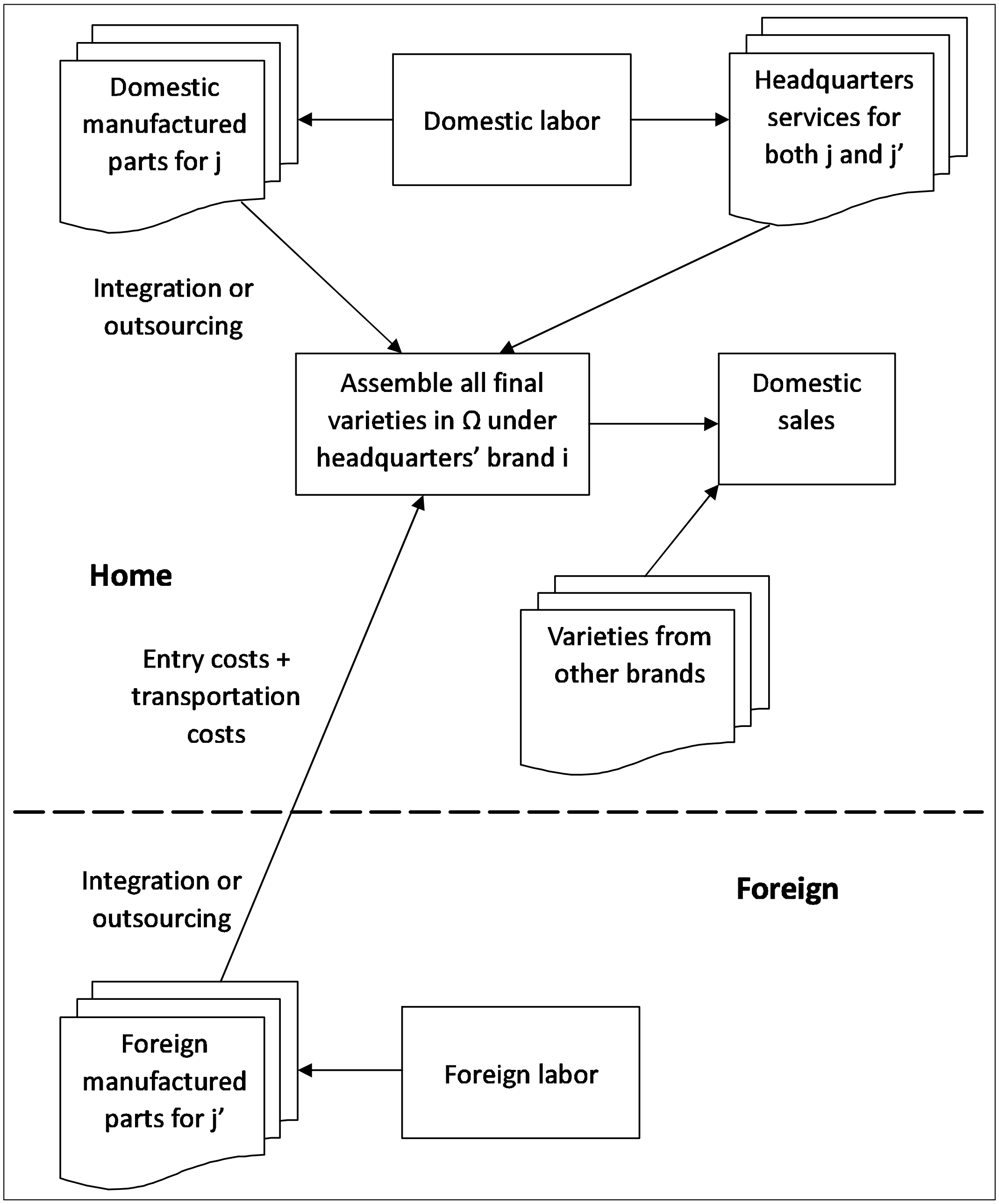


Table 1: Number of Affiliates and Intrafirm Trade: Looking Across Industries

Independent Variables	Dependent Variables					
	ln(Intrafirm Imports$_i$)			ln(No. of Affiliates$_i$)		
	[11-I]	[11-II]	[11-III]	[10-I]	[10-II]	[10-III]
Capital Intensity: $\ln(\frac{K_i}{L_i})$	0.931	0.375	0.102	0.755^{***}	0.75^{***}	0.676^{***}
	(0.62)	(0.66)	(0.68)	(0.27)	(0.26)	(0.25)
Material Intensity: $\ln(\frac{M_i}{L_i})$	-1	-0.263	-0.286	-0.817^{***}	-0.787^{***}	-0.839^{***}
	(0.6)	(0.69)	(0.68)	(0.25)	(0.24)	(0.23)
R&D Intensity: $\ln(\frac{RD_i}{L_i})$		0.425^{*}	0.342		0.26^{***}	0.262^{***}
		(0.12)	(0.12)		(0.63)	(0.6)
Affiliate Productivity: $\ln(\frac{Q_i}{L_i})$			0.372			0.317^{***}
			(0.38)			(0.13)
Constant	4.041^{***}	3.579^{***}	1.86	5.894^{***}	7.025^{***}	5.916^{***}
	(1.11)	(1.09)	(1.6)	(0.49)	(0.61)	(0.66)
Number of Obervations	30	30	30	114	114	114
Adjusted R-Squared	0.03	0.11	0.15	0.08	0.14	0.22

Notes: Standardized coefficents are reported. Standard errors are shown in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 2: Number of Affiliates and Intrafirm Trade: Looking Across Countries

Independent Variables	Dependent Variables					
	ln(Related Party Imports$_c$)			ln(No. of Affiliates$_c$)		
	[13-I]	[13-II]	[13-III]	[12-I]	[12-II]	[12-III]
Variable Exporting Costs: $\ln(\tau_c)$	-0.137	-0.123	-0.126	-0.212^{**}	-0.205^{**}	-0.208^{**}
	(0.28)	(0.28)	(0.28)	(0.41)	(0.41)	(0.41)
Fixed Entry Fee: $\ln(f_c)$	-0.381^{***}	-0.269^{**}	-0.281^{**}	-0.43^{***}	-0.377^{***}	-0.388^{***}
	(0.08)	(0.09)	(0.09)	(0.12)	(0.13)	(0.13)
Enfocement Costs: $\ln(Enf_c)$		-0.214^{**}	-0.228^{**}		-0.101	-0.113
		(0.25)	(0.25)		(0.37)	(0.37)
Labor Costs: $\ln(\frac{L_c}{K_c})$			-0.094			-0.17
			(0.11)			(0.16)
Constant	6.64^{***}	7.772^{***}	8.061^{***}	11.689^{***}	12.514^{***}	12.932^{***}
	(1.86)	(1.91)	(1.93)	(2.71)	(2.82)	(2.85)
Number of Obervations	109	109	109	109	109	109
Adjusted R-Squared	0.19	0.21	0.22	0.29	0.29	0.29

Notes: Standardized coefficents are reported. Standard errors are shown in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.