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Abstract

Gravity equations explaining foreign affiliates' sales are *ad hoc* and hence, estimated coefficients are hard to interpret. We therefore provide the theoretical underpinnings of the gravity equation applied to the analysis of sales of foreign affiliates of multinational firms. We argue that the success of the gravity equation results from the fact that it can be derived from various theoretical models. We illustrate this point by deriving a gravity equation from three different models of multinational firms. Using data on real affiliate sales, we show how this derived gravity equation can nevertheless be used to discriminate between the different theoretical models.

Keywords: Gravity equation, multinational firms, heterogeneity.

JEL classification: F23, F12, C21

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1 Introduction

The gravity equation is one of the most often applied empirical techniques to analyze bilateral trade. Yet, it is only recently that it has been applied to the empirical analysis of sales of foreign affiliates of multinational firms (Brainard, 1997; Braconier *et al.*, 2002; Egger and Pfaffermayr, 2004). Indeed, it provides a good fit in explaining the variation of the volume of affiliates' sales. The empirical literature using the gravity equation finds that home and host country's market size have a positive effect on the volume of affiliate sales while distance between the two countries has a negative effect on it.

However, according to the theory of multinational firms, distance raises the costs of exporting and influences positively the decision to set-up affiliates in foreign countries. Thus, there are *a priori* no reasons, why distance should affect negatively the volume of their sales. We adjust two models of the horizontal multinational firm to generate this negative relationship of affiliate sales and distance.

So far, the relationship between the theory of multinational firms and the empirical findings from the gravity equation is weak. Gravity equations explaining foreign affiliates' sales are *ad hoc* and hence, estimated coefficients are hard to interpret. We provide the theoretical underpinnings of the gravity equation applied to the analysis of sales of foreign affiliates. We show which implicit assumptions are applied by trade empiricists that use this equation. We shed lights on the theoretical mechanisms through which distance and market size of home and host countries influence the volume of affiliate's sales. To the best of our knowledge a theoretical foundation of the gravity equation has not been examined in the context of multinational firms' activities.

We believe that just as for international trade, the success of the gravity equa-

tion explaining affiliate sales results from the fact, that it can be derived from different theoretical models. In this paper, we present three theoretical models which differ significantly in their structure. We derive a gravity equation from each of them. The resulting gravity equations look similar but they imply different restrictions on the econometric model. The first two models explain the emergence of horizontal multinational firms. Both apply the proximity concentration framework. The first model assumes symmetric firms whereas the second one incorporates firm heterogeneity. The third model explain the emergence of vertical multinational firms using a factor proportion approach.

We start with a model of monopolistic competition and symmetric firms. This model is close to the seminal paper of Brainard (1997), but it incorporates intermediate inputs. We assume that part of these intermediates are imported from the home country. We base this assumption on the empirical fact that one third of world trade is intra-firm trade and this trade is increasingly in intermediate goods (Andersson and Fredriksson, 2000). In addition, the US Bureau of Economic Analysis (BEA, 2005) reports that the ratio of imports of goods shipped to US affiliates of foreign multinational firms over affiliate sales is about 17% in 2002. This survey data shows also that about 80% of these imports come from the parents.

In the model, firms decide how to enter international markets. Thereby, they could concentrate their production at home and reach distant consumers through exports. In this case, firms save the fixed costs associated with the supplementary production unit abroad. However, they could find it more profitable to set-up affiliates in the foreign country and save the distance costs associated with exports. Distance raises the costs of exporting and affects positively the decision to set-up affiliates in foreign countries. Yet, increasing distance affects negatively the volume of each affiliate's sales when production

requires the input intermediate inputs, which must be imported costly from the home market.

Then, we present a model of monopolistic competition with heterogeneous firms. This model extends Helpman *et al.* (2004), by relaxing the assumption that the fixed set-up costs are identical in all countries. We assume that fixed costs increase with distance and motivate this assumption by the fact that distance raises upfront search costs and organization costs (Chaney, 2006; Rauch, 1999). As in Helpman *et al.* (2004) and Melitz (2003), the mode of entry into foreign markets depends on firm's productivity. In particular, the equilibrium is characterized by the coexistence of multinational firms, exporters and domestic firms. The most productive firms become multinationals, less productive firms become exporters while the least productive firms serve only the domestic market. We show that in equilibrium the entry of multinational firms and thereby aggregated affiliates' sales decreases with distance. From both proximity-concentration models, we derive a gravity equation that looks similar to the structural gravity equation for international trade proposed by Redding and Venables (2004).

Finally, we derive the gravity equation from a version of a two-country factor-proportion model of fragmentation based on Venables (1999). Multinational firms geographically fragment their production process into stages based on factor intensities. They locate activities according to factor prices and link the different production units through trade (Feenstra and Hanson, 1996; Helpman, 1984; Markusen, 2002; and, Hanson *et al.* 2003, 2005 for an empirical assessment). Since trade involves costs that increase in distance, low distance costs therefore encourage fragmentation and affiliates' production.

Thus, we present three very different models and derive the gravity equation from each of them. We do this, because we believe that the success of the

gravity equation results from the fact that it can be derived from various models. Nevertheless, we can use gravity equations to discriminate between different models. In order to discriminate between the gravity equations that builds on models of horizontal FDI from the one derived from the vertical FDI model, we need affiliate sales data with variation in factor endowments and in market size. We use a dataset on bilateral sales of affiliates that has been taken from Braconier *et al.* (2003).¹ This dataset has the advantage to cover information on a large number of countries that varies over time.

We use the econometric methodology proposed by Santos Silva and Tenreyro (2006) that solves the problem of inconsistency of OLS estimates in presence of heteroscedasticity and takes into account zero-valued observations. We find much stronger support for gravity equations derived from model of horizontal multinationals, although we cannot strictly differentiate between horizontal and vertical multinational activities.

The paper includes six additional sections. We derive the gravity equation from the symmetric firm proximity-concentration model in Section 2, from a heterogenous firm proximity-concentration model in Section 3 and, from the factor-proportion model in Section 4. We present the data and the estimation strategy for an empirical discrimination between the horizontal and the vertical model in section 5. We show the results in section 6. We conclude in Section 7.

2 Foreign Production with Domestic Intermediate Inputs

We consider an economy with two sectors: agriculture, which produces a homogeneous good A and manufacturing which produces a bundle M of differ-

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entiated goods. Consumers purchase A and M and have identical preferences described by a utility function defined on A and M . Consumers preferences for single varieties of the M good are described by a sub-utility function defined on the varieties. The utility function of the representative consumer from country j has the Cobb-Douglas form given in equation (1):

$$U_j = X_{Aj}^\mu X_{Mj}^{(1-\mu)} \quad (1)$$

where $0 < \mu < 1$. X_{Mj} is a sub-utility function of CES-type defined in (2)

$$X_{Mj} = \left[\int_i \int_k x_{kij}^{(\sigma-1)/\sigma} dk di \right]^{\sigma/(\sigma-1)} \quad (2)$$

x_{kij} is country j 's consumption of a single variety produced by firm k from country i . The elasticity of substitution, σ , is the same for any pair of product and larger than one. We assume monopolistic competition in manufacturing so that each variety of the manufacturing good is produced by only one firm. All varieties are assumed to be symmetric. This simplifies the integral $\int_k x_{kij}^{(\sigma-1)/\sigma} dk$ from equation (2) to the product $n_i x_{ij}^{(\sigma-1)/\sigma}$, where we suppressed the firm subscript k . The price index in the manufacturing sector, P_{Mj} , corresponds to the CES sub-utility function: $P_{Mj} = \left[\int_i n_i p_{ij}^{1-\sigma} \right]^{1/(1-\sigma)}$. Given the total demand $(1 - \mu)Y_j$ for differentiated products in country j which is derived from equation (1), the demand for each variety is given by equation (3). Each firm's sales in foreign markets depend on its own price, p_{ij} , in country j , on the price index, P_j , in j and on j 's market size, Y_j .

$$x_{ij} = p_{ij}^{-\sigma} (1 - \mu) Y_j P_j^{\sigma-1} \quad (3)$$

Firm can serve foreign market j either by export or by producing abroad. They choose to produce abroad if it is more profitable than exporting, i.e if

equation (4) holds

$$\pi_i^{MNE} - \pi_i^{Ex} > 0 \Leftrightarrow (1 - \rho)[p_{ij}^{MNE} x_{ij}^{MNE} - p_{ij}^{Ex} x_{ij}^{Ex}] > f_j, \quad (4)$$

where $\rho = \sigma/(\sigma - 1)$ and f_j denotes the fixed costs for an additional plant in country j . Entry of multinational firms is determined by the level of the additional fixed costs but also by the difference in the sales in the foreign market. As seen in equation (4), the latter depends on the prices of the exported good p_{ij}^{Ex} relative to the prices of the good produced abroad p_{ij}^{MNE} . Note that the number of firms from country i that have affiliates in country j is independent of distance. Either all firms own affiliates in the foreign country or none. The number of firms is endogenously determined by the zero profit condition.

Following the proximity-concentration literature, we assume that exports incur distance costs of the iceberg-type. We denote distance costs between country i and j by τ_{ij} . Hence, $p_{ij}^{Ex} = p_{ii}\tau_{ij}$. We assume that the production of multinationals' affiliates relies on intermediate goods which are imported from the home country. The production technology of the variety of firm from country i in country j is given by the variable cost function $C_j = \left(\frac{w_j}{\epsilon}\right)^\epsilon \left(\frac{q_{ij}}{1-\epsilon}\right)^{1-\epsilon}$. This cost function stems from a Cobb-Douglas production function with cost share ϵ for labor and $1 - \epsilon$ for intermediate inputs. q_{ij} is the price for the intermediate good used in the foreign affiliate of a firm from country i in country j . w_j denotes the wage in country j . Like prices of differentiated manufacturing goods, the price of the intermediate good is subject to distance costs of the iceberg-type. Hence, $q_{ij} = q_{ii}\tau_{ij}$. Given that the optimal price of a monopolistic competitive firm is always a fixed markup over the marginal costs, $p_{ij} = c_{ij}/\rho$, and that marginal costs increase in distance costs, prices of goods produced in foreign affiliates also increase in distance costs. Consequently quantities sold decrease.

Nevertheless, profits from producing abroad might be higher than from exporting. The aggregate value of sales of country i 's firms' affiliates in country j is given by equation (5).

$$n_i p_{ij} x_{ij} = n_i p_{ii}^{1-\sigma} \tau_{ij}^{(1-\sigma)(1-\epsilon)} (1-\mu) Y_j P_j^{\sigma-1} \quad (5)$$

This equation of bilateral affiliates' sales can be transformed into a gravity equation for affiliate sales. It contains the home country's supply characteristics and the demand characteristics of the host country. As in Redding and Venables (2004), $n_i p_{ii}^{1-\sigma}$ refers to home country's *supply capacity* while $(1-\mu) Y_j P_j^{\sigma-1}$ refers to the host country j 's *market capacity*. We follow their terminology and denote market capacity by m_j and supply capacity by s_i . We denote bilateral foreign affiliates' production $n_i p_i x_{ij}$ by AS_{ij} . We assume that distance costs τ_{ij} are an increasing function of geographical distance between countries i and j , $\tau_{ij} = \tau D_{ij}^{\eta_1}$ with τ being unit distance costs and $\eta_1 > 0$.

$$AS_{ij} = s_i \left(\tau D_{ij}^{\eta_1} \right)^{(1-\sigma)(1-\epsilon)} m_j \quad (6)$$

Equation (6) can be written in log-linearized form as

$$\ln(AS_{ij}) = \alpha_1 + \zeta_1 \ln(s_i) - \beta_1 \ln(D_{ij}) + \xi_1 \ln(m_j) \quad (7)$$

where $\alpha_1 = (1-\sigma)(1-\epsilon)\ln(\tau)$, $\beta_1 = (\sigma-1)(1-\epsilon)\eta_1$. The structural gravity equation implies a constraint on the estimates of parameter ζ_1 and ξ_1 . They must equal one. It is straightforward to test whether this constraints hold in the empirical analysis. The distance parameter β_1 is negative, since $\sigma > 1$.

In this symmetric firm model, all firms produce the same amount in the foreign country j . There is no extensive margin. Either all firms produce in a foreign market or none. The negative effect of distance costs on affiliate sales AS_{ij} results from the costly import of intermediate goods by the foreign affiliate from its home country. Thus, the introduction of product-specific intermediate

goods in the Brainard model introduces an intensive margin of production abroad. Each firm produces less with increasing distance costs between two countries. Without specific intermediate goods there would be no effect of distance on aggregate affiliate sales other than the effect on entry which is by assumption equal for all firms. Positive affiliate sales in all host countries would be the same irrespective of their distance from the home country. All other (closer) countries would have zero affiliate sales.

3 Fixed Costs Increasing in Distance

As in the preceding section we consider two sectors of production, A and M . We assume consumers' preferences to be described by the same utility as in equation (1) and (2).

We depart however from the assumption of symmetric firms which yields an equilibrium where all firms are active in the foreign country independently of the distance between the two countries. Yet, it is a well-known empirical fact that the number of firms falls with distance between two countries. Since symmetric firm models cannot explain this fact, we incorporate heterogeneous firms in the model in the line of Helpman *et al.* (2004). We assume therefore that firms have different level of productivity that they draw from a common distribution. Differences in productivity translate into different marginal costs, different prices and different quantities for each firm k . We denote the marginal costs of a firm k by a_k and define the productivity level as $1/a_k$. Profit maximization yields a fixed markup over the marginal costs a_k of ρ . Thus, the price of firm k located in i and selling in country j , $p_{kij} = a_{kij}/\rho$ leads to firm-specific quantities sold in j . Equation (3), which described the optimal quantity sold in country j by a firm located in country i in our symmetric

firm model above changes slightly into equation (8) that considers firm-specific productivity levels.

$$x_{kij} = p_{kij}^{-\sigma} (1 - \mu) Y_j P_j^{\sigma-1} \quad (8)$$

Although denoted by the same variable, the price index, P_j , in country j differs from the one in the symmetric model. First, it is affected by the difference in productivity between firms and thus their different prices and quantities. Second, it is influenced by the channel that firms choose to serve market j . In fact, firms from country i can serve consumers in market j through export or through affiliates' production. Depending on their productivity level $1/a_k$, firms decide through which channel they will supply foreign markets. The price index of country j changes therefore to $P_j = \left[\int (p_{kij}^h)^{1-\sigma} dk \right]^{1/(1-\sigma)}$. The superscript h , $h = Ex, MNE$, indicates respectively whether a firm is an exporter or produces abroad.

We normalize the mass of firms from country i to one. Each firm compares the profits related to each mode of entry in market j . Firms that have a productivity level higher than $1/a_{ij}^{Ex}$ are active in country j and earn positive profits in this market. Firms with a productivity level of $1/a_{ij}^{MNE}$ are indifferent between exporting and producing abroad because both strategies yield the same profits. Firms with a higher productivity level than $1/a_{ij}^{MNE}$ produce in country j , because producing abroad is more profitable. Firms with lower productivity than $1/a_{ij}^{MNE}$ export to country j . The critical marginal cost levels (a) for a firm producing only for the home market i (b) for an exporting firm and (c) for an MNE are derived in equations (9) using the zero-profit conditions, respectively.

$$\left(a_i^{Dom} \right)^{1-\sigma} \frac{(1-\mu)Y_j(1-\rho)}{P_j^{1-\sigma} \rho^{1-\sigma}} = f^{Dom} \quad (9a)$$

$$\left(a_{ij}^{Ex} \tau_{ij} \right)^{1-\sigma} \frac{(1-\mu)Y_j(1-\rho)}{P_j^{1-\sigma} \rho^{1-\sigma}} = f^{Ex} \quad (9b)$$

$$(a_{ij}^{MNE})^{1-\sigma} (1 - \tau_{ij}^{1-\sigma}) \frac{(1 - \mu)Y_j(1 - \rho)}{P_j^{1-\sigma}\rho^{1-\sigma}} = f^{MNE} - f^{Ex} \quad (9c)$$

We assume that fixed costs increase in distance between the two countries i and j . We assume further that fixed costs of exporting f^{Ex} is a fixed share γ of the fixed costs, f^{MNE} , associated with the production abroad.

Following Helpman *et al.* (2004), we use the Pareto distribution to parameterize the distribution of firms with respect to their productivity. Aggregated affiliates sales of all firms from country i in the foreign market j , AS_{ij} , are thus given by equation (10).

$$\begin{aligned} AS_{ij} &= \int_0^{a_{ij}^{MNE}} \frac{(a_k/\rho)^{1-\sigma} g(1/a)}{P_j^{1-\sigma}} (1 - \mu)Y_j dk \\ &= \frac{\kappa}{\kappa - \sigma + 1} \left(\frac{a_{ij}^{Dom}}{\rho} \right)^{1-\sigma} \frac{(a_{ij}^{MNE})^{\kappa-\sigma}}{(a_{ij}^{Dom})^{\kappa-\sigma+1}} \frac{(1 - \mu)Y_j}{P_j^{1-\sigma}} \end{aligned} \quad (10)$$

Where a_i^{Dom} is critical marginal cost level for a firm from country that sells only in the home market. It is the highest marginal cost level observed by any active firm in country i . The critical marginal cost level a_{ij}^{MNE} determines aggregate affiliate sales, the number of affiliate from country i in country j and their average size.

The first term describe the *supply capacity* $s_i = \frac{\kappa}{\kappa - \sigma + 1} \left(\frac{a_{ij}^{Dom}}{\rho} \right)^{1-\sigma}$ of country i . The term gives the average size of the firms which are active in country i . Multiplied by the mass of all firms active in country i , which is one, the term equals the output of the M -sector in country i . The last term combining market size, $(1 - \mu)Y_j$, and price level, P_j , of country j is the *market capacity* of country j , m_j , just as in the symmetric firm model in Section 2. Finally, there is the middle term in equation (10), $\frac{(a_{ij}^{MNE})^{\kappa-\sigma}}{(a_{ij}^{Dom})^{\kappa-\sigma+1}}$, that affects affiliates sales. We show in the Appendix that this term is a negative function of distance between the countries i and j . We proxy this term by the flexible function $\Phi_{ij} = \lambda D_{ij}^{-\eta_2}$, where λ and η_2 are positive parameters and D_{ij} is the geographical distance

between the countries i and j . Aggregate affiliate sales of firms from country i in country j are thus given by:

$$AS_{ij} = s_i(\lambda D_{ij})^{-\eta_2} m_j \quad (11)$$

Log-linearizing equation (11) yields the second gravity equation.

$$\ln(AS_{ij}) = \alpha_2 + \zeta_2 \ln(s_i) - \beta_2 \ln(D_{ij}) + \xi_2 \ln(m_j) \quad (12)$$

where $\alpha_2 = -\eta_2 \ln(\lambda)$ and $\beta_2 = \eta_2$. As in the preceding model, the structural gravity equation implies a constraint on the estimates of parameter ζ_2 and ξ_2 . They must equal one. Note that Φ_{ij} is a negative function of distance because we have assumed distance dependent fixed costs. Without this assumption, the effect of distance on Φ_{ij} would be positive.

4 Factor-Proportion Theory

In this section, we derive a gravity equation from a factor-proportion model with multinational firms. Parallel to the gravity equation for international trade, the gravity equation does not arise as 'natural' from this class of models as it arises from the proximity-concentration framework in Section 2 and 3. Nevertheless, it is possible to derive an equation that explains aggregated affiliate sales with home and host country's GDP and distance, i.e. a gravity equation, from factor-proportion models. That is important to notice, because it clarifies that the good fit of the gravity equation by itself is no evidence in favor of the proximity-concentration framework relative to the factor-proportions framework.

According to factor-proportions theories, multinational firms can geographically fragment their production processes into stages and locate activities according to international differences in factor prices. Fragmentation is likely

to arise when the stages of production exhibit different factor intensities and when countries have different factor endowments and/or factor-prices (Helpman 1984, Venables 1999, Hanson *et al.* 2003, 2005).

We follow Venables (1999) in modeling the emergence of vertical multinational firms. We assume two countries and two perfectly competitive sectors, A and MZ , each producing a homogenous goods. Good A is freely traded between the two countries. This good is used as *numeraire*. Consumers are assumed to have identical and homothetic preferences. We assume that the technology of sector A can be characterized by the following unit cost function.

$$c(w_i, v_i) = c(w_j, v_j) = 1 \quad (13)$$

where the subscript i and j indicate the home and foreign country, respectively. w denotes the wage, the factor price of low-skilled labor L , v the salary, the factor price of high-skilled labor S . We assume that the unit-cost function in equation (13) is an increasing function of wage w and salary v .

Production of good M requires the use of an intermediate good Z . Both goods, M and Z , uses the two factors, low-skilled and high-skilled labor, in fixed proportion. Sector MZ can be either integrated, when both good M and Z are produced within the same country, or geographically fragmented, when M and Z are produced in different countries. Fragmented production benefits from each country's comparative advantage. The unit cost functions are given by

$$b_i^Z = \iota w_i + (1 - \iota)v_i \quad ; \quad b_j^Z = \iota w_j + (1 - \iota)v_j \quad (14a)$$

$$b_i^M = \varphi w_i + (1 - \varphi)v_i + \delta p_i^Z \quad ; \quad b_j^M = \varphi w_j + (1 - \varphi)v_j + \delta p_j^Z \quad (14b)$$

The coefficients ι and φ are fixed factor inputs per unit output. δ denotes the input of the intermediate good Z , in the production of the final good M . The prices p_l^Z with $l = i, j$ are the minimum costs of supply of the

intermediated good Z in the two countries. Thus, $p_i^Z \equiv \min[b_i^Z, \tau_{ij}^Z b_j^Z]$ and $p_j^Z \equiv \min[b_j^Z, \tau_{ij}^Z b_i^Z]$, where τ_{ij}^Z is the ad valorem distance cost.

If distance costs τ_{ij}^Z are high, production of MZ is integrated. Each country specializes in the production of the good, A or MZ , in which it has a comparative advantage. We assume that the countries have fixed endowments of both factors and that the home country i is the country relatively richly endowed with high-skilled labor. Firms in i produce the high-skilled-labor-intensive good, while firms in the foreign country j produce the low-skilled-labor-intensive good. However, the technologies described above exhibit factor intensity reversals, so that it is not obvious whether the production of good A or MZ uses high-skilled labor more intensively. We assume that the home endowment ratio $(S/L)_i$ is more capital intensive than combined MZ production, but less than A production. As consequence, firms in the home country i produce both good A and good MZ . The foreign country j fully specializes in the production of good A . Firms in country i produce good A more high-skilled labor intensive than firms in country j , because the relative price of low-skilled labor is higher in country i than in country j .

Fragmentation is profitable, in contrast, if the costs of shipping the intermediate good Z are low. We assume that the production of Z is low-skilled labor intensive relative to the production of M , $\iota < \varphi$. Firms from country i in sector MZ , have then an incentive to relocate the production of the low-skilled labor intensive stage Z to the foreign country j and specialize on the high-skilled labor intensive stage, i.e. the production of M , in the home country i . Specialization along the relative factor endowments is cost-efficient and therefore profit maximizing in this perfectly competitive setting. If distance costs are low enough, production of MZ is completely fragmented in a M stage carried out in the home country i and a Z stage produced in the host country j . Good

A is produced in both countries, although with different factor intensities in i and j .

Between these two full specialization equilibria, there exists a range of distance costs where integrated and fragmented production coexist. Starting from a situation of integrated MZ production at home, falling distance costs increases the profitability to produce the Z stage abroad. The fragmentation of production increases low-skilled labor demand in the low-skilled labor-abundant country j and reduces it in i . This raises the costs of production in j and reduces the costs of production in i until at the given distance costs, the incentives to fragment production is eliminated. In equilibrium, the prevailing production structure includes both integrated and fragmented firms.

Let θ be the share of Z production taking place in the host country j . θ is determined by the factor-price ratios $(w/v)_i$ at home and $(w/v)_j$ abroad and the distance costs τ_{ij}^Z . The factor-price ratios and the distance costs must combine to yield the same price in i for intermediate goods produced at home and in the foreign country ($p_i^Z = b_i^Z = \tau_{ij}^Z b_j^Z$). For the whole range of distance cost levels where integrated and fragmented production coexist, the share of fragmented production θ increases with falling distance costs τ_{ij}^Z ($\partial\theta/\partial\tau_{ij}^Z < 0$). The share of fragmented production θ is also affected by the relative factor endowment of the two countries, $S_i/(S_i + S_j)$ and $L_i/(L_i + L_j)$. Additionally, the factor price effect depends on the size of the two economies. With production of Z increasing in lower distance costs, the production of A decreases in the host country j .

Production of the intermediate good Z in country j results from the fragmentation of production in sector MZ . Since, Z is transferred within firms, production of Z can be seen as foreign affiliate output. The whole output of Z is then processed in country i and therefore sold as intra-firm transaction

to country i . Thus, the production of the intermediate good Z matches the sales of country i firms' foreign affiliates in country j AS_{ij} :

$$AS_{ij} = \delta(1 - \mu)Y\theta \quad (15)$$

Equation (15) gives the level of foreign affiliates' production. It is entirely intermediate good's production. The amount of intermediate's production depends on the share $1 - \mu$ of *total* income Y spend in *both* countries on the final good M and on the fraction δ of intermediates good Z that is necessary to produce good M . A fraction θ of intermediate good's production is produced in the country j .

As argued above, this fraction is a function of distance costs τ_{ij}^Z . In addition, θ is positively affected by the relative factor endowments ratio $(\frac{S_i}{S_i+S_j})/(\frac{L_i}{L_i+L_j})$ and negatively by the income ratio Y_i/Y_j between the two countries. We assume that the effects on θ can be separated in a function of distance costs $f(\tau_{ij}^Z)$, a function of relative factor endowment ratio $g_1(S_i/(S_i+S_j))/(L_i/(L_i+L_j))$ and a function of the income ratio $g_2(Y_i/Y_j)$.

As discussed above, distance costs have a negative effect on affiliates' production through the negative effect on θ , $\partial\theta/\partial\tau_{ij}^Z < 0$. Thus, production of foreign affiliates decrease in distance costs τ_{ij}^Z .

The fraction θ is also affected by the relative size of the countries $g_2(Y_j/Y_i)$. Whereas a large host country j affects the share θ of affiliate production positively ($\partial\theta/\partial Y_j > 0$), a large home country affects θ negatively ($\partial\theta/\partial Y_i < 0$). This is an important difference between this factor-proportion model and the proximity-concentration models above. The supply effect of the home country i affects affiliates' production negatively in the factor-proportion model. Assuming that functions f , g_1 and g_2 are separable, equation (15) can be restated

as:

$$AS_{ij} = \delta(1 - \mu)(Y_i + Y_j)g_2(Y_j/Y_i)f(\tau_{ij}^Z)g_1\left(\frac{K_i/(K_i + K_j)}{L_i/(L_i + L_j)}\right) \quad (16)$$

Linearizing equation (16) and assuming that distance costs τ_{ij}^Z are a function of distance D_{ij} , we derive a gravity equation, which is augmented by the relative factor endowments ratio and the sum of income of both countries.

$$\begin{aligned} \ln(AS_{ij}) = & \alpha_3 - \zeta_3 \ln(Y_i) + \xi_3 \ln(Y_j) - \beta_3 \ln(D_{ij}) \\ & + \nu RFE_{ij} + \vartheta \ln(Y_i + Y_j) \end{aligned} \quad (17)$$

where $RFE_{ij} = \ln(K_i/(K_i + K_j)) - \ln(L_i/(L_i + L_j))$. Although equation (17) looks similar to equations (7) and (12), the discussion of the income variables Y_i and Y_j is difficult. The interpretation of ζ and ξ is different from the models in Section 2 and 3. Since, affiliates' production takes place to reduce the overall costs of the firm, home country's, *supply capacity* Y_i affects affiliate production negatively. In contrast, host country's *supply capacity* Y_j affects affiliate production positively. Goods market demand is represented by the sum of *both* countries' incomes $\ln(Y_i + Y_j)$. Note that the coefficient of the demand variable ϑ is one, again.

Finally, the relative factor endowment ratio RFE of the two countries affects the amount of affiliates' production, because this ratio determines the minimum price p_i^Z of good Z and thereby the fraction of the intermediate good produced in the home and in the foreign country.

A miss-specified, ad hoc gravity equation without the relative skill variable RFE and the sum of income variable $\ln(Y_i + Y_j)$ suffers from an omitted variables bias. Yet, even if the vertical model is appropriate to describe the data, such a gravity equation yields the known pattern for the estimated coefficients. The coefficients of income variables $\ln(Y_i)$ and $\ln(Y_j)$ are both positive, the distance coefficient is negative. The income coefficients reflect *supply* and *demand capacity* in each country. *Demand capacity* is taken by the income

variables because the sum of income is a positive function both income variables $0 < \partial Y / \partial Y_l < 1$ with $l = i, j$.

Equation (17) gives the gravity equation explaining foreign affiliate sales if the vertical model describes affiliate production correctly. The equation must include the sum term, otherwise the estimates of country size would be biased. While the sum of country size affects foreign affiliate sales positively, the size of the home country alone has a negative effect on affiliates sales. The size of the host country affects affiliate sales positively. Distance exerts a negative effect on foreign affiliate sales. This is always the case and does not depend on the assumption that the effects on θ can be separated as nicely as we assumed above. If the effect on θ can not be separated like this, the gravity equation is a miss-specification but would nevertheless report a positive effect of the country sizes and a negative effect of distance, when applied to the data. There are no restrictions on the coefficients for the country size variable other than that the coefficient for the size of the home country i should be smaller than one.

5 Data and Estimation Strategy

5.1 Data

To distinguish between the gravity equations that build on models of horizontal FDI from those derived from the vertical FDI model, we need affiliates sales data with variation in factor endowments and in market size. We use a comprehensive dataset on affiliates sales that has been taken from Braconier, Nörback and Urban (2003).² The dataset covers information on a large num-

²We are very thankful to Pehr-Johan Nörback and Dieter Urban for sharing data and codes with us.

ber of countries. The data we use in this paper is slightly different from the data used in Braconier *et al.* (2003) since we do not have access to the Swedish outward FDI data because of confidentiality. We are however able to reproduce qualitatively their results.

We have bilateral affiliate sales data for 56 home countries and 75 host countries with observations for at least at least one year. The data are for the year 1986, 1990, 1994, and 1998. Overall, the sample is very unbalanced with 600 country pairs and 1356 observations. For instance, there are 111 combinations of home and host country with 444 observations with all four years of data and 203 country pairs with only one year of data. The number of observations is not evenly distributed over time. There are 541 observations in 1998, but only 145 observations in 1986. The database contains 209 observations (15.4%) with zero bilateral affiliate sales.

As Braconier *et al.*, we depict in the Edgeworth box diagram of Figure ?? the home country skilled labor share of the combined home and host skilled labor abundant, $\frac{S_i}{S_i+S_j}$, on the vertical axis and the home unskilled labor share of the combined home and host country unskilled labor endowment, $\frac{L_i}{L_i+L_j}$, on the horizontal axis. The ratio of the two shares is a determinant of affiliate sales in the vertical FDI model as given in equation (17). We see from Figure ?? that our dataset on affiliates sales offers large variation in factor endowments and market size.

Regarding the explanatory variables, the real GDP data in constant 1995 US dollar have been taken from the the World Development Indicators database of the World Bank. The distance variable comes from Braconier *et al.* (2003). We use bilateral distance in kilometers between two capitals. In a robustness check, we also include a FDI and Trade openness indicators that have been taken from Carr *et al.* (2001) and Braconier *et al.* (2003). We construct an adjacency

variable that takes the value of one when the home and host countries share a common border and zero otherwise.

5.2 Estimation Strategy

Several papers have shown that a nonlinear specification of the gravity model has important advantages over the standard log-linear specification. According to Santos Silva and Tenreyro (2006), in the presence of heteroscedasticity in the error term ε_{ij} log-linearization can cause the OLS estimator to be biased. This is because the log-linearization of the affiliates' sales variable changes the property of the error term, which become correlated with the explanatory variables in the presence of heteroscedasticity. In addition, log-linearization is incompatible with the existence of zeros in affiliates sales data. As emphasized by Anderson and van Wincoop (2004) and Helpman *et al.* (2007) for gravity models of bilateral trade, omitting the zero-valued observations leads to a non-random sample that can result in biased or inconsistent estimates.

We follow Santos Silva and Tenreyro (2006) and estimate a Poisson model pseudo-maximum likelihood. This estimation technique is robust to different patterns of heteroscedasticity and provide a natural way to deal with zeros in our data. We therefore estimate the empirical equation (18) and (19) where we use the dependent variable, AS_{ijt} in levels.

$$AS_{ijt} = \alpha + \zeta \ln(Y_{it}) + \xi \ln(Y_{jt}) + \beta \ln(D_{ij}) + \varepsilon_{ijt} \quad (18)$$

where subscript t denotes time. Equation (18) gives the standard gravity equation for foreign affiliate sales as derived from the horizontal models. The horizontal models predict the coefficients ζ and ξ of the home and host country GDP to be one. Additionally, the distance coefficient β is predicted to be

negative. As argued above although miss-specified, this equation also explains much of the variation of affiliate sales of vertical multinational firms.

$$AS_{ijt} = \alpha - \zeta \ln(Y_{it}) + \xi \ln(Y_{jt}) + \beta \ln(D_{ij}) + \nu RFE_{ijt} + \vartheta \ln(Y_{it} + Y_{jt}) + \varepsilon_{ijt} \quad (19)$$

Equation (19) gives the equation for foreign affiliate sales as derived from the vertical model. The vertical model predicts the coefficients ϑ of the sum of home and host countries GDP to be one, the coefficient ζ to be negative and ξ to be positive. Additionally, the distance coefficient β is predicted to be negative while the coefficient ν of the relative factor endowment RFE should be positive.

6 Results

We present several specifications of the gravity equation in Table (1). Specification (S1) contains the empirical results of the gravity equation derived from the proximity concentration models. In specification (S2), we add the omitted variables if one would derived the gravity equation from a factor proportion model. We present some robustness check in specification (S3) and (S4). Notice that all specifications include a full set of time, home and host country fixed effects. The robust standard errors have been computed as described by Wooldridge (1999).

– Table (1) about here –

The results presented in specification (S1) are in line with earlier results from gravity equations. Home and host country GDP affect foreign real affiliate sales positively whereas distance between the two countries affects sales negatively. The estimated coefficients are statistically significant at one percent. While the coefficients on home country GDP is not significantly different from one, the restriction on *both* coefficients being equal to unity is rejected at the five percent level of significance ($\chi^2(2) = 6.41$, *p-value*=0.041).³ The gravity equation derived from the proximity concentration models suggests that the coefficients on both GDP variables are one. Yet, this restriction is not supported by the data.

We include the relative factor endowment and the sum of GDP variables in specification (S2). The introduction of both variables change the results on the constraint imposed on the home and host GDP coefficients, but does not influence the coefficient of the distance variable. Both the home and host coefficients become statistically equal to one ($\chi^2(2) = 2.92$, *p-value*=0.232). Contrary to the prediction of the factor proportion model, the coefficient of the home country GDP variable is positive. We do not find any significant impact of the sum of GDP variable on real affiliates sales. The vertical gravity model predicts a coefficient of one. We find however a positive and significant coefficient of the relative factor endowment variable. Real affiliate sales increase in the high-skilled labor abundance of the home country, relative to the host country. This is in line with the prediction of our factor proportion gravity model.

Overall, the empirical results of specification (S2) give more support to horizontal multinational activities even if we cannot strictly discriminate between

³ This results is due to the rejection at five percent of unity of the host country GDP coefficient ($\chi^2(1) = 5.14$, *p-value*=0.023). the coefficient of the Home country GDP variable is statistically equal to one ($\chi^2(1) = 0.99$, *p-value*=0.321)

the horizontal and the vertical models. The vertical gravity model is supported by only one criteria: the positive and significant impact of the *RFE* coefficient on real affiliate sales. Moreover, the omission of relative factor endowment and the joint size of the home and the host country does not severely bias the estimation results found in specification (S1).

In specification (S3), we add a number of control variables including the FDI and trade openness index and an adjacency variable that takes the value of one when countries i and j share a common border. We do not find any significant impact of the trade and FDI openness indexes on real affiliate sales. Moreover, these variables do not change significantly the results presented in specification (S2). However, the adjacency variable is positive and significant at one percent level. Adding this variable roughly halves the estimated effect of distance on real affiliate sales. The coefficient of the overall size of the home and host countries becomes significantly negative. Note that the correlation between $Border_{ij}$ and $\ln(Y_i + Y_j)$ is positive and insignificant ($Corr = 0.019$, $p\text{-value}=0.528$). This results is driven by distant and small countries that have lower bilateral affiliates sales.⁴

We follow Braconier *et al.* and split our sample into observation where the home country is relatively skilled-labor abundant ($RFE > 0$) and into observations where it is unskilled-labor abundant ($RFE < 0$) in specifications (S4). We do not find any significant effect of the relative factor endowment in either case. We present only the results for the sub-sample with relatively skilled-labor abundant home countries ($RFE > 0$), because only this sub-sample can be explained within the theoretical framework of vertical multinational firms. This specification is most favorable for the vertical model. The joint size of

⁴We find 44 country pairs with 112 observations that share a common border. Among these are countries with the largest bilateral affiliate sales in the sample (Canada-USA, Germany-Netherland, Germany-France).

the home and host countries does not play any role in specification (S4). The prediction of the horizontal gravity model are supported when Home is relatively skilled-labor abundant. The estimated coefficients are significant and of the expected signs. Moreover, the home and host estimated GDP coefficients become jointly statistically equal to one ($\chi^2(2) = 0.75$, $p\text{-value}=0.688$).

7 Conclusion

We derive gravity equations explaining bilateral sales of foreign affiliates of multinational firms from three very different models of the multinational firm. Foreign affiliates' sales are positively affected by domestic supply capacity and foreign market capacity and negatively by distance between the two countries. We propose three different models to argue that the success the gravity equation has in empirical studies results from the fact that it can be derived from various models.

First, we model a production process of an foreign affiliate that depends on domestic intermediate inputs that are costly to trade. We show that for this case lower aggregate foreign multinational sales results from lower average foreign affiliates' production while the number of affiliates remains unchanged by distance costs. Second, we model fixed costs of production in the foreign country which increase with distance between countries in a heterogenous firms framework. In this setting, lower aggregate affiliate sales in more distant countries results from fewer active affiliates. Both models are proximity-concentration models that explain the emergence of horizontal multinational firms.

The third model of multinational firms, from which we derive the gravity equation, is based on the factor-proportion theory. Firms fragment their production process in order to benefit from countries' comparative advantages.

The derived gravity equation entails a *relative factor endowment* and an *joint size of home and host country* biases. Moreover, we show that bilateral affiliate sales are affected positively by both countries' income. However, the interpretation of the coefficients of the income variables is very different from their interpretation in the horizontal model case. Distance between the countries, in contrast, affects the volume of affiliate sales negatively just as in the gravity equations derived from proximity-concentration models. Finally, real affiliate sales increase in the high-skilled labor abundance of the home country, relative to the host country.

We use a novel econometric methodology and data on bilateral real affiliate sales to show which type of horizontal or vertical models is supported by the data. This methodology takes into account zero-valued observation and inconsistency problems of OLS estimates in presence of heteroscedasticity. Our findings give support to the horizontal models. In particular, we find that the omission of relative factor endowment and the overall size of the home and host countries does not severely bias the estimation results from horizontal gravity models.

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Appendices

A Distance and Critical Marginal Costs

The Φ term is a positive function of the minimum marginal cost level a_{ij}^{MNE} . $\frac{\partial \Phi}{\partial a_{ij}^{MNE}} = (\kappa - \sigma + 1) \frac{(a_{ij}^{MNE})^{\kappa - \sigma}}{(a_{ij}^{Dom})^{\kappa - \sigma + 1}} > 0$. κ and a_{ij}^{Dom} do not depend on distance but a_{ij}^{MNE} does.

We use equation (9c) to derive the effect of distance on the critical marginal cost level. We assume that fixed costs are a linear function of distance in a similar way as variable distance costs. Hence, $(1 - \phi) f_j^{MNE} = f D_{ij}$ and $\tau_{ij} = \tau D_{ij}^{\eta_1}$. Substituting this functional forms into equation (9c) gives:

$$\begin{aligned} & (a_{ij}^{MNE})^{1-\sigma} (1 - \tau_{ij}^{1-\sigma}) \frac{(1-\mu)Y_j(1-\rho)}{P_j^{\sigma-1}\rho^{1-\sigma}} = fD_{ij} \\ \Leftrightarrow a_{ij}^{MNE} &= \left(1 - (\tau D_{ij}^{\eta_1})^{1-\sigma}\right)^{\left(\frac{1}{\sigma-1}\right)} \Omega^{\left(\frac{1}{\sigma-1}\right)} fD_{ij}^{\left(\frac{1}{1-\sigma}\right)} \end{aligned}$$

where $\Omega = \frac{(1-\mu)Y_j(1-\rho)}{P_j^{\sigma-1}\rho^{1-\sigma}}$.

We derive the effect of distance on the minimum marginal costs level a_{ij}^{MNE} as

$$\begin{aligned} \frac{\partial a_{ij}^{MNE}}{\partial D_{ij}} &= \underbrace{\Omega^{\left(\frac{1}{\sigma-1}\right)} (fD_{ij})^{\frac{1}{1-\sigma}} \left(1 - (\tau D_{ij}^{\eta_1})^{1-\sigma}\right)^{\frac{1}{\sigma-1}}}_{<0} \\ &\quad \times \left[\eta_1 \tau^{1-\sigma} D_{ij}^{\eta_1(1-\sigma)-1} \left(1 - (\tau D_{ij}^{\eta_1})^{1-\sigma}\right)^{-1} - \frac{1}{\sigma-1} D_{ij}^{-1} \right] \end{aligned}$$

This first is positive if distance is not too small, i.e. $D_{ij} > \tau^{-1/\eta_1}$. The second term is negative if distance costs τ_{ij} are not too convex, i.e. η_1 is not too small. The second term is negative if

$$\begin{aligned} \frac{1}{(\sigma-1)D_{ij}} &> \frac{\eta_1 D_{ij}^{\eta_1(1-\sigma)-1}}{\tau^{\sigma-1} - D_{ij}^{\eta_1(1-\sigma)}} \\ \Leftrightarrow \frac{\tau^{\sigma-1} - D_{ij}^{\eta_1(1-\sigma)} (1 - (\sigma-1)\eta_1)}{(1-\sigma)D_{ij} (\tau^{\sigma-1} - D_{ij}^{\eta_1(1-\sigma)})} &< 0 \end{aligned}$$

The denominator is negative if $D_{ij} > \tau^{-1/\eta_1}$, while the numerator is positive if $(\sigma-1)\eta_1 > 1$. Thus, if distance is not too small and distance costs are not too convex, the effect of distance on the minimum marginal costs is negative. Affiliate production in countries further away require lower marginal costs of the firm. That in turn implies a negative effect of distance on the middle term Φ_{ij} .

We proxy the term $\left(\frac{\kappa}{\kappa-\sigma+1} \frac{a_{ij}^{MNE}}{a_i^{dom}}\right)^{\kappa-\sigma+1}$ which is a negative function of distance by the very flexible function $\Phi_{ij} = \lambda D_{ij}^{-\eta_2}$.

B Data

Table 1. Dependent variable: bilateral real affiliate sales, fixed effects poisson regression

	Label	(S1)	(S2)	(S3)	(S4)
Home Country GDP	$\ln(Y_i)$	0.813*** (0.19)	1.079*** (0.24)	1.088*** (0.29)	0.997** (0.46)
Host Country GDP	$\ln(Y_j)$	0.642*** (0.36)	0.802*** (0.12)	0.708*** (0.13)	0.714** (0.33)
Distance	$\ln(D_{ij})$	-0.517*** (0.05)	-0.516*** (0.07)	-0.250** (0.12)	-0.273** (0.13)
Relative Factor Endowment	RFE		0.822** (0.36)	0.485** (0.20)	-0.035 (0.31)
Sum of GDP	$\ln(Y_i + Y_j)$		-0.348 (0.23)	-0.484** (0.19)	-0.033 (0.25)
Adjacency	$Border_{ij}$			1.038*** (0.32)	0.812*** (0.29)
Home country protection index	$Prot_i$			-0.005 (0.00)	-0.004 (0.01)
Host country protection index	$Prot_j$			0.004 (0.00)	0.000 (0.00)
Home country investment index	Inv_i			-0.005 (0.01)	-0.001 (0.01)
Observation		1089	1089	1089	593
Test $\ln(Y_i) = \ln(Y_j) = 1$,		6.41** (0.041)	2.92 (0.232)	2.55 (0.281)	0.75 (0.688)
<i>p-value</i>		YES	YES	YES	YES
Home Country Fixed Effects		YES	YES	YES	YES
Host Country Fixed Effects		YES	YES	YES	YES
Time Country Fixed Effects		YES	YES	YES	YES

Robust standard error into brackets. ***, **, * significantly different from 0 at 1%, 5% and 10% level, respectively.

Table B.1
Descriptive Statistics

Variables	Obs.	Mean	Std. Dev.	Min	Max
AS_{ij}	1089	9098.306	26184.340	0.000	324133.4
$\ln(Y_i)$	1089	27.206	1.439	23.772	29.713
$\ln(Y_j)$	1089	26.788	1.397	23.772	29.713
$\ln(D_{ij})$	1089	8.112	1.139	5.159	9.853
$\ln(RFE)$	1089	0.058	0.444	-2.084	2.516
$\ln(Y_i + Y_j)$	1089	28.158	1.091	25.811	30.222
$Adjacency_{ij}$	1089	0.103	0.304	0	1
$Prot_i$	1089	27.906	12.054	6.800	81.410
$Prot_j$	1089	29.627	13.611	6.800	85.080
Inv_c_j	1089	34.005	11.670	12.500	79.430

Table B.2. Correlation Matrix

	AS_{ij}	$\ln(Y_i)$	$\ln(Y_j)$	$\ln(D_{ij})$	$\ln(RFE)$	$\ln(Y_i + Y_j)$	$Border_{ij}$	$Prot_i$	$Prot_j$	Inv_{ij}
AS_{ij}	1.000									
$\ln(Y_i)$	0.295***	1.000								
$\ln(Y_j)$	0.286***	-0.216***	1.000							
$\ln(D_{ij})$	-0.017	0.209***	0.051*	1.000						
$\ln(RFE)$	-0.111***	0.002	-0.208***	-0.037	1.000					
$\ln(Y_i + Y_j)$	0.356***	0.666***	0.470***	0.276***	-0.190***	1.000				
$Adjacency_{ij}$	0.153***	-0.019	0.104***	-0.473***	0.006	0.019	1.000			
$Prot_i$	0.093***	0.262***	0.025	0.237***	-0.227***	0.240***	-0.044	1.000		
$Prot_j$	-0.072	0.097***	-0.043	0.195***	0.274***	0.025	-0.050*	-0.011	1.000	
Inv_{ij}	-0.139***	0.146***	-0.226***	0.117***	0.395***	-0.074**	-0.044	-0.022	0.783***	1.000

***, **, * significantly different from 0 at 1%, 5% and 10% level, respectively.

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