Trade, Multinational Production, and the Gains from Openness* (Preliminary)

Natalia Ramondo[†]
University of Texas-Austin

Andrés Rodríguez-Clare[‡]
Pennsylvania State University and NBER

May 26, 2009

Abstract

Much attention has been devoted to the quantification of the gains from trade. In this paper we pursue a broader and arguably more important exercise by quantifying the gains from *openness*. This notion includes not only trade but all the other ways through which countries interact. We focus our attention here on multinational production (MP), which in 2004 was more than twice as large as trade flows. We present and estimate a model where countries interact through trade as well as MP, and then quantify the overall gains from openness and the role of both of these channels in generating those gains. We build a model where trade and MP are alternative ways to serve a foreign market, which makes them substitutes, but MP also relies on imports of intermediate goods from the home country, which make them complements. The model also allows for “bridge” MP, or export platforms, creating an additional channel for complementarities between trade and MP. Our results imply that the gains from openness are much larger than the gains from trade – this is thanks both to the large gains from MP and to our finding that trade and MP behave as complements.

*We benefited from comments by participants at various conferences and seminars. We have also benefited from comments and suggestions from Costas Arkolakis, Russell Cooper, Arnaud Costinot, Ana Cecilia Fielser, Chad Jones, Pete Klenow, Elhanan Helpman, Alexander Monge-Naranjo, Ellen McGrattan, Nancy Stokey, Joris Pinkse, Esteban Rossi-Hansberg, Jim Tybout, and Stephen Yeaple. We are particularly grateful to Sam Kortum and Jonathan Eaton for help with several data and technical questions that emerged during this research. Also, we thank Alex Tarasov for his excellent research assistance. All errors are our own.

[†]E-mail: nramondo@mail.utexas.edu

[‡]E-mail: andres@psu.edu

1 Introduction

Much attention has been devoted to the quantification of the gains from trade. In this paper our goal is to quantify the gains from *openness*. The notion of openness includes not only trade but all the other ways through which countries interact. Even if a country were to shut down trade, it could still benefit from foreign ideas through the activity of foreign affiliates of multinational firms (what we call multinational production) as well as the flow of ideas through migration, books, journals and the Internet, among others. Multinational production is arguably one of the most important channels through which countries benefit from openness. It is certainly as important as (if not more than) trade: by 2004, total sales of foreign affiliates of multinational firms in the world were more than twice as high as world exports. Furthermore, over the past two decades, while exports increased by a factor of five, sales of foreign affiliates have increased by a factor of seven (UNCTAD's World Investment Report, 2006).

The goal of this paper is to construct and calibrate a general equilibrium model where countries interact through trade and multinational production (MP), and then to quantify the overall gains from openness and the role of trade and MP in generating those gains. Our results imply that the gains from openness are five times as high as the gains from trade. This is thanks to the large gains from MP and to the fact that trade and MP behave as complements in the calibrated model. Moreover, our estimated gains from trade are significantly larger than the analogous results in Eaton and Kortum (2002) and Alvarez and Lucas (2007). This is an important implication of complementarity between trade and MP – by facilitating MP, trade generates larger gains than the ones implied solely by the trade flows in the data.

Calculating the gains from trade in a model that allows for trade and MP represents a significant departure from the standard practice in the literature, which is to consider trade as the only channel through which countries interact.¹ This has begun to change with some recent attempts to quantify the gains from MP, but this has been done using models that do not allow for trade.² Considering each of these channels separately may understate or overstate the associated gains depending on the existence of significant sources of complementarity or substitutability among them. To see this, suppose that MP depends on the ability of foreign affiliates to import inputs from their home country. In this case, shutting down trade would

¹Some recent attempts to quantify gains from trade in Ricardian models are Eaton and Kortum (2002), Alvarez and Lucas (2007), Waugh (2007), and Fieler (2007).

²See Burstein and Monge-Naranjo (2007), McGrattan and Prescott (2007), and Ramondo (2006).

also decrease MP and generate losses beyond those calculated in models with trade but no MP. Alternatively, trade and MP may behave as substitutes because they are competing ways of serving foreign markets. In this case, shutting down trade would generate smaller losses than in models with only trade because MP would partially replace the lost trade.

The literature has typically modeled trade and “horizontal” Foreign Direct Investment (FDI) as substitutes in the context of the “proximity-concentration” trade-off: firms choose to either serve a foreign market by exporting or opening an affiliate there (Brainard, 1997; Markusen and Venables, 1997; Helpman, Melitz, and Yeaple, 2004). On the other hand, the literature has modeled trade and “vertical” FDI as complements: foreign affiliates rely on intermediate goods imported from their parent firms to produce goods that are consumed in other markets (Markusen, 1984; Grossman and Helpman, 1985; Antras, 2003). The empirical evidence appears consistent with both of these views. Studies using data at the industry, product, or firm level, have concluded that MP and trade flows in *intermediate inputs*, often conducted within the firm, are complements, while MP and trade flows in *final goods* are substitutes (Belderbos and Sleuwaegen, 1988; Blonigen, 2001; Head and Ries, 2001; Head, Ries, and Spencer, 2004).

This paper presents a general equilibrium, multi-country, Ricardian model of trade and MP. The model has two sectors: tradable intermediate goods, and non-tradable consumption goods. All goods are produced with constant-returns-to-scale technologies which differ across countries, creating incentives for trade and MP. For non-tradable goods, serving a foreign market can only be done through MP, but for tradable goods we have to consider the choice between exports and MP. Trade flows are affected by iceberg-type costs that may vary across country pairs. To avoid these costs or to benefit from lower costs abroad, firms producing tradable goods may prefer to serve a country through MP rather than exports. But MP entails some efficiency losses as well. Moreover, to introduce complementarity between trade and MP, we assume that affiliates rely, at least partially, on imported inputs from their home country; in our empirical approach, we think of this as “intra-firm” trade.³ Since these imports are affected by trade costs (just as regular “arm-length” trade), this creates an extra cost of MP.

Our set-up allows firms to use a third country as a “bridge” or export platform, to serve a particular market; we refer to this as “bridge MP”, or simply BMP.⁴ For example, a firm

³The empirical evidence points to significant intra-firm trade flows related to multinational activities (Hanson, Mataloni, and Slaughter, 2003; Bernard, Jensen, and Schott, 2005; and Alfaro and Charlton, 2007).

⁴We avoid referring to this type of MP as “vertical” MP because the main motivation for BMP in our model is to avoid trade costs rather than allocating different stages of the production process across locations according

from country i producing a tradable good v can serve country n by doing MP in country l , and ship it to country n . This entails MP costs associated with the pair $\{i, l\}$, and also trade costs associated with the pair $\{l, n\}$.⁵

The multiplicity of choices regarding how to serve a foreign market makes trade and MP substitutes: exports and MP are alternative ways of serving a foreign market. However, the possibility of BMP creates complementarities between trade and MP: the decision by country i of serving market n producing in a third country l generates a trade flow from l to n associated with MP from i to l . Moreover, when country i serves market n through MP, there is an “intra-firm” trade flow in intermediate inputs from country i associated with it. Thus, even in a world without BMP, our model generates complementarities between trade and MP.⁶

We estimate the model using data on bilateral trade and MP flows for a set of OECD countries, as well as data on intra-firm trade flows for U.S. multinationals and foreign multinationals operating in the U.S. However, as it is well known, the trade data alone cannot identify the parameter that determines the strength of comparative advantage – θ in Eaton and Kortum (2002). Thus, we appeal to the model’s implications for the long run growth rate to calibrate this parameter. In particular, although the model we present is static, in the Appendix we show that the equilibrium of the static model can be seen as the steady state equilibrium of a dynamic model where productivity evolves according to an exogenous “research” process. This dynamic model exhibits “semi-endogenous” growth as in Jones (1995) and Kortum (1997), and is closely related to Eaton and Kortum (2001). Importantly, growth is driven by the same mechanism that generates the gains from openness in the static model, namely the aggregate economies of scale associated with the fact that a larger population is linked to a higher stock of non-rival ideas. This is why calibrating the comparative advantage parameter so that the dynamic model generates a growth rate that matches the one we observe in the data seems appropriate.

We use the estimated model to compute the joint gains from trade and MP; we think of

to their comparative advantage.

⁵Even among rich countries, foreign subsidiaries of multinationals often sell a sizable part of their output outside of the host country. For example, around 30% of total sales of US affiliates in Europe are not done in the host country of production (Blonigen, 2005).

⁶We note that MP can be seen as a channel for international technology diffusion, since a country’s technologies end up being used abroad. In this sense, our model captures the idea that trade facilitates technology diffusion, at least diffusion associated with multinational activities. On the other hand, our model does not incorporate any causal link whereby trade or MP enhance international knowledge spillovers. The large literature on this topic is surveyed in Keller (2004).

these gains as the overall gains from openness. We also compute the separate gains from these two channels. Our results suggest that the gains from openness are much higher than the gains from trade: the average OECD country's real income is 15% higher thanks to the joint gains from trade and MP compared to isolation (i.e., no trade and no MP). In contrast, shutting down trade would lead to real income losses of only 3% for the average OECD country. The difference between these two numbers arises due to the large gains from MP in our estimated model: shutting down MP would lead to losses of 9% for the average OECD country. Of course, these gains and losses are much higher for smaller countries. For example, gains from openness are 30% for Belgium whereas they are only 5% for the United States. As a small country, Belgium benefits greatly both from trade and MP, although the gains from MP almost double those from trade.

As we mentioned above, the fact that exports and MP are alternative ways to serve foreign consumers makes trade and MP substitutes, but the existence of BMP and the assumption that MP generates a demand for home-country inputs makes trade and MP complements. The estimated model suggests that the second force dominates, so that trade and MP behave as complements.

In Section 2, we introduce the model, describe the equilibrium, and present the symmetry case. Section 3 describes the calibration procedure and results. Section 4 presents the calculated gains from openness. Section 5 concludes. All proofs are in the appendix, as well as an extension of the model to a dynamic set-up. We also show some summary statistics from the data and model's simulations.

2 The Model

We extend Eaton and Kortum's (2002) model of trade to incorporate MP. Our model is Ricardian with a continuum of tradable intermediate goods and non-tradable final goods, produced under constant-returns-to-scale. We adopt the probabilistic representation of technologies as first introduced by Eaton and Kortum (2002), but we enrich it to incorporate MP. We embed the model into a general equilibrium framework similar to the one in Alvarez and Lucas (2007).

2.1 The Closed Economy

To introduce the notation and main features of our model, consider first a closed economy with L units of labor. A representative agent consumes a continuum of final goods, indexed by $u \in [0, 1]$ in quantities $q_f(u)$, deriving utility

$$U = \left[\int_0^1 q_f(u)^{\frac{\sigma_f-1}{\sigma_f}} du \right]^{\frac{\sigma_f}{\sigma_f-1}},$$

with $\sigma_f > 0$. Final goods are produced with labor and a continuum of intermediate goods indexed by $v \in [0, 1]$. Formally, intermediate goods are aggregated into a *composite intermediate good* via a CES production function,

$$Q = \left[\int_0^1 q_g(v)^{\frac{\sigma_g-1}{\sigma_g}} dv \right]^{\frac{\sigma_g}{\sigma_g-1}},$$

with $\sigma_g > 0$. This composite intermediate good and labor are used to produce final goods via Cobb-Douglas technologies with varying productivity levels,

$$q_f(u) = z_f(u) L_f(u)^\alpha Q_f(u)^{1-\alpha}. \quad (1)$$

The variables $L_f(u)$ and $Q_f(u)$ denote the quantity of labor and the composite intermediate good used in the production of final good u , respectively, and $z_f(u)$ is a productivity parameter. Similarly, intermediate goods are produced according to

$$q_g(v) = z_g(v) L_g(v)^\beta Q_g(v)^{1-\beta}. \quad (2)$$

Resource constraints are

$$\begin{aligned} \int_0^1 L_f(u) du + \int_0^1 L_g(v) dv &= L, \\ \int_0^1 Q_f(u) du + \int_0^1 Q_g(v) dv &= Q. \end{aligned}$$

To complete the description of the environment in the closed economy, we assume that the productivity parameters $z_f(u)$ and $z_g(v)$ are random variables drawn independently from a Fréchet distribution with parameters T and $\theta > \max\{1, \sigma - 1\}$, $F(z) = \exp(-Tz^{-\theta})$, for $z > 0$.

To describe the competitive equilibrium for this economy it is convenient to introduce the notion of an *input bundle for the production of final goods*, and an *input bundle for the production*

of intermediate goods, both of which are produced via Cobb-Douglas production functions with labor and the composite intermediate good, and used to produce final and intermediate goods, as specified in (1) and (2), respectively. The unit cost of the input bundle for final goods is $c_f = Aw^\alpha P_g^{1-\alpha}$, and the unit cost of the input bundle for intermediate goods is $c_g = Bw^\beta P_g^{1-\beta}$, where w and P_g are the wage and the price of the composite intermediate good, respectively, $A \equiv \alpha^{-\alpha}(1-\alpha)^{\alpha-1}$, and $B \equiv \beta^{-\beta}(1-\beta)^{\beta-1}$. In a competitive equilibrium prices of final goods are given by $p_f(u) = c_f/z_f(u)$, and prices of intermediate goods are given by $p_g(v) = c_g/z_g(v)$. In turn, the aggregate price for intermediates satisfies $P_g^{1-\sigma} = \int_0^1 p_g(v)^{1-\sigma} dv$. Figure 1 illustrates the cost structure in the closed economy.

Figure 1: Cost Structure in the Closed Economy

The characterization of the equilibrium follows closely the analysis in Eaton and Kortum (2002) and Alvarez and Lucas (2007), so we omit the details. Suffice it to say here that the equilibrium real wage is given by

$$\frac{w}{P_f} = \tilde{\gamma} \cdot T^{\frac{1+\eta}{\theta}}, \quad (3)$$

where $P_f^{1-\sigma_f} = \left(\int_0^1 p_f(u)^{1-\sigma_f} du \right)$ is the price index for final goods, $\eta \equiv (1-\alpha)/\beta$, and $\tilde{\gamma}$ is a positive constant.⁷

⁷In Alvarez and Lucas (2007) the real wage is proportional to $T^{\eta/\theta}$ rather than $T^{(1+\eta)/\theta}$. The difference arises because we also have T affecting the productivity for final goods.

2.2 The World Economy

Now consider a set of countries indexed by $i \in \{1, \dots, I\}$ with preferences and technologies described above. Country i has L_i units of labor. Intermediate goods are tradable but final goods are not. Trade is subject to iceberg-type costs: $d_{nl} \geq 1$ units of any good must be shipped from country l for one unit to arrive in country n . We assume that $d_{nn} = 1$, and the triangle inequality holds (i.e., $d_{nl} \leq d_{nj}d_{jl}$ for all n, l, j).

Each country i has a technology to produce each final good and each intermediate good, at home or abroad. These technologies are described by the vectors $\mathbf{z}_{fi}(u) \equiv \{z_{f1i}(u), \dots, z_{fIi}(u)\}$ and $\mathbf{z}_{gi}(v) \equiv \{z_{g1i}(v), \dots, z_{gIi}(v)\}$. When a country i produces in another country $l \neq i$, we say that there is multinational production (MP) by country i in country l . [Sometimes, we just say that MP in country l is carried out by country i “multinationals”.] The corresponding productivity parameter in this case is $z_{fli}(u)$, or $z_{gli}(v)$. We adopt the convention that the subscript n denotes the destination country, l the country of production, and i the country where the technology originates. Note that if $z_{fli}(u) = z_{gli}(v) = 0$ whenever $l \neq i$, for all $u, v \in [0, 1]$, our model collapses to the Alvarez and Lucas (2007) version of Eaton and Kortum (2002) model of trade with no MP.

We assume that MP incurs an iceberg-type efficiency loss of $h_{li} \geq 1$ associated with using an idea from i to produce in l . Thus, whereas national production of final good u in country l entails unit cost $c_{fl}/z_{flu}(u)$, MP of final good u by i in l entails unit cost $c_{fl}h_{li}/z_{fli}(u)$. We assume that $h_{ii} = 1$. Similarly, whereas national production of intermediate good v in l has unit cost $c_{gl}/z_{glv}(v)$, MP of intermediate good v by i in l entails unit cost $c_{gli}/z_{gli}(v)$. The unit cost c_{gli} differs from $c_{fl}h_{li}$ because we assume that MP in intermediate goods requires the use of what we call a *multinational input bundle for the production of intermediate goods*. In particular, we assume that the multinational input bundle combines the national input bundle from the home country (i.e., the country where the technology originates) and the host country (i.e., the country where production takes place). The home country national input bundle must be shipped to the host country of production, and this implies paying the corresponding transportation cost. The cost of the home country national input bundle used in MP by country i in country l is then $c_{gi}d_{li}$. The host country national input bundle has cost c_{gl} , but MP incurs an efficiency loss of $h_{li} \geq 1$, so the cost of the host country national input used in MP by i in l is $c_{gl}h_{li}$. Combining the costs of home and host country national inputs into a CES aggregator,

the unit cost of the multinational input bundle for intermediates produced by i in l is

$$c_{gli} = \left[(1-a) (c_{gl} h_{li})^{1-\xi} + a (c_{gi} d_{li})^{1-\xi} \right]^{\frac{1}{1-\xi}}, \quad (4)$$

where $a \in [0, 1]$ and $\xi > 1$. Note that $c_{gii} = c_{gi}$. Moreover, if $a = 0$, then $c_{gli} = c_{gl} h_{li}$. The parameter ξ indicates the degree of substitutability between the national input bundles from the home and host countries. It is a key parameter for our estimated welfare gains.

Finally, we assume that the productivity vectors $\mathbf{z}_{fi}(u)$ and $\mathbf{z}_{gi}(v)$ for each good are random variables that are drawn independently across goods and countries from a multivariate Fréchet distribution with parameters $(T_{1i}, T_{2i}, \dots, T_{Ii})$, $\theta > \max\{1, \sigma - 1\}$, and $\rho \in [0, 1)$,⁸

$$F_i(\mathbf{z}_{si}) = \exp \left[- \left(\sum_l \left(T_{li} (z_{sli})^{-\theta} \right)^{\frac{1}{1-\rho}} \right)^{1-\rho} \right]. \quad (5)$$

Note that

$$\lim_{x \rightarrow \infty} F_i(x, x, \dots, z_{sli}, \dots, x) = \exp \left[-T_{li} z_{sli}^{-\theta} \right],$$

so that the marginal distributions are Fréchet. The parameter ρ determines the degree of correlation among the elements of $\mathbf{z}_{si}$: if $\rho = 0$, productivity levels are uncorrelated across production locations, while in the limit as $\rho \rightarrow 1$, they are perfectly correlated, so that productivity is independent of the production location (i.e., $z_{sii} = z_{sli}$, for all l).

2.3 Equilibrium Analysis

Since final goods are identical except for their productivity parameters (i.e., they enter preferences symmetrically), we follow Alvarez and Lucas (2007) and drop index u , labeling final goods by $Z_f \equiv (\mathbf{z}_{f1}, \dots, \mathbf{z}_{fI})$. Similarly, we label intermediate goods by $Z_g \equiv (\mathbf{z}_{g1}, \dots, \mathbf{z}_{gI})$. The unit cost of a final good Z_f in country n produced with a technology from country i is $c_{fn} h_{ni} / z_{fni}$, while the unit cost of an intermediate good Z_g in country n produced in country l with a technology from country i is $c_{gli} d_{nl} / z_{gli}$.

In a competitive equilibrium the price of final good Z_f in country n is simply the minimum unit cost at which this good can be obtained, $p_{fn}(Z_f) = \min_i c_{fn} h_{ni} / z_{fni}$. Similarly, the price of intermediate good Z_g in country n is $p_{gn}(Z_g) = \min_{i,l} c_{gli} d_{nl} / z_{gli}$. Note that if $l = i$, then the intermediate good is exported from i to n while if $i \neq l = n$ there is MP from i to n . Finally,

⁸This distribution is discussed in footnote 14, Eaton and Kortum (2002).

if $i \neq l$ and $l \neq n$ then country l is used as an export platform by country i to serve country n . We say that in this case there is “bridge MP”, or simply BMP, by country i in country l .

The following proposition describes a number of convenient results regarding the choice of goods according to the origin of the technology and the location of production, as well as a characterization of prices and expenditure shares.

Proposition 1 (a) *The shares of final and intermediate goods that country n buys produced with country i technologies are, respectively,*

$$\phi_{fni} = \frac{\Phi_{fni}}{\Phi_{fn}} \text{ and } \phi_{gni} = \frac{\Phi_{gni}}{\Phi_{gn}},$$

where

$$\Phi_{fni} \equiv T_{ni} (c_{fn} h_{ni})^{-\theta}, \Phi_{gni} \equiv \left(\sum_l \left(T_{li} (c_{gli} d_{nl})^{-\theta} \right)^{\frac{1}{1-\rho}} \right)^{1-\rho}, \text{ and } \Phi_{sn} \equiv \sum_i \Phi_{sni}, \text{ for } s = f, g;$$

(b) *Of the intermediate goods bought by country n that are produced with country i technologies, the share that is produced in country l is*

$$\pi_{gni,l} = \left(\frac{T_{li} (c_{gli} d_{nl})^{-\theta}}{\Phi_{gni}} \right)^{\frac{1}{1-\rho}};$$

(c) *The average price of goods that are purchased in any market n does not depend on the source of the technology or the location of production; and (d) The price index in country n , is given by*

$$P_{sn} = \gamma_s \Phi_{sn}^{-1/\theta}, \quad (6)$$

for $s = g, f$, where $\gamma_s \equiv \Gamma(1 + (1 - \sigma_s)/\theta)^{1/1-\sigma}$, and $\Gamma(\cdot)$ is the Gamma function.

Since Φ_{sn} , for $s = g, f$ is a function of model’s parameters and unit costs, c_{sn} , which in turn is a function of wages and the price index P_{gn} , the set of equations associated with (6), for $s = g$ and $n = \{1, \dots, I\}$, implicitly determines P_{gn} as a function of $\mathbf{w} = (w_1, \dots, w_I)$. In vector notation, this defines the function $P_g(\mathbf{w})$: $I \rightarrow I$ (see Alvarez and Lucas, 2007). Together with $P_g(\mathbf{w})$, equation (6) for $s = f$ also defines a function $P_f(\mathbf{w})$ that determines the price index for final goods as a function of wages.

The total expenditure on final goods by country n is equal to the country’s total income, $w_n L_n$. We refer to the total value of final goods produced in n with country i technologies as

the value of MP in final goods by i in n , denoted by Y_{fni} . Part (c) of Proposition 1 implies that ϕ_{sni} and $\pi_{sni,l}$ not only represent the share of goods purchased by country n produced with different technologies and in different production locations, but also expenditure shares. Thus,

$$Y_{fni} = \phi_{fni} w_n L_n.$$

Note that $\sum_i Y_{fni} = w_n L_n \sum_i \phi_{fni} = w_n L_n$.

Since total expenditure on intermediates by country n is $P_{gn} Q_n$, the value of MP in intermediates by country i in country l to serve country n is $\phi_{gni} \pi_{gni,l} P_{gn} Q_n$. Thus, MP in intermediates by i in l is

$$Y_{gli} = \sum_n \phi_{gni} \pi_{gni,l} P_{gn} Q_n. \quad (7)$$

Total imports by country n from l are given by the sum of intermediate goods produced in country l with technologies from any other country, $\sum_i \phi_{gni} \pi_{gni,l} P_{gn} Q_n$, plus the imports of country l 's input bundle for intermediates used by country l 's multinationals operating in country n . To compute this second term, let ω_{nl} be the cost share of the home country input bundle for the production of intermediates in country n by multinationals from country l . From (4), $\omega_{nl} = a(c_{gl} d_{nl} / c_{gnl})^{1-\xi}$. The value of imports of the input bundle for intermediates by n from l associated with MP by l in n is $\omega_{nl} Y_{gnl}$. Total imports by country n from $l \neq n$ are then given by

$$X_{nl} = \sum_i \phi_{gni} \pi_{gni,l} P_{gn} Q_n + \omega_{nl} Y_{gnl}. \quad (8)$$

For country n , aggregate imports are $\sum_{l \neq n} X_{nl}$, while aggregate exports are $\sum_{l \neq n} X_{ln}$. The trade balance condition is then

$$\sum_{l \neq n} X_{nl} = \sum_{l \neq n} X_{ln}. \quad (9)$$

As in Alvarez and Lucas (2007), the total expenditure on the composite intermediate good is proportional to the country's total income. Formally,

Proposition 2 $P_{gn} Q_n = \eta w_n L_n$, for all n .

Since the terms ϕ_{gni} , $\pi_{gni,l}$, and ω_{li} are functions of $\mathbf{w}$, the trade balance conditions constitute a system of I equations in $\mathbf{w}$. This system of equations together with some normalization of wages yields an equilibrium wage vector $\mathbf{w}$.

2.4 Gravity

In general, it is not possible to express trade flows from l to n as a function of the bilateral trade cost d_{nl} and country specific variables for l and n : the general model does not have a gravity equation. However, there is one special case for which a gravity equation can be derived. When $\rho = 0$ and $a = 0$, it can be shown that

$$X_{nl} = \frac{T'_l (c_{gl} d_{nl})^{-\theta}}{\sum_k T'_k (c_{gk} d_{nk})^{-\theta}} \eta w_n L_n, \quad (10)$$

where $T'_l \equiv \sum_i T_{li} h_{li}^{-\theta}$ is an adjusted technology parameter for l that takes into account the possibility of using technologies from other countries appropriately discounted by the efficiency losses h_{li} . This expression is exactly as the one in Eaton and Kortum (2002), and implies that country l 's normalized import share in country n depends only on the trade cost d_{nl} , and the price indices P_{gn} and P_{gl} ,

$$\frac{X_{nl}/w_n L_n}{X_{ll}/w_l L_l} = \left(\frac{d_{nl} P_{gl}}{P_{gn}} \right)^{-\theta}. \quad (11)$$

In the gravity literature, d_{nl} is called a “bilateral resistance” term while P_{gl} and P_{gn} are called “multilateral resistance” terms.

To understand why this result does not hold in the general case with $\rho > 0$, note that there are I^2 ways to produce any intermediate good, resulting from the combination of I source countries and I production locations. The productivity parameters $z_{g1i}, z_{g2i}, \dots, z_{gIi}$ associated with source country i are positively correlated (since $\rho > 0$) whereas the productivity parameters $z_{gl1}, z_{gl2}, \dots, z_{glI}$ associated with production location l are uncorrelated (by assumption of independence across the vectors $\mathbf{z}_{gi}$, for $i = 1, 2, \dots, I$). The different degrees of correlation among the elements of the columns and rows of the Z_g matrix makes it generally impossible to express all the determinants of bilateral trade flows in a bilateral resistance term together with multilateral resistance terms, as in (11).⁹

Analogously, we can explore whether there is a gravity-like relationship for MP flows. In

⁹The only exception is when $a = 0$ and $T_{li} h_{li}^{-\theta}$ is “separable” in the sense that it can be written as the product of a source and a destination-specific terms: $T_{li} h_{li}^{-\theta} = \lambda_l \mu_i$, for all l, i . In this case we obtain an expression similar to (10) but with T'_i substituted by $T''_i = \lambda_l^{\frac{1}{1-\rho}}$, and θ substituted by $\theta/(1-\rho)$. The reason why this works is that the distribution of $(\tilde{z}_{g1}, \tilde{z}_{g2}, \dots, \tilde{z}_{gI})$, for $\tilde{z}_{gl} \equiv \max_i \{z_{gli}/c_{gli}\}$, is multivariate Fréchet with parameters θ and ρ .

the special case with $\rho = 0$ and $a > 0$, using (7) and some manipulation, we get

$$Y_{gli} = \eta \gamma^{-\theta} \frac{T_{li} c_{gli}^{-\theta}}{P_{gl}^{-\theta}} \cdot \sum_n \left(\frac{d_{nl} P_{gl}}{P_{gn}} \right)^{-\theta} w_n L_n.$$

The second term on the RHS can be interpreted as the “market potential” of country l , while the term $T_{li} c_{gli}^{-\theta} / P_{gl}^{-\theta}$ captures the “relative competitiveness” of i technologies in country l . If we use Ψ_{gl} to denote the market potential of country l in intermediates, then we can write

$$\frac{Y_{gli} / \Psi_l}{Y_{gii} / \Psi_i} = \left(\frac{\tilde{h}_{gli} P_{gi}}{P_{gl}} \right)^{-\theta}, \quad (12)$$

where $\tilde{h}_{gli}^{-\theta} = (T_{li} c_{gli}^{-\theta} / T_{ii} c_{gii}^{-\theta})$ is an average relative cost of producing in country l rather than in country i with country i ’s technologies. The term $\tilde{h}_{gli}$ in (12) plays the analogous role of the bilateral resistance term $d_{nl}^{-\theta}$ in (11).

2.5 Symmetry

To gain some additional intuition about the model, we consider the case of symmetric countries. The symmetric case can be solved analytically, yet the basic intuition carries to the general case with asymmetric countries. We calculate the gains from openness, and explore the role of trade and MP in generating those gains. We are particularly interested in understanding the conditions under which trade and MP behave as substitutes or complements. We are also interested in the sources of complementarity – that is, we want to differentiate between the complementarity that arises from the possibility of doing “bridge” MP and the complementarity that arises from the use of the home country’s input bundle in MP activities (i.e. the role of the parameters ξ and a).

Symmetry entails $L_i = L$ for all i ; $d_{nl} = d$, $h_{nl} = h$, for all $l \neq n$. Moreover, we assume that $T_{li} = T$, for all l, i . In equilibrium wages, costs, and prices are equalized across countries, $w_n = w$, $c_n = c$, and $P_{sn} = P_s$, for $s = g, f$. Thus, the cost of the multinational input bundle collapses to $c_{gli} = m \cdot c_g$ (and $c_{gll} = c_g$), where $m \equiv [(1 - a)h^{1-\xi} + ad^{1-\xi}]^{\frac{1}{1-\xi}}$. The share of spending in the home input bundle done by MP is simply $\omega = a(d/m)^{1-\xi}$.

The equilibrium is characterized as follows. In the case of final goods the situation is straightforward: a country uses its own technologies for local production to serve domestic consumers, and for MP abroad to serve foreign consumers. For intermediate goods, there is trade, MP and BMP. Countries use some of their own technologies for local production to

satisfy domestic and foreign consumers (through exports). They also engage in MP abroad and the resulting output is sold to local consumers (MP), sent back home or sold to third markets (BMP). There is also trade associated with the import of the home country input bundle for MP.

For intermediate goods, in the special case with $\rho \rightarrow 1$, we can show that BMP vanishes, and trade and MP do not overlap: if $d > h$, there is only MP and trade associated with MP (i.e., imports of the home country input bundle), but there is no other trade of individual intermediate goods; while if $h > d$, there is only trade (no MP) (see the Appendix).

We can solve for the real wage in terms of trade and MP costs (d , h and m) and parameters η , θ and ρ .

Proposition 3 *Under symmetry, the equilibrium real wage is given by*

$$\frac{w}{P_f} = \tilde{\gamma}^{-1} [1 + (I - 1)h^{-\theta}]^{\frac{1}{\theta}} [\Delta_0 + (I - 1)\Delta_1]^{\frac{\eta}{\theta}} T^{\frac{1+\eta}{\theta}}, \quad (13)$$

where

$$\Delta_0 \equiv \left(1 + (I - 1)(md)^{-\frac{\theta}{1-\rho}}\right)^{1-\rho} \quad (14)$$

$$\Delta_1 \equiv \left(d^{-\frac{\theta}{1-\rho}} + m^{-\frac{\theta}{1-\rho}} + (I - 2)(md)^{-\frac{\theta}{1-\rho}}\right)^{1-\rho}, \quad (15)$$

and $\tilde{\gamma}$ is a constant.

This result shows how access to foreign ideas through trade and MP increases a country's real wage. We discuss this further in the context of the associated results about the gains from trade and MP.

The gains from openness (GO) are given by the change in the real wage, w/P_f , from isolation ($d, h \rightarrow \infty$) to the “benchmark” ($d, h < \infty$). The gains from trade (GT) are the gains of moving from isolation to only trade ($d < \infty, h \rightarrow \infty$), while the gains from MP (GMP) are the gains of moving from isolation to only MP ($h < \infty, d \rightarrow \infty$). Finally, we calculate the gains of moving from a situation with only MP ($h < \infty, d \rightarrow \infty$) to a situation with both trade and MP ($h, d < \infty$). This alternative definition of gains from trade is denoted by GT' . Similarly, we define GMP' as the gains from moving from a situation with only trade ($d < \infty, h \rightarrow \infty$) to a situation with both trade and MP.

Proposition 4 *Under symmetry, gains from openness are:*

$$GO = [1 + (I - 1)h^{-\theta}]^{\frac{1}{\theta}} \cdot [\Delta_0 + (I - 1)\Delta_1]^{\frac{\eta}{\theta}}, \quad (16)$$

where Δ_0 and Δ_1 are given by (14) and (15), respectively.

Gains from trade are:

$$GT = \lim_{h \rightarrow \infty} GO = [1 + (I - 1)d^{-\theta}]^{\frac{\eta}{\theta}}, \quad (17)$$

while gains from MP are:

$$GMP = \lim_{d \rightarrow \infty} GO = [1 + (I - 1)h^{-\theta}]^{\frac{1}{\theta}} \cdot [1 + (I - 1)\tilde{m}^{-\theta}]^{\frac{\eta}{\theta}}, \quad (18)$$

where

$$\tilde{m} \equiv \lim_{d \rightarrow \infty} m = (1 - a)^{\frac{1}{1-\epsilon}} h. \quad (19)$$

Finally, gains from trade given MP are $GT' = GO/GMP$ and gains from MP given trade are $GMP' = GO/GT$.

The expression for GT in equation (17) indicates that a country that opens up to only trade benefits from $I - 1$ foreign technologies, but at a “discount” of $d^{-\theta}$. Not surprisingly, GT decreases with d . Similarly, the expression for GMP in equation (18) indicates that a country that opens up to only MP benefits from $I - 1$ foreign technologies, but at a discount of $\tilde{m}^{-\theta}$ (i.e. the cost adjustment of the multinational input bundle when trade is not feasible) in the intermediate goods’ sector, and at a discount $h^{-\theta}$ in the final goods’ sector. Clearly, GMP decreases with h .

Gains from openness in equation (16) indicate that a country that opens up to both trade and MP in the intermediate goods’ sector benefits from using its own technologies at home and abroad, captured by the term Δ_0 , and $I - 1$ foreign technologies, captured by the term Δ_1 . When domestic technologies are used (the term Δ_0), production can be carried out in $I - 1$ foreign locations through MP at the cost m , and then goods shipped back home at the cost d . Hence, technologies are “fully” discounted at $(md)^{-\theta/(1-\rho)}$. In turn, foreign technologies can be accessed by importing goods in which case they are discounted by $d^{-\theta/(1-\rho)}$ (first term in Δ_1), by doing MP in which case they are discounted by $m^{-\theta/(1-\rho)}$ (second term in Δ_1), and by doing BMP in $I - 2$ different locations in which case the full discount $(md)^{-\theta/(1-\rho)}$ applies (third term

in Δ_1). The term in the first bracket in equation (16) captures the gains from accessing $(I - 1)$ foreign technologies through MP in the final goods' sector, at a discount of $h^{-\theta}$.

It is clear that GO decreases with h as well as d : the higher the MP or trade costs, the lower the gains from openness. Additionally, the parameter ρ only appears in GO , in association with intermediates' goods, but not in GT and GMP . Since ρ indicates the correlation between cost draws for a given source country across different production locations, it is only relevant when BMP is feasible, that is, when both trade and MP are allowed. We can see that GO decreases with ρ : the higher the correlation between technologies used to produce in different countries by firms of a given origin, the lower the gains from doing BMP (as shown in Lemma 2 in the Appendix).

Finally, gains from trade given MP, GT' , indicate that, with respect to having only MP, a country that opens up to trade derives extra benefits coming from the possibility of doing BMP, and using the home input bundle for MP. Analogously, gains from MP given trade GMP' indicate the extra benefits from using technologies for production in countries different from the one they originate.

We talk about complementarity and substitutability between trade and MP in two equivalent ways. Trade and MP are complements when $GO > GT \times GMP$, or $GT' > GT$. Trade and MP are substitutes when $GO < GT \times GMP$ or $GT' < GT$. Finally, trade and MP are independent when $GO = GT \times GMP$ or $GT' = GT$.¹⁰ The following proposition shows under which parameter configuration trade and MP behave as substitutes or complements.

Proposition 5 (a) Assume $\rho = 0$. Trade and MP are independent if $a = 0$ and complements if $a > 0$; (b) Assume $0 < \rho < 1$. (b1) If $a = 0$ then trade and MP are substitutes. (b2) If $a > 0$ then there exists ξ_0 and ξ_1 such that trade and MP are complements for $\xi < \xi_0$ and substitutes for $\xi > \xi_1$. (c) Assume $a > 0$ and $\xi - 1 > \theta$. There exists $\hat{\rho}$ such that for $\rho > \hat{\rho}$ trade and MP are substitutes.

To gain some intuition for these results, start from the case with $\rho = a = 0$. As shown above, in this case trade satisfies the gravity equation in (11), reflecting independence between trade and MP. As ρ increases above zero, the positive correlation between productivity draws across locations generates substitutability. Alternatively, if a increases above zero, the demand

¹⁰Since $GMP > 0$ then $\text{sign}(GO - GT \times GMP) = \text{sign}\left(\frac{GO - GT \times GMP}{GMP}\right)$, but from (??) we can write $GT' = GO/GMP$, hence $\text{sign}\left(\frac{GO - GT \times GMP}{GMP}\right) = \text{sign}(GT' - GT)$.

for home-country inputs by multinationals introduces complementarity. If both $\rho > 0$ and $a > 0$ then we need to consider parameters ξ and θ . If ξ is close to 1 then the low elasticity of substitution between home and host country inputs for MP generates complementarity between trade and MP, whereas the contrary occurs if ξ is large.

Part (a) of the proposition implies that, by continuity, if $a > 0$ and ρ is close to zero then trade and MP are complements. A natural question is whether trade and MP become substitutes as ρ increases towards 1 (assuming $a > 0$). Part (c) of the proposition states that this is indeed the case as long as $\xi - 1 > \theta$. To understand this condition, note that $\xi - 1$ governs the effect of trade costs on trade flows in Armington or Krugman models whereas θ has an analogous role in Ricardian models. Thus, in our model, $\xi - 1 > \theta$ implies that the effect of trade costs on “intra-firm” trade flows is larger than their effect on “arms-length” trade flows. More importantly, for ρ close to 1, $\xi - 1 > \theta$ implies that an increase in MP costs (h) leads to decline in imports by multinationals, making MP and trade substitutes.

3 Model’s Calibration

As explained below, we calibrate the model’s parameters using data on bilateral trade in manufacturing goods and bilateral gross value of production of foreign affiliates, normalized by expenditure in manufacturing and all sectors, respectively, as well as intra-firm imports of foreign affiliates, a size measure of equipped-labor, and real income per capita. We use standard bilateral variables such as distance, common border, and common language, to calibrate trade and MP costs. We consider nineteen OECD countries.

We use the calibrated version of the model to calculate gains from openness, and in this way, illustrate the rich implications of the model for the interactions among trade and MP. We are particularly interested in understanding the role of intra-firm trade and BMP in generating complementarity, and in affecting the contribution of trade and MP to welfare gains. We show how gains from trade and MP change with some key parameters of the model.

3.1 Data Description

We restrict our analysis to a set of nineteen OECD countries: Australia, Austria, Belgium/Luxemburg, Canada, Denmark, Spain, Finland, France, United Kingdom, Germany, Greece, Italy, Japan,

Netherlands, Norway, New Zealand, Portugal, Sweden, United States.¹¹ For bilateral variables, we have 342 observations, each corresponding to a country-pair. Depending on availability, our observations are an average over the period 1990-2002, or for the late nineties.

We use data on manufacturing trade flows from country i to country n as the empirical counterpart for trade in intermediates, X_{ni} in the model. These data are from the STAN data set for OECD countries, an average over 1990-2002.

The empirical counterpart for bilateral MP flows is the gross value of production for multinational affiliates from i in n , $Y_{ni} \equiv Y_{fni} + Y_{gni}$ in the model.¹² The available data for this variable include all sectors combined as averages over 1990-2002. The main source of these data is UNCTAD.¹³ The number of observations drops to 219 country-pairs for which we have available data for this flow.

In the model, we normalize bilateral trade flows by the importer's total expenditure on intermediate goods, and our measure of bilateral MP flows by total expenditure in final goods in the host country. In the model, trade shares and MP shares are given, respectively, by:

$$\tilde{X}_{ni} = \frac{X_{ni}}{\eta w_n L_n} \quad (20)$$

$$\tilde{Y}_{ni} = \frac{Y_{fni} + Y_{gni}}{w_n L_n}, \quad (21)$$

where $\eta w_n L_n$ is total expenditure in intermediate goods, and $w_n L_n$ is total expenditure in final goods (and also total income due to the trade balance condition.)

In the data, we compute total expenditure in intermediate goods as gross production in manufacturing in country n , plus total imports of manufacturing goods into country n from the remaining eighteen OECD countries in the sample, minus total manufacturing exports from country n to the rest of the world. Data on these three variables for each country are from the STAN database. We use an average of these series over the period 1990-2002. Analogously, we compute total expenditure in final goods for country n as gross domestic product for country n , plus total imports into country n from the remaining eighteen OECD countries in the sample, minus total exports from country n to the rest of the world. Data on GDP is from the World Development Indicators, and total exports and imports are from Feenstra and Lipsey (2005), averaged over the period 1990-2002.

¹¹These countries are also the ones considered by Eaton and Kortum (2002).

¹²This measure includes both local sales in n and exports to any other country, including the home country i .

¹³See Ramondo (2006) for a detailed description.

We use intra-firm imports from the home country done by foreign affiliates of multinational firms as the empirical counterpart for imports of the national input bundle for intermediates from the home country for MP (i.e., $\omega_{ni}Y_{gni}$ in the model). We only have data on intra-firm trade involving the United States, from the Bureau of Economic Analysis (BEA). We combine data on intra-firm exports from the United States to affiliates of American multinationals in foreign countries with data on imports done by affiliates of foreign multinationals located in the United States from their parent firms, as an average over the period 1999-2003. We normalize intra-firm trade flows from country i to n by gross production of affiliates from i in n ,

$$\tilde{\omega}_{ni} = \frac{\omega_{ni}Y_{gni}}{Y_{gni} + Y_{fni}}, \quad (22)$$

for $n = US$ or $i = US$.

For the empirical counterpart of the bilateral share of MP in intermediate goods,

$$\frac{Y_{gni}}{Y_{gni} + Y_{fni}}, \quad (23)$$

we use data on bilateral gross production of American affiliates abroad and foreign affiliates in the US in the manufacturing sector as share of total gross production in the foreign market and the US, respectively, from BEA (average over the period 1999-2003).

When the US is the source country, we are able to compute the empirical counterpart of the share BMP in the model (i.e. the share of the value of production done by i in l that is sold in a different market n). The BEA divides total sales of American affiliates produced in country l into sales to the local market, to the US, and to third foreign markets. This is the empirical counterpart for $\sum_{n \neq l} \phi_{gni} \pi_{gni,l} X_{gn} / (Y_{gli} + Y_{fli})$, from $i = US$ in a country l belonging to the OECD(19). We average out across l 's, and obtain an average bilateral BMP share for the US affiliates in the OECD(19). We consider an average over the period 1999-2003.

We need an empirical counterpart for the variable L_i . We think of this variable as capturing the total number of “equipped” units of labor available for production, so employment must be adjusted to account for human and physical capital available per worker. We use the measure of equipped labor constructed by Klenow and Rodriguez-Clare (2005), for OECD(19) countries, as an average over the nineties. Countries with more equipped labor are considered larger.

We use data on real income per capita (PPP-adjusted) to calibrate the technology parameters T_{li} as explained below. Data are from the Penn World Tables (6.2), as an average over the nineties. In the model, this variable is the ratio of $w_n L_n / P_{fn}$ to population in country n . Both

L_n and population are from the data, while the wage w_n and the price index for final goods P_{fn} are a result of computing the model's equilibrium.

Finally, we use bilateral distance, common border, and common language, to calibrate trade and MP cost.¹⁴ See the Appendix for summary statistics.

3.2 Calibration Procedure

We reduce the number of parameters to calibrate by assuming the following functional forms. First, following Fieler (2008), we assume that trade and MP costs in the intermediate goods' sector are approximated by the following functions:

$$d_{ni} = 1 + (\delta_0^d + \delta_{dist}^d dist_{ni}) \times (\delta_{border}^d)^{b_{ni}} \times (\delta_{language}^d)^{l_{ni}} \quad (24)$$

$$h_{ni} = 1 + (\delta_0^h + \delta_{dist}^h dist_{ni}) \times (\delta_{border}^h)^{b_{ni}} \times (\delta_{language}^h)^{l_{ni}}, \quad (25)$$

for all $n \neq i$, with $d_{nn} = 1$ and $h_{nn} = 1$. The variable $dist_{ni}$ is the distance (in thousands of kilometers) between i and n . The variables b'_{ni} s (l'_{ni} s) equals one if countries share a border (a language), and zero otherwise. Hence, if $\delta_{border} < 1$ sharing a border reduces iceberg costs. Similarly, if $\delta_{language} < 1$, sharing a language reduces iceberg costs. We need to calibrate a set of eight parameters, $\Upsilon = \{\delta_0^d, \delta_0^h, \delta_{dist}^d, \delta_{dist}^h, \delta_{border}^d, \delta_{border}^h, \delta_{language}^d, \delta_{language}^h\}$.

The resulting set of parameters to calibrate is

$$\{\{T_{li}\}_{l,i=1}^I, \Upsilon, a, \xi, \rho, \theta, \alpha, \beta\}.$$

We set the labor share in the intermediate goods' sector, β , to 0.5, and the labor share in the final sector, α , to 0.75, as calibrated by Alvarez and Lucas (2007).¹⁵ Then, we have $\eta \equiv (1 - \alpha)/\beta = 0.5$.

Turning to θ , it is well known that this parameter cannot be separately identified from the parameters in Υ by running a gravity equation (see Eaton and Kortum, 2002, and Fieler, 2008). Thus, we appeal to the model's implications for the growth rate of the real wage. The model

¹⁴These variables are from the Centre d'Etudes Prospectives et Informations internationales (CEPII). Bilateral distance is the distance in kilometers between the largest cities in the two countries. Common language is a dummy equal to one if both countries have the same official language or more than 20% of the population share the same language (even if it is not the official one). Common border is equal to one if two countries share a border.

¹⁵Alvarez and Lucas (2007) calibrate the parameters α and β to match the fraction of U.S. employment in the non-tradable sector and the share of labor in the total value of tradable goods produced, respectively. Jones (2009) also uses $\beta = 0.5$.

in the previous section is static. However, as we show in the Appendix, the equilibrium of the static model can be seen as the steady state equilibrium of a dynamic model where the vectors of productivity parameters Z_g and Z_f evolve according to an exogenous “research” process. This dynamic model exhibits “semi-endogenous” growth as in Jones (1995) and Kortum (1997), and is closely related to Eaton and Kortum (2001). Importantly, growth is driven by the same mechanism that generates the gains from openness in the static model, namely the aggregate economies of scale associated with the fact that a larger population is linked to a higher stock of non-rival ideas. Hence, calibrating θ to generate a growth rate in the dynamic model that matches the one we observe in the data seems reasonable. Growth rates in the steady state are the same for all countries, and not affected by openness. This implies that the growth rate for the open economy is the same as the one for the closed economy. From equation (3), the growth rate of the real wage in the closed economy is $(1 + \eta)/\theta$ times the growth rate of the parameter T . In the growth model for the open economy there is no a single parameter T but rather the whole matrix of T'_{li} s. As shown in the Appendix, our assumptions imply that all these T'_{li} ’s grow at some common rate g_λ . Hence the steady state growth rate of real wages for all countries is

$$g = \left[\frac{1 + \eta}{\theta} \right] g_\lambda. \quad (26)$$

We want the model to be consistent with a growth rate of TFP of 1%, as calculated by Klenow and Rodríguez-Clare (2005) for the OECD over the last four decades. We set g_λ equal to the growth rate of employment in R&D over the last decades in the five top R&D countries, which according to Jones (2002) has been 4.8%.¹⁶ Using (26) and $\eta = 0.5$, the observed values for g and g_λ imply $\theta = 7.2$. This is remarkably close to the central values of θ of 8.3 and 6.7 in Eaton and Kortum (2002) and Alvarez and Lucas (2007), respectively, which were pinned down following very different methodologies.

We assume that the technology parameters T_{li} are given by $T_{li} = \lambda_i \lambda_l^{1-\rho}$, as derived in the Appendix, where the parameters λ ’s represent the stock of ideas in a country. Thus, we just need to calibrate a vector of nineteen parameters, $\{\lambda_1, \dots, \lambda_{19}\}$.

¹⁶An alternative approach to calibrate θ is to target the elasticity of TFP to population across countries while controlling for the effects of trade, institutions and geography, as in Alcalá and Ciccone (2004). Depending on the specification, these authors find an elasticity ranging from 1/6 to 1/4.5, a range which encompasses our target of 1/4.8. Interestingly, it has been documented that metabolic rates decline with an organisms body mass with an elasticity of 1/4 (see West, Brown and Enquist, 1997).

We end up with the following set of parameters to calibrate,

$$\Gamma \equiv \{\{\lambda_i\}_{i=1}^I, \Upsilon, a, \xi, \rho\}.$$

Our calibration procedure is as follows. Given θ, β, α , a set of parameter values Γ , the matrices for bilateral distance, common border and common language, and the vector of country sizes L_n from the data on R&D employment, we compute the model's equilibrium, and generate a simulated data set with 361 observations (one for each country-pair, including the domestic pairs), for the following variables: trade shares, MP shares, “intra-firm” trade shares ($\tilde{\omega}_{ni}$ in 22), and real income per capita. Additionally, the model generates MP by i in n in the intermediate goods sector (as a share of total MP by i in n), BMP by i in l (as share of total MP by i in n), trade costs d_{ni} , and MP costs h_{ni} . The algorithm used to compute the model's equilibrium extends the one in Alvarez and Lucas (2007).

The calibration procedure searches for: (i) Υ, a, ξ , and ρ such that the (weighted) sum of the square difference of trade shares, MP shares, and intra-firm trade shares, between the model and the data, respectively, is minimized,

$$\sum_{n,i;n \neq i} \frac{1}{N_X^{obs}} \left(\tilde{X}_{ni}^{data} - \tilde{X}_{ni}^{model} \right)^2 + \frac{1}{N_Y^{obs}} \left(\tilde{Y}_{ni}^{data} - \tilde{Y}_{ni}^{model} \right)^2 + \sum_{n,i;n \neq i; n,i=USA} \frac{1}{N_\omega^{obs}} \left(\tilde{\omega}_{ni}^{data} - \tilde{\omega}_{ni}^{model} \right)^2;$$

and (ii) the technology parameters $\{\lambda_i\}_{i=1}^I$ such that the absolute difference of real income per capita (relative to the US) between the model and the data is minimized.

A measure of the explanatory power of the model for trade shares R_X^2 , MP shares R_Y^2 , and intra-firm trade shares R_ω^2 , respectively, is given by:

$$R_H^2 = 1 - \frac{\sum_{n,i;n \neq i} \left[\tilde{H}_{ni}^{data} - \tilde{H}_{ni}^{model} \right]^2}{\sum_{n,i;n \neq i} (\tilde{H}_{ni}^{data})^2} \quad (27)$$

where $H = X, Y, \omega$.

We can think about the sources of identification as follows. By decreasing the iceberg trade and MP cost parameters in Υ , trade and MP shares decrease, respectively. Increasing the parameter a increases the share of “intra-firm” trade in total MP ($\tilde{\omega}_{ni}$). The parameter ρ helps to match bilateral trade and MP shares, mostly through changes in the amount of BMP; the average share of BMP by i in l increases with ρ . Finally, increasing the technology parameter λ_i increases a country's real income per capita.

3.3 Results

Table 1 reports the calibrated parameters while Table 3 reports the targeted moments, both from the data and calibrated model. Table 2 shows the implied statistics for trade costs, MP costs, and the implied correlation between the two. We report the calibrated values for the country-level technology parameters λ_i in the Appendix.

Parameter	Value	Definition
δ_{dist}^d	0.13	trade and MP cost parameters: $d_{ni} = 1 + (\delta_0^d + \delta_{dist}^d dist_{ni}) \times (\delta_{border}^d)^{b_{ni}} \times (\delta_{language}^d)^{l_{ni}}$ $h_{ni} = 1 + (\delta_0^h + \delta_{dist}^h dist_{ni}) \times (\delta_{border}^h)^{b_{ni}} \times (\delta_{language}^h)^{l_{ni}}$
δ_{dist}^h	0.05	
δ_{border}^d	0.75	
δ_{border}^h	0.79	
$\delta_{language}^d$	0.70	
$\delta_{language}^h$	0.68	
δ_0^d	0.47	correlation between cost draws in (5)
δ_0^h	0.45	
ρ	0.16	
a	0.20	
ξ	1.9	
α	0.75	
β	0.5	labor share in intermediate goods
θ	7.2	parameter in (5)

Table 1: Calibrated Parameters.

Table 1 shows that the effect of distance on trade costs more than doubles the one on MP costs: the coefficients on distance are $\delta_{dist}^d = 0.13$ for trade, and $\delta_{dist}^h = 0.05$, for MP. A country-pair that is 20% further apart has 21% higher trade cost, and only 2.8% higher MP costs. The effect of border and language is rather similar on both trade and MP costs. Overall, these calibrated “gravity” parameters’ translate into 25% higher average trade costs (2.1 against 1.7) across country-pairs, as shown in Table 2. This result is driven by the fact that there is more MP than trade in the data. The parameter a together with the elasticity of substitution ξ in Table 1 regulates the magnitude of intra-firm trade.¹⁷ The parameter ρ , that indicates the degree of correlation between technology draws across different locations of production, regulates the amount of BMP, one of our “out of sample ” moments shown in Table 3.

¹⁷Indeed, if we calibrate the model assuming that the bilateral intra-firm trade share is 14% rather than 7.4% as observed in the data, we need to increase a to 0.48 and decrease ξ to 1.3.

	Trade Costs	MP Costs
	d_{ni}	h_{ni}
Average	2.1	1.7
Standard Deviation	0.4	0.2
Correlation Coefficient	0.98	

Table 2: Calibrated Trade and MP Costs.

Moments	Data	Model
Avg. trade share in manufacturing from i to n	0.019 (0.03)	0.019 (0.039)
Avg. MP share by i in n	0.022 (0.04)	0.022 (0.028)
Avg. “intra-firm” trade shares from i to n (for US) (as share of MP by i in n)	0.074 (0.07)	0.074 (0.02)
Correlation btw. trade and MP shares from i to n	0.73	0.85
Avg. MP in manufacturing by i in n (for US) (as share of total MP by i in n)	0.48 (0.12)	0.49 (0.03)
Avg. “BMP” by i in n (for US) (as share of MP by i in n)	0.3 (0.17)	0.09 (0.07)

SE in parenthesis.

Table 3: Moments: Data and Model.

Table 3 shows statistics generated by the model’s equilibrium at the calibrated parameters. For trade and MP shares, we report mean, standard error and correlation coefficient. The average share of MP in manufacturing as well as the average BMP share (for US affiliates abroad) are not included in the calibration procedure.

As expected, the model matches the average bilateral trade and MP shares, as well as the average bilateral intra-firm trade share for the US, as observed in the data. However, it delivers a higher correlation between bilateral trade and MP shares than the one observed in the data. The model matches fairly well the proportion of MP in manufacturing as observed in the data. One failure of the model is that it generates a low BMP share. While the data for US affiliates in OECD countries shows that 30% of the value of production is sold in countries other than the country of production, the model only generates 9%.¹⁸

¹⁸Lower ρ implies less correlation across technologies in different production locations, thus, more BMP.

The next two tables and figures show how well the calibrated model captures the pattern of trade and MP observed in the data. Table 4 shows the measure of the model’s explanatory power in (27), for bilateral trade, MP, and intra-firm trade. Additionally, we present correlations between magnitudes in the model and data for bilateral trade and MP shares across country-pairs, aggregate exports, imports, outward MP and inward MP as share of GDP of the receiving country. Not surprisingly, the model performs fairly well in terms of matching the observed

Model’s “Explanatory power”:	
bilateral trade shares	0.69
bilateral MP shares	0.40
bilateral “intra-firm” trade shares (for US)	0.38
Correlations model data:	
Bilateral Trade Shares	0.82
Bilateral MP Shares	0.49
Total Exports Shares	0.82
Total Imports Shares	0.84
Total Outward MP Shares	0.17
Total Inward MP Shares	0.45

Bilateral MP = gross value of production for affiliates from country i in n ; Total Outward MP = total gross value of production for foreign affiliates from country i ; Total Inward MP = total gross value of production for foreign affiliates in country n .

Table 4: Goodness of Fit: Calibrated Model.

trade and MP shares across country-pairs, 0.82 and 0.49, respectively. The explanatory power of the model decreases to 0.38 when bilateral intra-firm trade shares for/to the US are considered.

When we aggregate exports and imports as shares of exporter’s and importer’s GDP, respectively, by country, correlations between model and data are still high, 0.82 and 0.84, respectively. Correlations are slightly lower, 0.45, for aggregate inward MP shares, by country, measured as total sales of foreign affiliates in the country, as share of host’s country GDP. However, the model does poorly in terms of aggregate outward MP shares by country measured as total sales of affiliates abroad (as shares of source country’s GDP), dropping to 0.17.

We further explore the relationship between aggregate exports, imports, inward, and outward MP shares, and country’s size in Figures 2 and 3.

Letting $\rho \rightarrow 0$ increases the average BMP share to 11% from 9% in Table 3, but it never gets close to the magnitude observed in the data.

Figure 2: Size and MP shares, by country: Data and Model

Figure 3: Size and Trade shares, by country: Data and Model

The right panel of Figure 2 shows outward MP as share of recipient country's GDP, for the model and the data, against the model's GDP, $w_i L_i$. The model underestimates large countries as the United States, Japan, and Germany, and overestimates small countries that have very low (e.g. Spain and New Zealand) outward MP relative to size. The left panel shows

the analogous scatter for inward MP. The model captures reasonably well large countries, as United States and Japan, and slightly overestimates inward MP into small countries, as share of their size.¹⁹ Figure 3 is analogous to Figure 2 for export and import shares. The model captures fairly accurately the pattern of aggregate export and import shares with respect to country size; it slightly underestimates large countries such as the United States and Japan, and a very small country such as Netherlands with very high export and import shares.²⁰

OLS estimates of gravity equations. We discuss the relationship between the parameter θ and the elasticity of trade flows to trade costs. Consider the following regression:

$$\log \tilde{X}_{ni} = D_n^x + S_i^x + b_x \log d_{ni} + u_{ni}^x, \quad (28)$$

where D_n^x and S_i^x are destination and source country fixed effects, and d_{ni} are trade costs. In a model with only trade, the OLS estimate of b_x is the elasticity of trade flows to trade costs and equals θ . However, as shown in the section on gravity, in a model with trade, MP (and “intra-firm” trade), this is true only in the very special case where $a = 0$ and $\rho = 0$. In general, θ is not the trade elasticity, and b_x is not a good estimate of the trade elasticity. Since trade and MP are not independent, the positive correlation between trade and MP costs biases the results. If trade and MP are substitutes, then b_x has a downward bias (closer to zero): higher trade costs imply higher MP costs that in turn increase trade flows, off-setting the direct negative effect of trade costs. If trade and MP are complements, then b_x has an upward bias (more negative): as trade costs increase, MP costs increase, and trade flows decrease, reinforcing the direct negative effect of trade costs. To evaluate the bias in OLS estimates of trade elasticities, we control for MP costs in (28), and compare b_x with b_d from the following regression,

$$\log \tilde{X}_{ni} = S_i + D_n + b_d \log d_{ni} + b_h \log h_{ni} + v_{ni}, \quad (29)$$

using simulated trade shares $\tilde{X}_{ni}$ and trade costs d_{ni} . The coefficient b_x seems to be upward biased ($b_x = -6.36$ (s.e. 0.07) and $b_d = -4.4$ (s.e. 0.07)). This finding is consistent with trade and MP costs positively correlated, *and* our result that trade and MP are complements according to our calibrated model (see next section).

However, since $\rho > 0$, b_d does not recover θ . Moreover, with $a > 0$, the elasticity of trade flows to trade costs also depends on $\xi - 1$; while arms-length trade is affected by θ , “intra-firm”

¹⁹The correlation between outward MP shares and country size in the data is -0.07, while in the model is -0.59; for inward MP, this correlation is -0.32 in the data, and -0.64 in the model.

²⁰The correlation between export shares and country size in the data is -0.45, while in the model is -0.63; for import shares, this correlation is -0.54 in the data, and -0.63 in the model.

trade is affected by $\xi - 1$. Hence, b_x and b_d is a combination of θ and $\xi - 1$. What is the effect of $\xi = 1.9$ on the magnitude of the divergence between b_x and b_d , and θ ? To explore this issue we simulate the model by setting $\xi - 1 = \theta = 7.2$. The OLS estimates for b_x and b_d from running (28) and (29) on these simulated data are -7.63 and -7.59 , respectively. Thus, when trade and MP are (close to) independent, the bias in b_x (almost) disappears. Further, b_d is close to θ .

Similarly, OLS estimates for the elasticity of “intra-firm” trade shares to trade cost can be biased. Consider the following equation:

$$\log \omega_{ni} = D_n^\omega + S_i^\omega + b_\omega \log d_{ni} + u_{ni}^\omega, \quad (30)$$

where D_n^ω and S_i^ω are again destination and source country fixed effects, respectively. Running OLS on (30) using simulated data for $\tilde{\omega}_{ni}$ and the calibrated trade costs for d_{ni} gives $b_\omega = -0.32$ (s.e. 0.001).²¹ When we control for MP costs h_{ni} , and run a similar regression as in (29), the coefficient b_ω increases to -0.75 (s.e. 0.001). This downward bias is again explained by the positive correlation between trade and MP costs. Additionally, the downward bias in b_ω translates into an underestimation of the parameter ξ . Since the coefficient $b_\omega = 1 - \xi$, the OLS estimate in (30) would imply an elasticity of substitution ξ of 1.3. When we control for h_{ni} , the estimate for ξ goes up to 1.75, much closer to our calibrated ξ which equals 1.9.

4 Gains from Openness, Trade, and Multinational Production

We measure gains from openness, trade, and MP by changes in real wages in terms of the final consumption good, w_n/P_{fn} . We calculate real wages under: no trade and no MP (isolation), only trade, and only MP. The increase in the real wage as we move from isolation to the calibrated version of the model with trade and MP yields the gains from openness, GO . Similarly, the increase in the real wage as we move from isolation to only trade yields the gains from trade, GT , while moving from isolation to only MP yields the gains from MP, GMP . Finally, the increase in the real wage from only MP to trade and MP yields gains from trade in the presence of MP, GT' , and analogously, the increase in the real wage from only trade to trade and MP yields gains from MP in the presence of trade, GMP' . We also calculate the gains

²¹Hanson, Mataloni, and Slaughter (2005) run a similar regression to the one in 30 using data on intra-firm imports in goods for further processing done by foreign affiliates of American multinational firms. Their estimates range from -0.64 to -0.26.

from trade coming from a calibrated version of the model with only trade, GT^* , and the gains from MP coming from a calibrated model with only MP, GMP^* .²² Finally, we show gains separately for the intermediate goods' sector, where both trade and MP are possible, and for the final goods' sector where only MP is possible.²³

Table 5 shows the calculated gains averaged across OECD countries, and Table 6 presents them by country.

	$(w_n/P_{fn}) / (w'_n/P'_{fn})$						
Avg. OECD (19)	GO	GT	GT'	GT^*	GMP	GMP'	GMP^*
All	1.15	1.03	1.05	1.03	1.09	1.11	1.11
Intermediate Tradable Sector	1.06	1.03	1.05	1.03	1.01	1.03	1.04
Final Non-Tradable Sector	1.08	-	-	-	1.08	1.05	1.07

Table 5: Gains from Openness, Trade, and MP. Average for nineteen OECD countries.

The implied average gains from openness (GO) are 15%. This is large relative to the gains coming from models with only trade, which are $GT^* = 3\%$. MP turns out to be an important source of gains: while the gains from trade (GT) implied by the model are 3%, the gains from MP (GMP) are 9%. The reason is that MP flows are higher than trade flows in the data – total inward MP flows are more than double total imports in the data. This is related to the fact that MP is feasible in the non-tradable final goods sector. In fact, if we shut down MP in the final goods sector, GMP falls to just 1%. The extra gains from adding MP in the final goods sector are 8%. Further, GO drops to 6% if MP were shut down in this sector.

The calculated gains suggest that $GO > GT \times GMP$, indicating that trade and MP are complements. Or alternatively, $GT' > GT$ and $GMP' > GMP$. By construction, this complementarity comes from the intermediate goods sector, where $GO^g > GT^g \times GMP^g$.

The complementarity between trade and MP is also reflected in the fact that GT' is higher than GT^* – in fact GT' is almost twice as high as GT^* .²⁴ By decreasing the cost of MP, trade generates larger gains than the ones implied solely by the trade flows in the data. One of the

²²Details of these calibrations are presented in the Appendix.

²³GMP in the intermediate goods sector are calculated by comparing real wages under isolation and a situation where MP is only allowed in the tradable sector (analogous calculation for GMP in the final goods' sector). GMP^{prime} in the intermediate goods' sector are calculated by comparing real wages under only trade and under trade and MP only in intermediates (analogous for the final goods' sector).

²⁴With complementarity between trade and MP, a model with only trade needs a lower trade cost to match the data than a model with both trade and MP. Thus, the gains from trade in a model with only trade are higher than GT , but still lower than GT' .

benefits of our approach in this paper is precisely that it allows us to quantify the indirect gains from trade associated with the facilitation of MP.

The analogous exercise for MP reveals that gains arising from a model with only MP, GMP^* , calibrated to match bilateral MP shares and income per capita, gives very similar results to the model with trade and MP; GMP^* is almost identical to GMP' . Even if most gains from MP are realized in the final goods sector, as in the model with trade and MP, a model with only MP would deliver higher gains from MP in both sectors (4% against 3% for tradable goods, and 7% against 5% for non-tradable goods).²⁵

In Table 6, we show GO , GT , GMP , GT' , GMP' , GT^* , and GMP^* , by country. Countries are ordered by their size in terms of our measure of equipped labor. Indeed, gains from openness decrease with size. Trade and MP in all countries behave as complements ($GO > GT \times GMP$, or, $GT' > GT$, or $GMP' > GMP$), even if the gap is different across countries. For instance, a country like Belgium, which represents around 1% of OECD(19)'s equipped labor, has $GO = 1.30$, while $GT \times GMP = 1.26$; the United States, the largest country in the sample, has $GO = 1.05$ and $GT \times GMP = 1.04$.

5 Final Remarks

It seems reasonable to think that countries - specially small ones - benefit greatly from their interaction with the rest of the world. But whereas the attention has been devoted to trade as the main channel for such benefits, we argue in this paper for the need to broaden the scope of the investigation to other channels. We have taken a step in this direction by developing and calibrating a multi-country general-equilibrium Ricardian model of trade and MP. An important consideration in building this model has been to allow for forces that make trade and MP substitutes as well as those that make them complements. The calibration reveals that, on net, trade and MP behave as complements and, as a result, the calculated gains from openness are higher than the product of the separate gains from trade and MP. Moreover, the gains from openness are much higher than the gains from trade, both because of complementarity and because of the large gains from MP, most of which materialize in the final good (non-tradable) sector. Finally, the gains from trade calculated as the increase in real income from a situation with only MP to the benchmark (with trade and MP) are significantly higher than

²⁵ GMP' can be written as $GMP'_f \times GMP'_g \times GT$ where $GMP'_f = GO_f/GT$.

	GO	GT	GMP	GT'	GMP'	GT^*	GMP^*	$L_i / \sum_k L_k$
			$(w_n/P_{fn})/(w'_n/P'_{fn})$					(%)
New Zealand	1.08	1.01	1.05	1.02	1.07	1.01	1.05	0.4
Finland	1.21	1.05	1.13	1.07	1.16	1.05	1.15	0.6
Norway	1.19	1.05	1.11	1.07	1.14	1.05	1.16	0.6
Denmark	1.18	1.05	1.09	1.08	1.12	1.05	1.11	0.7
Portugal	1.21	1.04	1.14	1.07	1.17	1.04	1.12	0.7
Greece	1.20	1.03	1.14	1.06	1.17	1.03	1.16	0.8
Austria	1.21	1.06	1.11	1.09	1.14	1.06	1.12	0.8
Belgium	1.30	1.09	1.16	1.13	1.19	1.09	1.16	1.0
Sweden	1.18	1.04	1.11	1.06	1.14	1.04	1.17	1.1
Netherlands	1.17	1.04	1.10	1.07	1.12	1.04	1.12	1.6
Australia	1.02	1.00	1.02	1.01	1.02	1.00	1.02	2.2
Spain	1.12	1.02	1.08	1.04	1.10	1.02	1.09	3.1
Canada	1.17	1.04	1.11	1.06	1.13	1.04	1.13	4
Italy	1.08	1.01	1.05	1.03	1.07	1.02	1.06	4.9
France	1.14	1.02	1.09	1.04	1.11	1.03	1.12	5.8
Great Britain	1.12	1.02	1.09	1.04	1.10	1.02	1.11	6
Germany	1.18	1.02	1.13	1.05	1.16	1.02	1.21	10
Japan	1.02	1.00	1.02	1.00	1.02	1.00	1.04	19
United States	1.05	1.00	1.04	1.01	1.04	1.00	1.05	37

Countries are sorted by equipped labor.

Table 6: Gains from Openness, Trade, and MP, by country.

those calculated in models with only trade, as in Eaton and Kortum (2002) and Alvarez and Lucas (2007). This is because our model can capture the indirect gains from trade associated with the facilitation of MP in the presence of complementarity.

References

- Alcala, F., Ciccone, A. 2004. "Trade and productivity". *Quarterly Journal of Economics*, 119 (2), 613-646.
- Alfaro, Laura, and Andrew Charlton. 2007. "Intra-Industry Foreign Direct Investment ". Unpublished manuscript.
- Alvarez, Fernando, and Robert E. Lucas. 2006. "General Equilibrium Analysis of the Eaton-Kortum Model of International Trade". *Journal of Monetary Economics*. Volume 54, Issue 6.
- Belderbos, R. and L. Sleuwaegen. 1998. "Tariff jumping DFI and export substitution: Japanese electronics firms in Europe". *International Journal of Industrial Organization*, Volume 16, Issue 5, September, 601-638.
- Bernard, Andrew, J. Bradford Jensen, and Peter Schott. 2005. "Importers, Exporters, and Multinationals: a Portrait of Firms in the US that Trade Goods". NBER, Working Paper 11404
- Blonigen, B. A. 2001. "In Search Of Substitution Between Foreign Production And Exports". *Journal of International Economics*. Volume 53 (Feb), 81-104.
- Blonigen, B. A. 2005. "A Review of the Empirical Literature on FDI Determinants". Mimeo, University of Oregon.
- Brainard, Lael. 1997. "An Empirical Assessment of the Proximity-Concentration Trade-o. between Multinational Sales and Trade". *American Economic Review*, 87:520-44.
- Broda, Christian, and David Weinstein. 2006. "Globalization and the Gains from Variety". *Quarterly Journal of Economics*, Volume 121, Issue 2.
- Burstein, Ariel, and Alex Monge-Naranjo. 2006. "Aggregate Consequences of International Firms in Developing Countries". Unpublished.
- Carr, David, James Markusen, and Keith Maskus. 2001. "Estimating the Knowledge-Capital Model of the Multinational Enterprise". *American Economic Review*, 91: 693-708.
- Eaton, Jonathan, and Samuel Kortum. 1999. "International Technology Diffusion: Theory and Measurement". *International Economic Review*, 40(3), 1999, 537-570.

- Eaton, Jonathan, and Samuel Kortum. 2001. "Technology, Trade, and Growth: A Unified Framework". *European Economic Review*, 45, 742-755.
- Eaton, Jonathan, and Samuel Kortum. 2002. "Technology, Geography and Trade". *Econometrica*, Vol. 70(5).
- Eaton, Jonathan, and Samuel Kortum. 2006. "Innovation, Diffusion, and Trade". *NBER*, WP 12385.
- Feenstra, Robert, and Robert Lipsey. 2005. NBER-United Nations Trade Data.
- Garetto, Stefania. 2007. "Input Sourcing and Multinational Production" Mimeo, University of Chicago.
- Hanson, Gordon, Raymond Mataloni, and Matthew Slaughter. 2003. "Vertical Production Networks in multinational firms". NBER Working Paper No. 9723.
- Head, Keith, John Ries, and Barbara Spencer. 2004. "Vertical Networks and U.S. Auto Parts Exports: Is Japan Different?" *Journal of Economics & Management Strategy*, 13(1), 37-67.
- Head, Keith, and John Ries. 2004. "Exporting and FDI as Alternative Strategies". *Oxford Review of Economic Policy*, Vol. 20, No. 3.
- Helpman, Elhanan. 1984. "A Simple Theory of International Trade with Multinational Corporations". *Journal of Political Economy*, 92:3, pp. 451-471.
- Helpman, Elhanan, Marc Melitz, and Yona Rubinstein. 2004. "Trading Partners and Trading Volumes". *Quarterly Journal of Economics*, forthcoming.
- Helpman, Elhanan, Marc Melitz, and Stephen Yeaple. 2004. "Export versus FDI with Heterogeneous Firms". *American Economic Review*, Vol. 94(1): 300-316(17).
- Jones, Charles I. 1995. "R&D-Based Models of Economic Growth". *Journal of Political Economy*, Vol. 103, pp. 759-784.
- Jones, Charles I. 2002.
- Keller, Wolfgang. (2004). "International Technology Diffusion". *Journal of Economic Literature* 42: 752-782.

Keller, Wolfgang. 2008. "International Trade, Foreign Direct Investment, and Technology Spillovers". Forthcoming in *Handbook of Technological Change*, edited by Bronwyn Hall and Nathan Rosenberg, North-Holland.

Klenow, Peter, and Andrés Rodríguez-Clare. 2005. "Externalities and Growth". *Handbook of Economic Growth*, Vol. 1A, P. Aghion and S. Durlauf, eds., 817-861 (chapter 11).

Kortum, Samuel. 1997. *Econometrica*

Krugman, Paul. (1979). "Increasing Returns, Monopolistic Competition, and International Trade". *Journal of International Economics*.

Lipsey, Robert, and M. Weiss. 1981. "Foreign Production and Exports in Manufacturing Industries". *The Review of Economics and Statistics*, 63(4).

Markusen, James. 1984. "Multinationals, Multi-plant Economies, and the Gains from Trade". *Journal of International Economics*, 16(205-226).

Markusen, James and Anthony Venables. 1998. "Multinational Trade and the New Trade Theory". *Journal of International Economics*, 46(183-203).

Markusen, James. 1995. "The Boundaries of Multinational Enterprises and the Theory of International Trade". *Journal of Economic Perspectives*, Vol. 9, No. 2, pp. 169-189.

McGrattan, Ellen, and Edward Prescott. 2007. "Openness, Technology Capital, and Development". Federal Reserve Bank of Minneapolis WP 651.

Ramondo, Natalia. 2006. "Size, Geography, and Multinational Production". Unpublished, University of Texas-Austin.

Rodríguez-Clare, Andrés. 2007. "Trade, Diffusion, and the Gains from Openness". Unpublished, Penn State University.

Waugh, Michael. 2007. "International Trade and Income Differences". Mimeo, University of Iowa.

West, Geofv B., James H. Brown, Brian J. Enquist. 1997. "A General Model for the Origin of Allometric Scaling Laws in Biology". *Science*, Vol. 276. no. 5309, pp. 122 - 126.

A Proofs

Proof of Proposition 1. Consider first the case of intermediate goods and let $p_{gni} \equiv \min_l c_{gli} d_{nl} / z_{gli} p_{gnli}$. The probability that p_{gni} is lower than p is

$$\begin{aligned} G_{gni}(p) &= 1 - \Pr(z_{gli} \leq c_{gli} d_{nl} / p \text{ for all } l) \\ &= 1 - \exp \left[- \left(\sum_l \left(T_{li} (c_{gli} d_{nl} / p)^{-\theta} \right)^{\frac{1}{1-\rho}} \right)^{1-\rho} \right] \\ &= 1 - \exp [-\Phi_{gni} p^\theta] \end{aligned}$$

Since $G_{gni}(p)$ is independent across i , then the reasoning in Eaton and Kortum (2002) can be immediately applied to show that country n will buy goods produced with country i 's technologies for a measure of goods equal to $\phi_{gni} = \Phi_{gni} / \sum_j \Phi_{gnj}$. The corresponding result for final goods in point (a) of Proposition 1 is derived simply by letting $d_{nl} \rightarrow \infty$ for $n \neq l$.

Moving on to part (b), consider the intermediate goods that country n buys that are produced with country i technologies. What is the share of these goods that are produced in country l ? This is equal to the probability that, for a specific good, country l is the cheapest location for i to produce for n with its technology. This is equivalent to $\frac{c_{gli} d_{nl}}{z_{gli}} \leq \frac{c_{gji} d_{nj}}{z_{gji}}$ or $z_{gji} \leq \left[\frac{c_{gji} d_{nj}}{c_{gli} d_{nl}} \right] z_{gli}$ for all $j \neq l$. Without loss of generality, assume that $l = 1$. The probability that $z_{ji} \leq a_{ni,j} z_{1i}$ for all $j \neq 1$ where $a_{ni,j} \equiv \frac{c_{gji} d_{nj}}{c_{g1i} d_{n1}}$ is given by $\int_0^\infty F_1(z, a_{ni,2}z, \dots, a_{ni,I}z) dz$. But

$$F_1(z, a_{ni,2}z, \dots, a_{ni,I}z) = \left((c_{g1i} d_{n1})^{\frac{1}{\theta}} \Phi_{ni} \right)^{1-\frac{1}{1-\rho}} T_{1i}^{\frac{1}{1-\rho}} \theta z^{-\theta-1} \exp \left[- (c_{g1i} d_{n1})^{\frac{1}{\theta}} \Phi_{ni} z^{-\theta} \right]$$

and

$$\int_0^\infty \theta c_{g1i} d_{n1} \Phi_{ni} z^{-\theta-1} \exp \left[- c_{g1i} d_{n1} \Phi_{ni} z^{-\theta} \right] dz = 1$$

This implies that

$$\int_0^\infty F_1(z, a_{ni,2}z, \dots, a_{ni,I}z) dz = \frac{\left(T_{1i} (c_{g1i} d_{n1})^{-\theta} \right)^{\frac{1}{1-\rho}}}{\sum_j \left(T_{ji} (c_{gji} d_{nj})^{-\theta} \right)^{\frac{1}{1-\rho}}}$$

and the result follows immediately.

To prove part (c), focus on intermediate goods and condition on market n and technologies from country i . The probability that $p_{gni} \leq p$ and that l is the least cost production location to reach n is the probability that $d_{nl} c_{gli} / z_{gli} \leq p$ and $d_{nj} c_{gji} / z_{gji} \geq d_{nl} c_{gli} / z_{gli}$, or $z_{gli} \geq d_{nl} c_{gli} / p$

and $z_{gji} \leq \frac{d_{nj}c_{gji}}{d_{ni}c_{gli}} z_{gli}$. Without loss of generality, assume that $l = 1$ and again let $a_{ni,j} \equiv \frac{d_{nj}c_{gji}}{d_{ni}c_{gli}}$. We want to compute $\int_{d_{n1}c_{g1i}/p}^{\infty} F_1(z, a_{ni,2}z, \dots, a_{ni,I}z)dz$. But simple math establishes that

$$\int_{d_{n1}c_{g1i}/p}^{\infty} F_1(z, a_{ni,2}z, \dots, a_{ni,I}z)dz = \left((d_{n1}c_{g1i})^{\theta} \Phi_{gni} \right)^{-\frac{1}{1-\rho}} T_1^{\frac{1}{1-\rho}} (1 - \exp(-\Phi_{gni}p^{\theta}))$$

The distribution of prices in market n conditional on the good on the good produced in 1 with technology i , we need to divide by $\pi_{ni,1}\phi_{gni}$. This yields a probability equal to

$$1 - \exp(-\Phi_{gni}p^{\theta}) = G_{gni}(p)$$

Since this does not depend on 1, it implies that for market n and conditioning on country i technologies, the distribution of p that actually are produced in l is the same for $l = 1, 2, \dots, I$. But independence across i allows us to apply the results from Eaton and Kortum (2002) to establish that the distribution of prices for goods that n actually buys from i is $G_{gn}(p) = 1 - \exp(-\Phi_{gn}p^{\theta})$ for all i . This implies that the average price of goods is the same irrespective of where they are produced and irrespective of the origin of the technology. The proof for final goods follows immediately from independence across the i .

Finally, part (d) follows from the fact that $G_{gn}(p) = 1 - \exp(-\Phi_{gn}p^{\theta})$ and $G_{fn}(p) = 1 - \exp(-\Phi_{fn}p^{\theta})$ and the results in Eaton and Kortum (2002). $\square$

Proof of Proposition 2. First note that $P_n Q_n$ is the total cost of the intermediate goods *used in production* in country n . We first calculate the total cost of the intermediate goods *produced* in country n . This is $w_n L_{gn} + P_{gn} Q_{gn}$, plus the intra-firm imports of foreign multinationals located in n , $\sum_{i \neq n} \omega_{ni} Y_{gni}$, minus the exports of the domestic input bundle for intermediates to country n 's subsidiaries abroad, $\sum_{i \neq n} \omega_{in} Y_{gin}$. Hence, the total cost of intermediate goods produced in country n is

$$w_n L_{mn} + P_{gn} Q_{gn} + \sum_{i \neq n} \omega_{ni} Y_{gni} - \sum_{i \neq n} \omega_{in} Y_{gin}.$$

In equilibrium, this must be equal to the value of intermediate goods produced in country n , hence

$$w_n L_{mn} + P_{gn} Q_{gn} + \sum_{i \neq n} \omega_{ni} Y_{gni} - \sum_{i \neq n} \omega_{in} Y_{gin} = \sum_i Y_{gni}. \quad (31)$$

But

$$\begin{aligned}
\sum_i Y_{gni} &= \sum_i \sum_j \phi_{gji} \pi_{gji,n} P_{gj} Q_j \\
&= \sum_i \phi_{gni} \pi_{gni,n} P_{gn} Q_n + \sum_{j \neq n} \sum_i \phi_{gji} \pi_{gji,n} P_{gj} Q_j \\
&= \sum_i \phi_{gni} \pi_{gni,n} P_{gn} Q_n + \sum_{j \neq n} (X_{jn} - \omega_{jn} Y_{gjn})
\end{aligned}$$

Substituting into (31) and simplifying we get

$$w_n L_{mn} + P_{gn} Q_{gn} + \sum_{i \neq n} \omega_{ni} Y_{gni} = \sum_i \phi_{gni} \pi_{gni,n} P_{gn} Q_n + \sum_{i \neq n} X_{in}$$

Using the trade balance condition (9) to substitute $\sum_{i \neq n} X_{in}$ for $\sum_{i \neq n} X_{ni}$, using (8), and then simplifying yields

$$w_n L_{mn} + p_{mn} Q_{gn} = \left(\sum_i \sum_j \phi_{gnj} \pi_{gnj,i} \right) P_{gn} Q_n$$

But $\sum_i \sum_j \phi_{gnj} \pi_{gnj,i} = \sum_j \phi_{gnj} \sum_i \pi_{gnj,i} = 1$, hence,

$$w_n L_{gn} + P_{gn} Q_{gn} = P_{gn} Q_n. \quad (32)$$

We know that

$$\frac{L_{fn}}{Q_{fn}} = \left(\frac{\alpha}{1 - \alpha} \right) \frac{P_{gn}}{w_n}, \quad (33)$$

and

$$\frac{L_{gn}}{Q_{gn}} = \left(\frac{\beta}{1 - \beta} \right) \frac{P_{gn}}{w_n}. \quad (34)$$

Plugging (34) into (32) we get

$$\left(\frac{\beta}{1 - \beta} \right) P_{gn} Q_{gn} + P_{gn} Q_{gn} = P_{gn} Q_n,$$

from which we get $Q_{gn} = (1 - \beta) Q_n$. Using $Q_{fn} + Q_{gn} = Q_n$, we have

$$Q_{fn} = \beta Q_n. \quad (35)$$

Plugging $Q_{gn} = (1 - \beta) Q_n$ back into (32), we get

$$w_n L_{mn} = \beta P_{gn} Q_n.$$

Using $L_{gn} + L_{fn} = L_n$, we have

$$w_n(L_n - L_{fn}) = \beta P_{gn} Q_n. \quad (36)$$

From (33) and (35), we get

$$w_n L_{fn} = \left(\frac{\alpha}{1-\alpha} \right) \beta P_{gn} Q_n.$$

Using (36), we then have $L_{fn} = \left(\frac{\alpha}{1-\alpha} \right) (L_n - L_{fn})$, and hence $L_{fn} = \alpha L_n$. Plugging into (36), we get finally get $(1-\alpha)w_n L_n = \beta P_{gn} Q_n$, or $P_{gn} Q_n = \eta w_n L_n$. ■

Proof of Proposition 3. Under symmetry, $w_i = w$, for all i . The price index for intermediate goods, in Proposition 1, collapses to:

$$\begin{aligned} P_g &= \gamma \Psi_g^{-1/\theta} \\ &= (\gamma B)^{1/\beta} \cdot [\Delta_0 + (I-1)\Delta_1]^{-\frac{1}{\beta\theta}} \cdot T^{-\frac{1}{\beta\theta}} \cdot w. \end{aligned}$$

where

$$\begin{aligned} \Delta_0 &\equiv \left(1 + (I-1)(md)^{-\frac{\theta}{1-\rho}} \right)^{1-\rho} \\ \Delta_1 &\equiv \left(d^{-\frac{\theta}{1-\rho}} + m^{-\frac{\theta}{1-\rho}} + (I-2)(md)^{-\frac{\theta}{1-\rho}} \right)^{1-\rho}. \end{aligned}$$

The price index for final goods is then:

$$\begin{aligned} P_f &= \gamma \Psi^{-1/\theta} \\ &= \gamma [1 + (I-1)h^{-\theta}]^{-1/\theta} \cdot T^{-1/\theta} \cdot c_f \\ &= \gamma [1 + (I-1)h^{-\theta}]^{-1/\theta} \cdot T^{-1/\theta} \cdot A w^\alpha P_g^{1-\alpha} \\ &= (\gamma A) (\gamma B)^\eta [1 + (I-1)h^{-\theta}]^{-\frac{\eta}{\theta}} \cdot [\Delta_0 + (I-1)\Delta_1]^{-\frac{\eta}{\theta}} \cdot T^{-\frac{\eta}{\theta}} \cdot w \end{aligned}$$

Then, the real wage is:

$$\frac{w}{P_f} = \tilde{\gamma}^{-1} [1 + (I-1)h^{-\theta}]^{1/\theta} [\Delta_0 + (I-1)\Delta_1]^{\frac{\eta}{\theta}} T^{\frac{1+\eta}{\theta}}, \quad (37)$$

where $\tilde{\gamma} \equiv (\gamma A) (\gamma B)^\eta$. ■

Characterization of Symmetric Equilibrium

Under symmetry, we can derive explicit expressions for the trade and MP shares as well as for the real wage. MP in final goods from any other country as a share of a country's total income is given by

$$\tilde{Y}_f \equiv \frac{Y_{fni}}{w_n L_n} = \frac{h_f^{-\theta}}{1 + (I-1)h^{-\theta}}$$

for $i \neq n$. The term $h^{-\theta}$ captures the impact of the efficiency loss of MP on equilibrium MP flows; it acts as a “discount” on the importance of foreign technologies.

Turning to intermediate goods, we have

$$\tilde{Y}_g \equiv Y_{gni}/\eta w_n L_n = \tilde{Y}_{g1} + \tilde{Y}_{gB,0} + \tilde{Y}_{gB,1}$$

for $i \neq n$. The term $\tilde{Y}_{g1}$ captures MP for goods destined to stay in the domestic market, while $\tilde{Y}_{gB,0}$ is MP for goods that go back to the country where the technology originates, and $\tilde{Y}_{gB,1}$ goes to a third market. Both $\tilde{Y}_{gB,0}$ and $\tilde{Y}_{gB,1}$ take place through BMP. The respective formulas are

$$\tilde{Y}_{g1} = \frac{\Delta_1^{1-\frac{1}{1-\rho}} m^{-\frac{\theta}{1-\rho}}}{\Delta_0 + (I-1)\Delta_1}, \quad \tilde{Y}_{gB,0} = \frac{\Delta_0^{1-\frac{1}{1-\rho}} (md)^{-\frac{\theta}{1-\rho}}}{\Delta_0 + (I-1)\Delta_1}, \quad \tilde{Y}_{gB,1} = \frac{(I-2)\Delta_1^{1-\frac{1}{1-\rho}} (md)^{-\frac{\theta}{1-\rho}}}{\Delta_0 + (I-1)\Delta_1}.$$

The equilibrium trade share is given by:

$$\tilde{X} \equiv X_{nl}/\eta w_n L_n = \tilde{X}_{0,B} + \tilde{X}_1 + \tilde{X}_{1,B} + \omega \tilde{Y}_g$$

for $l \neq n$. The term $\tilde{X}_{0,B}$ captures the imports of goods produced abroad with a country's own technologies through BMP; the term $\tilde{X}_1$ is the standard component associated with imports from a country that used that country's technology for production; the term $\tilde{X}_{1,B}$ captures the imports of goods produced with foreign technologies through BMP; and the term $\omega \tilde{Y}_g$ captures the imports of the input bundle for domestic operations of foreign multinationals. The formulas for $\tilde{X}_{0,B}$ and $\tilde{X}_{1,B}$ are the same as the formulas for $\tilde{Y}_{gB,0}$ and $\tilde{Y}_{gB,1}$, respectively, while $\tilde{X}_1 = \tilde{Y}_{g1}(d/m)^{-\frac{\theta}{1-\rho}}$.

It is easy to see from these results that the total value of BMP as a share total MP is

$$BMP = \frac{\tilde{Y}_{gB,0} + \tilde{Y}_{gB,1}}{\tilde{Y}_g} \cdot \frac{\tilde{Y}_g}{\tilde{Y}_f + \tilde{Y}_g}$$

Assume $\rho \rightarrow 1$, that is, technology draws are the same across production locations. In this case, $BMP \rightarrow 0$. Further, when $h > d$, $\tilde{Y}_g \rightarrow 0$, and there is only trade, $\tilde{X} = d^{-\theta}/(1+(I-1)d^{-\theta})$. On the contrary, when $h < d$, trade is just associated with MP flows, $\tilde{X} = \omega m^{-\theta}/(1+(I-1)m^{-\theta}) = \omega \tilde{Y}_g$.

Proof of Proposition 4. The real wage under isolation is obtained by letting $d \rightarrow \infty$ and $h \rightarrow \infty$ in (37):

$$\left(\frac{w}{P_f}\right)^{ISOL} = \tilde{\gamma}^{-1} \cdot T^{\frac{1+\eta}{\theta}}.$$

By setting $h \rightarrow \infty$ in (??), the real wage when there is only trade is:

$$\left(\frac{w}{P_f}\right)^T = \tilde{\gamma}^{-1} \cdot [1 + (I - 1)d^{-\theta}]^{\frac{\eta}{\theta}} \cdot T^{\frac{1+\eta}{\theta}}.$$

Similarly, the real wage when there is only MP is:

$$\left(\frac{w}{P_f}\right)^{MP} = \tilde{\gamma}^{-1} \cdot [1 + (I - 1)h^{-\theta}]^{1/\theta} \cdot [1 + (I - 1)\tilde{m}^{-\theta}]^{\frac{\eta}{\theta}} \cdot T^{\frac{1+\eta}{\theta}},$$

where

$$\tilde{m} \equiv \lim_{d \rightarrow \infty} m = (1 - a)^{\frac{1}{1-\varepsilon}} h.$$

Thus, $GO = P_f^{ISO}/P_f$, $GT = P_f^{ISO}/P_f^T$, $GMP = P_f^{ISO}/P_f^{MP}$, $GT' = P_f^{MP}/P_f$ and $GMP' = P_f^T/P_f$. $\square$

Lemma 1 *GO is decreasing in ρ .*

Proof of Lemma 1. Assume $I \geq 2$, $m, d \geq 1$, $\theta > 1$ and $\rho \in [0, 1)$. We want to show that

$$GO^g(\rho) = \left[1 + (I - 1)(md)^{-\frac{\theta}{1-\rho}}\right]^{1-\rho} + (I - 1) \left[d^{-\frac{\theta}{1-\rho}} + m^{-\frac{\theta}{1-\rho}} + (I - 2)(md)^{-\frac{\theta}{1-\rho}}\right]^{1-\rho}$$

is decreasing in ρ . Note that if $m \rightarrow \infty$ or $d \rightarrow \infty$ then $dGO^g(\rho)/d(1 - \rho) \rightarrow 0$. Also note that $[1 + (I - 1)(md)^{-\theta/(1-\rho)}]^{1-\rho}$ is clearly increasing in $1 - \rho$ because $1 + (I - 1)(md)^{-\theta/(1-\rho)}$ is higher than one. It is left to show that $[d^{-\theta/(1-\rho)} + m^{-\theta/(1-\rho)} + (I - 2)(md)^{-\theta/(1-\rho)}]^{1-\rho}$ is increasing in $1 - \rho$. Without loss of generality, we assume that $m > d \geq 1$, then $\frac{m}{d} > 1$. We have

$$\begin{aligned} & \left[d^{-\frac{\theta}{1-\rho}} + m^{-\frac{\theta}{1-\rho}} + (I - 2)(md)^{-\frac{\theta}{1-\rho}}\right]^{1-\rho} \\ &= \left[d^{-\frac{\theta}{1-\rho}} \left\{1 + \left(\frac{m}{d}\right)^{-\frac{\theta}{1-\rho}} + (I - 2)m^{-\frac{\theta}{1-\rho}}\right\}\right]^{1-\rho} \\ &= d^{-\theta} \left\{1 + \left(\frac{m}{d}\right)^{-\frac{\theta}{1-\rho}} + (I - 2)m^{-\frac{\theta}{1-\rho}}\right\}^{1-\rho} \end{aligned}$$

Since $1 + \left(\frac{m}{d}\right)^{-\theta/(1-\rho)} + (I - 2)m^{-\theta/(1-\rho)} > 1$, $\frac{m}{d} > 1$, $m > 1$; $\left\{1 + \left(\frac{m}{d}\right)^{-\theta/(1-\rho)} + (I - 2)m^{-\theta/(1-\rho)}\right\}^{1-\rho}$ is increasing in $1 - \rho$. In the case of $d > m$, the logic is the same. $\square$

Lemma 2 For $\rho \rightarrow 1$, if $\xi > 1 + \theta$, $GO^g < GT \times GMP^g$.

Proof of Lemma 2. Recall that $GO^g = [\Delta_0 + (I - 1)\Delta_1]^{\eta/\theta}$. For $\rho \rightarrow 1$, Δ_0 in equation (14) collapses to:

$$\lim_{\rho \rightarrow 1} \Delta_0 = \frac{1}{\min[1; (md)^\theta]} = 1,$$

and Δ_1 in equation (15) collapses to:

$$\lim_{\rho \rightarrow 1} \Delta_1 = \frac{1}{\min[d^\theta; (m)^\theta; (md)^\theta]} = \begin{cases} d^{-\theta} & \text{for } h > d \\ m^{-\theta} & \text{for } h < d \end{cases}$$

Hence:

$$\lim_{\rho \rightarrow 1} GO^g = \begin{cases} 1 + (I - 1)d^{-\theta} & \text{for } h > d \\ 1 + (I - 1)m^{-\theta} & \text{for } h < d. \end{cases}$$

Recall that $GT \times GMP^g = 1 + (I - 1)[d^{-\theta} + \tilde{m}^{-\theta} + (I - 1)(d\tilde{m})^{-\theta}]$. Then, with $h > d$, $GO^g < GT \times GMP^g$, and $GT' = GO^g/GMP^g < GT$.

With $h < d$, $GO^g < GT \times GMP^g$, and $GT' < GT$, only if

$$(m^{-\theta} - \tilde{m}^{-\theta}) < d^{-\theta} [1 + (I - 1)\tilde{m}^\theta].$$

Hence, it is sufficient that:

$$\left(\frac{m}{d}\right)^{-\theta} - \left(\frac{\tilde{m}}{d}\right)^{-\theta} < 1.$$

Replacing $m = \left[ad^{1-\xi+(1-a)h^{1-\xi}}\right]^{\frac{1}{1-\xi}}$, and $\tilde{m} = (1 - a)^{\frac{1}{1-\xi}}h$, the sufficient condition is:

$$\left[(1 - a)\left(\frac{h}{d}\right)^{1-\xi} + a\right]^{-\frac{\theta}{1-\xi}} - \left[(1 - a)\left(\frac{h}{d}\right)^{1-\xi}\right]^{-\frac{\theta}{1-\xi}} < 1,$$

that it is satisfied if $\xi - 1 > \theta$. $\square$

Proof of Proposition 5. Let $GO = GO^f \cdot GO^g$, that is, decompose gains from openness into a term for gains in the final goods' sector, $GO^f \equiv [1 + (I - 1)h^{-\theta}]^{1/\theta}$, and another term for gains in the intermediate goods' sector, $GO^g \equiv [1 + (I - 1)(d^{-\theta} + m^{-\theta} + (I - 1)(md)^{-\theta})]^{\eta/\theta}$. Similarly, gains from MP can be decompose in an analogous way, $GMP = GMP^f \cdot GMP^g$, where $GO^f = GMP^f$. Thus, GT'^g/GMP^g .

(a) For $\rho = 0$, $GO^g = [1 + (I - 1)(d^{-\theta} + m^{-\theta} + (I - 1)(md)^{-\theta})]^{\eta/\theta}$. Since $GT \times GMP^g = [1 + (I - 1)(d^{-\theta} + \tilde{m}^{-\theta} + (I - 1)(\tilde{m}d)^{-\theta})]^{\eta/\theta}$, for all ρ , we have that: if $a = 0$, $\tilde{m} = m$, and thus $GO^g = GT \times GMP^g$, and $GT' = GT$; if $a > 0$, $\tilde{m} > m$, and thus $GO > GT \times GMP^g$ (It directly follows that $GT' = GO^g/GMP^g > GT$).

(b1) For $a = 0$, $\tilde{m} = m$. By Lemma 1, we know that $dGO^g/d\rho < 0$. Then, $GO_{\rho=0}^g > GO^g$ for any $0 < \rho < 1$. By a), $GO_{\rho=0}^g = GT \times GMP^g$. It follows that for any $\rho \in (0, 1)$, $GO^g < GT \times GMP^g$, and hence, $GT'^g/GMP^g < GT$.

b2) For $a > 0$, $\lim_{\xi \rightarrow 1} \tilde{m} \rightarrow \infty$, and hence $\lim_{\xi \rightarrow 1} GMP = 0$. It follows then that $\lim_{\xi \rightarrow 1} GO > \lim_{\xi \rightarrow 1} [GT \times GMP]$. Conversely, $\lim_{\xi \rightarrow \infty} m, \tilde{m} = \min[h_g, d]$. This implies that $\lim_{\xi \rightarrow \infty} GO < \lim_{\xi \rightarrow \infty} [GT \times GMP]$.

c) For $a > 0$, $\tilde{m} > m$. By Lemma 1, we know that $dGO^g/d\rho < 0$. Also, $d(GT \times GMP^g)d\rho \rightarrow 1$. By 1), we know that for $\rho = 0$, $GO^g > GT \times GMP^g$. By Lemma 2, for $\rho \rightarrow 1$, if $\xi > 1 + \theta$, $GO^g < GT \times GMP^g$. By continuity, it follows that there exists $\hat{\rho} \in (0, 1)$ such that for $\rho < \hat{\rho}$, $GO^g > GT \times GMP^g$ and $GT'^g/GMP^g > GT$; and for $\rho > \hat{\rho}$, $GO^g < GT \times GMP^g$ and $GT' = GO^g/GMP^g < GT$. $\square$

B The Dynamic Model

Imagine that each country is composed of a number of locations. Let lv denote location v in country l and let N_l be the number of locations in country l . An idea in country i has a productivity q_{lvi} in location v of country l . Assume that the vector $\mathbf{q}_i = (q_{11i}, q_{12i}, \dots, q_{1N_1i}, \dots, q_{I1i}, q_{I2i}, \dots, q_{IN_Ii})$ is drawn from the following multivariate distribution:

$$H(\mathbf{q}_i) = 1 - \left(\sum_{l=1}^I \sum_{v=1}^{N_l} \left(\frac{q_{lvi}}{\underline{\varepsilon}} \right)^{-\frac{\theta}{1-\rho}} \right)^{1-\rho}$$

with $\sum_{l=1}^I \sum_{v=1}^{N_l} q_{lvi}^{-\theta/(1-\rho)} < \underline{\varepsilon}^{-\theta/(1-\rho)}$ for $\rho \in (0, 1)$ and $\theta > 1$. Note that the marginal distribution of $q_{lvi} \geq \underline{\varepsilon}$ for any lvi is $1 - (q_{lvi}/\underline{\varepsilon})^{-\theta}$, so we can think of $H(\cdot)$ as a multivariate Pareto distribution.

Research is modeled as the creation of ideas, although for simplicity here we assume that this is exogenous. In particular, we assume that there is an instantaneous (and constant) rate of arrival $\bar{\varepsilon}\zeta_i$ of new ideas per person in country i . The parameter ζ_i varies across countries and captures differences in the “research” productivity across countries, while $\bar{\varepsilon}$ is a common

parameter that will be normalized below. Ideas are specific to goods, and the good to which an idea applies can be an intermediate good or a final good with equal probability. If the idea applies to an intermediate (final) good the identity of the good is drawn from a uniform distribution in $v \in [0, 1]$ ($u \in [0, 1]$). This implies that at time t there is a probability $R_i(t) = \bar{\varepsilon} \zeta_i L_i(t)$ of drawing an idea for any particular (intermediate or final) good. The arrival of ideas is then a Poisson process with rate function $\bar{\varepsilon} R_i(t)$, so the number of ideas that have arrived for a particular good by time t is distributed Poisson with rate $\bar{\varepsilon} \lambda_i(t)$, where $\lambda_i(t) \equiv \int_0^t R_i(s) ds$. (From here onwards, we suppress the time index as long as it does not cause confusion.)

The technology frontier for country i is the upper envelope of all the vectors $\mathbf{q}_i$. That is, letting Ω_{lvi} denote the set of all q_{lvi} associated with ideas existing in country i at a certain point in time, then the technology frontier for country i is $\mathbf{x}_i \equiv (\max\{q_{11i} \in \Omega_{11i}\}, \max\{q_{12i} \in \Omega_{12i}\}, \dots, \max\{q_{1N_1i} \in \Omega_{1N_1i}\}, \dots, \max\{q_{I1i} \in \Omega_{I1i}\}, \dots, \max\{q_{IN_Ii} \in \Omega_{IN_Ii}\})$. This is distributed according to

$$\begin{aligned} \Pr(X_{11i} \leq x_{11i}, \dots, X_{IN_Ii} \leq x_{IN_Ii}) &= \sum_{k=0}^{\infty} \frac{e^{-\bar{\varepsilon} \lambda_i} (\bar{\varepsilon} \lambda_i)^k}{k!} H(\mathbf{x}_i)^k \\ &= e^{-\bar{\varepsilon} \lambda_i} \sum_{k=0}^{\infty} \frac{[\bar{\varepsilon} \lambda_i H(\mathbf{x}_i)]^k}{k!} = e^{-\bar{\varepsilon} \lambda_i (1 - H(\mathbf{x}_i))} \\ &= \exp \left[-\bar{\varepsilon} \bar{\varepsilon}^\theta \lambda_i \left(\sum_{l=1}^I \sum_{v=1}^{N_l} x_{lvi}^{-\frac{\theta}{1-\rho}} \right)^{1-\rho} \right] \end{aligned}$$

for $\sum_{l=1}^I \sum_{v=1}^{N_l} x_{lvi}^{-\theta/(1-\rho)} < \bar{\varepsilon}^{-\theta/(1-\rho)}$. Letting $z_{li} \equiv \max\{x_{l1i}, \dots, x_{lN_li}\}$ be the highest productivity among all country i ideas as they apply to locations of country l , then

$$F_i(z_i) = \exp \left[-\bar{\varepsilon} \bar{\varepsilon}^\theta \lambda_i \left(\sum_{l=1}^I N_l z_{li}^{-\frac{\theta}{1-\rho}} \right)^{1-\rho} \right]$$

for $\sum_{l=1}^I N_l z_{li}^{-\theta/\rho} < \bar{\varepsilon}^{-\theta/(1-\rho)}$. Letting $T_{li} \equiv \lambda_i N_l^{1-\rho}$, setting $\bar{\varepsilon} \bar{\varepsilon}^\theta = 1$, and taking the limit as $\bar{\varepsilon}^\theta \rightarrow 0$, then we get the multivariate Fréchet distribution in (5).

Assuming that L_i grows at the constant rate g_L (assumed to be common across countries) then in steady state we must have $\lambda_i = R_i/g_L$, so λ_i and hence T_{li} grow at rate g_L for all l, i . This implies that the static equilibrium described in Section 2.2 is replicated at all dates, and that the real wage in all countries is increasing at rate $g = \frac{1}{\theta}(1 + \eta)g_L$.

C Summary Statistics and Alternative Calibrations

	Mean	Standard Deviation	Observations
Distance (in km)	6,006	6,099	342
Common Language	0.11	0.31	342
Common Border	0.09	0.28	342
bilateral trade share	0.019	0.035	342
bilateral MP share	0.021	0.043	219
bilateral intra-firm share [†]	0.074	0.072	34
bilateral MP share in manufacturing [†]	0.48	.13	33

[†]: from/to the United States.

Table 7: Summary Statistics.

	Data			Model	
	Equipped Labor	Population	real GDP pc (relative to US)	real GDP pc	λ_i
Australia	0.061	0.0688	0.7774	0.7455	0.678
Austria	0.0231	0.0304	0.7385	0.7212	0.5937
Belgium	0.0281	0.0385	0.7341	0.7026	0.5134
Canada	0.1084	0.1114	0.8079	0.7993	0.4452
Denmark	0.0183	0.0199	0.8207	0.8409	0.5854
Spain	0.0837	0.1493	0.5457	0.5003	0.6173
Finland	0.0167	0.0194	0.6901	0.7009	0.4008
France	0.1597	0.2254	0.708	0.7113	0.8174
Great Britain	0.1647	0.223	0.6828	0.6902	0.6965
Germany	0.269	0.3092	0.7293	0.7954	0.5795
Greece	0.023	0.0396	0.4441	0.4018	0.2654
Italy	0.1342	0.2177	0.7039	0.6496	1.0536
Japan	0.5218	0.4768	0.8127	0.9048	0.6446
Netherlands	0.0449	0.0587	0.7389	0.73	0.6676
Norway	0.0176	0.0166	0.827	0.898	0.4598
New Zealand	0.0114	0.0139	0.591	0.5198	0.278
Portugal	0.0192	0.0377	0.4733	0.3743	0.3064
Sweden	0.0309	0.0333	0.7285	0.7829	0.4699
United States	1	1	1	1	1

Table 8: Country's Statistics: Data and Model.

as % of GDP	Data				Model			
	Exports	Imports	MP		Exports	Imports	MP	
			inward	outward			inward	outward
Australia	0.05	0.10	0.28	0.10	0.02	0.02	0.08	0.18
Austria	0.18	0.24	0.29	0.13	0.32	0.32	0.45	1.75
Belgium	0.45	0.48	0.46	0.22	0.38	0.38	0.61	1.62
Canada	0.23	0.22	0.46	0.26	0.22	0.22	0.48	0.74
Denmark	0.23	0.19	0.12	0.17	0.27	0.27	0.38	1.63
Spain	0.11	0.15	0.25	0.03	0.13	0.13	0.37	0.41
Finland	0.22	0.16	0.23	0.48	0.25	0.25	0.51	1.13
France	0.13	0.14	0.20	0.18	0.16	0.16	0.40	0.39
Great Britain	0.12	0.15	0.35	0.32	0.12	0.12	0.38	0.36
Germany	0.16	0.13	0.29	0.29	0.13	0.13	0.54	0.16
Greece	0.09	0.17	0.07	0.01	0.16	0.16	0.55	0.52
Italy	0.12	0.12	0.15	0.07	0.10	0.10	0.25	0.39
Japan	0.05	0.02	0.06	0.16	0.01	0.01	0.09	0.02
Netherlands	0.32	0.27	0.50	1.00	0.24	0.24	0.41	0.94
Norway	0.11	0.17	0.17	0.18	0.25	0.25	0.45	1.24
New Zealand	0.14	0.18	0.25	0.04	0.07	0.07	0.28	0.53
Portugal	0.18	0.26	0.58	0.04	0.22	0.22	0.53	0.82
Sweden	0.23	0.19	0.32	0.36	0.21	0.21	0.48	0.77
United States	0.04	0.05	0.18	0.16	0.03	0.03	0.17	0.06

Table 9: Trade and MP Statistics: Data and Model.

	trade and MP	only trade	only MP
	(I)	$h_{gni} \rightarrow \infty$	$d_{ni} \rightarrow \infty$
δ_{dist}^d	0.13	0.13	N/A
δ_{dist}^h	0.05	N/A	0.05
δ_{border}^d	0.75	0.75	N/A
δ_{border}^h	0.79	N/A	0.79
$\delta_{language}^d$	0.70	0.70	N/A
$\delta_{language}^h$	0.68	N/A	0.68
δ_0^d	0.47	0.46	N/A
δ_0^h	0.45	N/A	0.49
a	0.20	N/A	N/A
ρ	0.16	0.16	0.16
θ	7.2	7.2	7.2

Table 10: Three calibrations: trade and MP, only trade, and only MP.

	trade and MP (I)	only trade $h_{gni} \rightarrow \infty$	only MP $d_{ni} \rightarrow \infty$
“Explanatory power” for:			
bilateral trade shares	0.69	0.69	N/A
bilateral MP shares	0.40	N/A	0.24
bilateral intra-firm trade shares	0.38	N/A	N/A
Correlations model data:			
Bilateral Trade Shares	0.82	0.82	N/A
Bilateral MP Shares	0.49	N/A	0.35
Total Exports Shares	0.82	0.80	N/A
Total Imports Shares	0.84	0.81	N/A
Total Outward MP Shares	0.17	N/A	0.08
Total Inward MP Shares	0.45	N/A	0.29
Implied Costs:			
Avg. trade costs (d_{ni})	2.1	2.1	N/A
Avg. MP costs (h_{gni})	1.7	N/A	1.7

Bilateral MP = sales of affiliates from country i in n ; Total Outward MP = total sales of foreign affiliates from country i ; Total Inward MP = total sales of foreign affiliates in country n .

Table 11: Goodness of Fit: benchmark, only trade, and only MP.