International production, technology diffusion, and trade

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Abstract

The paper develops a general equilibrium model of international production and trade. Technology is carried across borders by multinational producers and the set of technologies being used in a particular country is endogenous. Production locations are chosen based on the costs of production and getting the product to market. The model incorporates vertical, horizontal, offshoring, and export-platform FDI. Estimated model parameters describe the states of technology in different countries, barriers to international investment, and trade costs. The model is used to quantify the welfare effects of international production and trade and to investigate the effects of free-trade agreements on offshoring.

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1 Introduction

International production is an important feature of the modern economy. It occurs when firms set up production in one or more locations outside of their home countries. This international movement of producers coexists with the international movement of goods and services, with both having the potential to greatly improve world productivity and welfare.

One of the important benefits of international production is the diffusion of technology. A firm establishing production in a foreign country brings along its production technology, thus benefitting the host country. While this benefit is important to all countries, it is especially important to the developing countries that lack productive domestic technologies.

This paper develops a general equilibrium model of international production and trade. In the model, producers may choose to locate production in their home countries or anywhere in the world and they may sell their output anywhere in the world. An important component of the model is the technology transfer associated with multinational production.

When deciding where to produce, producers shop for a location that gives them the lowest cost of production and getting their product to market. As the result of this choice, a producer may

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end up making its product in its home country, target market country, or a third country. The same producer may choose different production locations to serve different markets.[1]

The model incorporates productivity differences across producers. Productivity achieved in production is determined by the technology being used and the ability of a firm to implement this technology. Technology is developed in the home country while the ability of the firm to implement it depends on the location of production.

Technological differences are probabilistic and described by a statistical distribution, as in Eaton and Kortum (2002). However, while their model has producers drawing productivity in the country where they are located, the model of this paper allows producers to draw productivity in their home country and then bring this technology to the country where they produce. Therefore, this paper extends the methodology of Eaton and Kortum (2002) to include foreign direct investment and the associated technology transfer. This extension endogenizes technology used in production.

The model yields expressions relating bilateral international trade and production to technology, factor costs, implementation factors, and trade costs. The model is parametrized using the average of the 1997-2003 data on bilateral trade and international production in manufactures for the following countries: Canada, Europe, Japan, United States, and the rest of the world (ROW). The estimated parameters include bilateral trade costs, measures of the states of technology and impediments to its implementation. The paper also measures the contribution of international production to technology diffusion.

The model is used to perform several counterfactual simulations that address questions interesting to economists and policy-makers. The first set of simulations quantifies the welfare effects of the current levels of the international production and trade in manufactures. It is found that all countries benefit from trade and international production. The magnitude of the gains from trade are similar to those found in Eaton and Kortum (2002) and is greater than the magnitude of the gains from international production.

The second set of simulations quantifies the welfare effects of moving to a world in which international trade is free and producers can establish foreign operations just as easily as they can establish the domestic ones, a scenario called free international production in this paper. The welfare effects of such a move are found to be much greater than the welfare effects of the current levels of international production and trade. For countries that currently have productive domestic technologies, moving to free trade or free international production brings similar welfare gains. The ROW, however, which is dominated by developing countries, benefits much more from international production than trade.

The last simulation looks at the effect of a free-trade agreement between the U.S. and ROW on offshoring by the U.S. producers. The politically sensitive topic of offshoring often comes up in discussions of free trade agreements with developing countries. While offshoring currently constitutes a relatively small fraction of the total output of the U.S. firms, there is a fear that it may grow significantly as the result of free–trade agreements with developing countries, which have much lower wages.

The model is able to provide a quantitative forecast of a maximum possible change in offshoring

[1]The international investment literature distinguishes between the horizontal foreign direct investment (FDI), when firms establish production in foreign countries in order to circumvent trade costs, and vertical FDI, when firms do it in order to take advantage of cheaper inputs. In the latter case, the output of the foreign plant may be sold back to the home country (a scenario called offshoring) or to a third country (a scenario called export-platform FDI). The model of this paper allows for all of these possibilities.

in response to a free trade agreement between the U.S. and ROW, where the wage is about ten times lower than in the U.S. It is found that there is a substantial increase in the offshoring activity by the U.S. producers, but the absolute magnitude of offshoring remains small as a fraction of the total U.S. output or spending. The significant impediments encountered by the U.S. firms attempting to set up production in the ROW prevent a greater increase in offshoring.

There are few existing models that combine international production and trade, because of various technical challenges inherent in creating such a model. Markusen, Venables, Konan and Zhang (1996), Yeaple (2003), Helpman (2006), Keller and Yeaple (2008) create two- or three-country models of various modes of FDI and trade. By comparison, the model of this paper is able to parsimoniously describe a multi-country world where producers engage in various modes of FDI and trade. Ramondo and Rodríguez-Clare (2009) create a multi-country model of multinational production and trade that can be viewed as an alternative to the model of this paper.

There is a number of models that consider each mode of international production in isolation. These models can be classified into two categories: those that consider producer heterogeneity in productivity and those that do not.

There are models of vertical FDI where firms search for low factor costs. Helpman (1984, 1985) develops such a model without producer heterogeneity. Garetto (2008), and Yeaple (2009) are two recent papers that incorporate producer heterogeneity. There are several models of the export-platform FDI, all without producer heterogeneity (Hanson, 2001; Ekholm, Forslid and Markusen, 2005).

There are models of horizontal FDI, where firms replicate the same activity in many locations. The models without producer heterogeneity include Markusen (1984) and Markusen and Venables (1998, 2000). The models with producer heterogeneity include Helpman, Melitz and Yeaple (2004) and Ramondo (2008).

There is also a model of FDI called the knowledge-capital (KK) model (Markusen, 1997; Markusen, 2002). The central feature of this model is that technology developed at the headquarters of a firm is copied to affiliates in many countries. This feature also exists in the model of this paper.

The rest of the paper is organized as follows. Section 2 presents the stylized facts regarding FDI. Section 3 explains the model. Sections 4 describes the data. Section 5 explains the parameter estimation procedure and presents the parameter estimates. Section 7 performs several counterfactual simulations using the model. Section 8 concludes.

2 Terminology and stylized facts of international production

While the stylized facts about international trade are fairly widely known, the facts about international production are not. Therefore, it may be useful to review them here in order to motivate the model that follows.

International production (IP) is the result of foreign direct investment (FDI). FDI is an investment in another country with the ability to exert managerial control over the production process.[2] For practical purposes, international agencies equate managerial control to a 10% stake in the enterprise. The FDI is done by multinational corporations (MNCs) that have headquarters in a home country and operations in one or more other countries. The foreign operations of MNCs are

[2] The description of FDI and FDI data sources in this section is necessarily brief. It is based in part on Lipsey (2001) who provides a much more detailed review.

called foreign affiliates. If they are majority-owned (stake greater than 50%) then they are called majority-owned foreign affiliates (MOFAs).

Producers have several reasons to move production outside their home countries. First, it allows them to circumvent trade costs when serving foreign markets. Producers will be more likely to produce in a foreign country that is distant or has high import barriers. International production (IP) that occurs in order to achieve proximity of production to market is typically called "horizontal" IP. The foreign direct investment (FDI) that is required to establish international production in this case is called "horizontal" FDI. This form of FDI is an alternative to trade.

Second, moving production to other countries allows producers to take advantage of cheaper inputs. It is often cheaper labor, but can also be other inputs, such as intermediate goods. International production that occurs when producers shop around for cheapest production costs is typically called "vertical" IP and the required FDI the "vertical" FDI. A special case of vertical IP occurs when a firm produces in a foreign country and sells goods back to its home country, a phenomenon called offshoring. Firms can also move production to a foreign country in order to serve a third country, a scenario called the export-platform IP.

The size of international production can be measured in several ways. It can be measured by the cumulative investment made by the MNCs into their affiliates. This measure is called the stock of FDI and is calculated from the annual FDI flows reported in national accounts. The size of IP can also be measured by the output, sales, employment, or reported assets of the affiliates.

There are advantage and disadvantage to using each of these measures. FDI flows are available for a wide range of countries and years, but are volatile and may be inaccurate because investments are often routed through the third countries. Industry distribution of FDI may be inaccurate for a similar reason: investments are often routed through holding companies in other industries. In addition, the FDI stocks reported by statistical agencies do not take into account changes in asset and currency values.

The data on affiliates' output, sales, employment, and assets is collected by industrial surveys and reflects ownership and industry more accurately than FDI flows. However, this data is available for only a few countries and years. The collection and reporting methodologies of this data are sometimes inconsistent across countries.

Despite all the problems with the international production data noted above, the quantity and quality of the IP data is improving and we now have a reasonably good picture of international production. We know that most of it occurs in developed countries: 70% of the world FDI inflows is received by industrial countries and 70% of the U.S. MOFAs (by output) are in the G7 countries.[3]

The level of parental control of foreign affiliates is high: most (85% for the U.S.) are majority-owned. Most of the R&D is done in the home country: only 13% of the U.S. MNC's R&D is performed by their MOFAs.

Most of the foreign affiliates' output is sold locally (66% for the U.S. MOFAs). The rest is sold to the home country and third countries (11% and 23% for the U.S. MOFAs). However, there is significant heterogeneity in these numbers across host countries. For example, the percentage of the U.S. MOFA's output sold locally varies between 22% in Bermuda and 95% in India. Figure D1 shows how this number varies across countries. The percentage of the U.S. MOFAs' output sold to the U.S. varies between 0.2% in Greece and 46% in Barbados. The U.S. MOFAs' sales to the third countries vary between 2% of output in India and 70% in Luxemburg.[4]

[3] Data cited in this section is from UNCTAD (2004, 2005), BEA database, and Mataloni and Yorgason (2002).

[4] These numbers are totals for all sectors. The variation is even greater if only manufacturing is considered.

Produce	Sell	Name
Home	Home	Domestic non-exporting firm
Home	Foreign	Domestic exporting firm
Foreign	Home	Vertical IP, Offshoring
Foreign	Foreign	Horizontal IP
Foreign	Third country	Export platform

Table 1: Modes of operation of producers

Sales to home are the result of offshoring. Sales to the third countries are the result of the export-platform IP. Offshoring and export-platform IP are usually considered to be the types of vertical IP. The size of the local sales, on the other hand, is often used to measure the magnitude of the horizontal IP.

It is interesting to compare two different ways that a company can serve a foreign market: trade and local production. To make this comparison, we look at the ratio of the U.S. merchandise exports to the local sales of the U.S. MOFAs. The most striking feature of this data is how much it varies across countries. Some countries, such as Bermuda (0.08), Poland (0.11), and the U.K. (0.15), are served mostly by multinational production. Other countries, such as Israel (5.5), Costa Rica (2.65), and Korea (2.24), are served mostly through exports. Figure D2 shows the variation of the ratio across countries.[5] The task of the model in the following section is to explain the multitude of strategies and behaviors of producers.

3 Model of international production and trade

There are N countries. In every country there is a continuum of producers, each making a single good indexed by a real number $j \in [0, 1]$. Consumers have CES preferences over the goods. Every product has a blueprint for making it, a result of the R&D effort. Looking at the blueprint, engineers can predict its productivity. This predicted productivity will be called the blueprint productivity and denoted by $z(j) \in (0, \infty)$.

The R&D process is probabilistic and producers draw their blueprint productivities from a statistical distribution. Every country has its own blueprint for making j, so the blueprint productivity of good j in country h is denoted by $z_h(j)$. This productivity is the realization of a random variable Z_h which has a country-specific distribution with cdf F_h^z.[6]

A producer draws its blueprint productivity in its home country, but can manufacture its product anywhere in the world using its blueprint. The same producer may establish production facilities in many countries. Each of these affiliates can then sell its product in many countries around the world. Table 1 lists various options for a producer to organize its operations.

Throughout the paper, the home country of a producer will be denoted by h, the county of production by i, and the country of sale by n.

In order to start production in country i, a producer needs to implement its blueprint there. For various reasons, the productivity achieved in the production of good j may be different from its stated blueprint productivity $z_h(j)$. This difference, called the implementation factor, is affected

[5] The ratios of exports to local sales in manufacturing are slightly higher, but vary just as much across countries.

[6] This section will not assume specific distributional forms for the random variables, but will derive the results in the general case. Section 3.3 will impose distributional forms and derive the expressions that will be put to data.

by the location of production and denoted by $\phi_{ih}(j)$. The productivity achieved in production is $\phi_{ih}(j)z_h(j)$.[7]

While $z_h(j)$ is the productivity predicted by engineers from the blueprint of j, the productivity of the actual production process may end up being higher or lower. Therefore, the implementation factor $\phi_{ih}(j)$ is allowed to vary between 0 and ∞. If $0 < \phi_{ih}(j) < 1$, the actual productivity is lower than what is projected by the blueprint. If $1 < \phi_{ih}(j) < \infty$, the actual productivity is higher than projected.[8]

The implementation factor varies across goods, which means that blueprints from country h for different goods j will be implemented in country i with different degrees of success. We can say that while the blueprint productivity depends on the strength of the R&D department, the implementation factor depends on the strength of the local management team of a producer.

The implementation process is probabilistic and the implementation factors are drawn from a distribution with cdf F_{ih}^{ϕ} which is specific to each country pair $\{i, h\}$. A higher mean of this distribution makes country i more attractive to producers from country h. Implementation factors are independent across countries i and h, and across goods j.

A producer from h that manufactures good j in country i and sells it in country n pays the production cost c_i, transportation cost d_{ni}, and sees its blueprint productivity change by $\phi_{ih}(j)$. Therefore, its total cost of this enterprise is $v_{nih}(j) = c_i d_{ni}/\phi_{ih}(j)$. This cost can be thought of as a cost of getting a blueprint to market. Note that $v_{nih}(j)$ is inversely proportional to the implementation factor $\phi_{ih}(j)$, so that a higher $\phi_{ih}(j)$ leads to a lower total cost of getting a blueprint to market. Since ϕ_{ih} is a random variable, v_{nih} is also a random variable with cdf F_{nih}^{v}.

The production cost c_i consists of the payments for factors and intermediate goods. Assuming that capital and labor are the only factors, and that production function is Cobb-Douglas, the production cost is

$$c_i = r_i^{\alpha} w_i^{\beta} p_i^{1-\alpha-\beta}, \tag{1}$$

where α is the share of capital in output, β is the share of labor, and p_i is the price of the intermediate goods bundle.

Transportation cost has the "iceberg" form. To receive \$1 of product in country n, a producer has to send $d_{ni} \geqslant 1$ dollars of product from country i. Domestic trade cost is set to one: $d_{nn} \equiv 1$.

Since the goods market has perfect competition, producers set prices equal to their costs. A producer of j from h manufacturing in i and selling in n sets the price $p_{nih}(j) = v_{nih}(j)/z_h(j)$. This producer is successful in n only if it is the lowest-price supplier of j there. Therefore, it chooses a production location i in order to minimize the cost of getting its blueprint of good j to country n. The minimum such cost will be denoted by $v_{nh}(j) = \min_i \{v_{nih}(j)\}$. The price in country n of product j made by an h producer will then be $p_{nh}(j) = v_{nh}(j)/z_h(j)$.[9]

[7] This specification is equivalent to using "iceberg" costs for international investment, an approach that has been previously used by the empirical literature on FDI as well as the more recent models of FDI with heterogeneous producers.

[8] The unbounded supports of the distributions of $z(j)$ and $\phi(j)$ mean that the model cannot replicate zero trade or investment flows between countries. Ramondo (2008) and Chor (2009) develop models where zero trade or FDI flows are made possible by bounding the support of the technology distributions. While allowing unbounded supports limits the applicability of the model to large countries or country blocks, it also reduces the complexity of the model and makes it more tractable.

[9] Why cannot ϕ_{ih} be the same for all goods j, same as trade cost d_{ni}? If ϕ_{ih} were the same for all goods j, then for a given pair of countries $\{n, h\}$ there would have been only one (for all goods j) production location i^* that gives the minimum cost to market. An implication is that for a given pair of countries, there could only be trade or IP

The timing of the model is as follows: each producer draws its blueprint productivity $z_h(j)$ in its home country h, then draws adjustment factors $\phi_{ih}(j)$ for all possible production locations i. Knowing these values, each producer decides whether to produce and where to produce.

Since the cost to market $v_{nih}(j)$ is independent across manufacturing locations i, the minimum cost to market V_{nh} is a random variable distributed with cdf

$$\begin{aligned} F^v_{nh} &= \Pr\left(V_{nh} \leqslant v\right) = 1 - \Pr\left(V_{nh} > v\right) = 1 - \Pr\left(V_{nih} > v, \forall i\right) \\ &= 1 - \textstyle\prod_i \Pr\left(V_{nih} > v\right) = 1 - \prod_i \left(1 - F^v_{nih}\right). \end{aligned} \tag{2}$$

Country h presents country n with the distribution of prices p_{nh}, which has cdf F^p_{nh}. Consumers in n buy from the lowest-price supplier of j, so the price of j there is $p_n(j) = \min_h \{p_{nh}(j)\}$. Since the minimum cost to market $v_{nh}(j)$ is independent across h, the distribution of prices in country n is

$$\begin{aligned} F^p_n &= \Pr\left(P_n \leqslant p\right) = 1 - \Pr\left(P_n > p\right) = 1 - \Pr\left(P_{nh} > p, \forall h\right) \\ &= 1 - \textstyle\prod_h \Pr\left(P_{nh} > p\right) = 1 - \prod_h \left(1 - F^p_{nh}\right). \end{aligned} \tag{3}$$

The CES price index in country n is

$$p_n = E\left[P_n^{1-\sigma}\right]^{1/(1-\sigma)} = \left[\int_0^\infty p^{1-\sigma} dF^p_n(p)\right]^{1/(1-\sigma)}. \tag{4}$$

It is assumed that the intermediate goods bundle consists of all goods combined in the CES fashion. Therefore, p_n is also the price of the intermediate goods bundle in (1).

The probability that a producer from h locates its manufacturing in i in order to supply n with j is $\chi_{nih} \equiv \Pr\left(A_{nih}\right) = \Pr\left(B_{nh} \cap C_{nih}\right) = \Pr\left(B_{nh}\right) \Pr\left(C_{nih}\right)$, where event A_{nih} is "a producer from h locates its manufacturing in i in order to supply n with j, event B_{nh} is "a producer from h is the lowest-price supplier of j in n, and event C_{nih} is "country i provides the lowest cost to market n for a producer of j from h. The last equality holds because events B_{nh} and C_{nih} are independent.

Addressing each of these two events individually, we have

$$\Pr\left(C_{nih}\right) = \Pr\left(v_{nih}(j) \leqslant \min_s \{v_{nsh}(j), s \neq i\}\right) = \textstyle\int_0^\infty \prod_{s \neq i} \left(1 - F^v_{nsh}(v)\right) dF^v_{nih}(v). \tag{5}$$

The second equality holds because v_{nih} are independent across i. The probability of the event B_{nh} is

$$\Pr\left(B_{nh}\right) = \Pr\left(p_{nh}(j) \leqslant \min_s \{p_{ns}(j), s \neq h\}\right) = \textstyle\int_0^\infty \prod_{s \neq h} \left(1 - F^p_{ns}(p)\right) dF^p_{nh}(p). \tag{6}$$

Thus, the probability that a producer from h would locate its manufacturing in i in order to supply n with j is

$$\chi_{nih} = \left[\textstyle\int_0^\infty \prod_{s \neq h} \left(1 - F^p_{ns}(p)\right) dF^p_{nh}(p)\right] \times \left[\textstyle\int_0^\infty \prod_{s \neq i} \left(1 - F^v_{nsh}(v)\right) dF^v_{nih}(v)\right]. \tag{7}$$

Since there is a continuum $[0, 1]$ of producers, χ_{nih} is also the fraction of goods that n buys from the i-located h producers. It means that $\sum_h \sum_i \chi_{nih} = 1$. Note that the two integrals in equation (7) are guaranteed to converge because F^p_{ns} and F^v_{nsh} are cdf's of random variables.

(FDI), but not both. In fact, for some country pairs, there could be no trade or investment (all production would take place in a third country). When ϕ_{ih} is random, different producers from h may choose different ways of serving market n.

3.1 Trade and foreign direct investment

Since χ_{nih} is the fraction of goods that n buys from the i-located h producers, then $X_{nih} = \chi_{nih} X_n$, where X_n is the total spending in n, is equal to the sales in n of the i-located h producers. The total spending in n on the goods manufactured in i, i.e. the volume of imports from i to n, is

$$\Pi_{ni} = \pi_{ni} X_n, \tag{8}$$

where

$$\pi_{ni} = \sum_s \chi_{nis} \tag{9}$$

is the probability that a producer located in i (of any origin h) is the least-price supplier in n.[10] Note that the definition of π_{ni} means that $\sum_s \pi_{ns} = 1$.[11]

Total sales of the affiliates of h located in i are

$$S_{ih} = \sum_n \left(\chi_{nih} X_n \right). \tag{10}$$

Note that for given i and h, events A_{nih} are not mutually exclusive across n's. Some affiliates sell to just one country while others sell to many countries. So, the probabilities χ_{nih} cannot be added up across n, but the dollar amounts can.[12]

The stock of foreign direct investment is derived from the sales of foreign affiliates S_{ih}. Let κ_{ih} be the fraction of capital stock in i that is owned by the producers from h. Then, the stock of foreign direct investment in i owned by the h producers is $\kappa_{ih} K_i$. Let λ_{ih} be the fraction of the labor force in i employed by the producers from h. These definitions of κ_{ih} and λ_{ih} mean that $\sum_s \kappa_{is} = \sum_s \lambda_{is} = 1$.

Then, note that the distribution of the production efficiencies $\phi_{ih} z_h$ of the producers that are actually producing in i is the same regardless of their origin h. In other word, conditioning on the origin h does not affect the distribution of $\phi_{ih} z_h$. A country h with a higher state of technology and lower barriers to investment in i will increase the number of affiliates in i until the distribution of their efficiencies is the same as that of the affiliates from the other countries (and that of i's domestic producers).

The above means that the average (across producers) capital-output ratio (and also the labor-output ratio) is the same for any origin h. This allows us to relate κ_{ih} and λ_{ih} to the sales of foreign affiliates:

$$\kappa_{ih} = \lambda_{ih} = \frac{S_{ih}}{Q_i} = \frac{1}{Q_i} \sum_n \left(\chi_{nih} X_n \right). \tag{11}$$

Therefore, both κ_{ih} and λ_{ih} measure the ownership structure of a country's producers.

[10] Note that for given n and i, events A_{nih} across different h's are mutually exclusive. In other words, two producers from any two locations h_1 and h_2 cannot establish manufacturing facilities in the same location i in order to supply the same product j to the same market n. Therefore χ_{nih} are additive across origins h. Also, for given n and h events A_{nih} across different i's are mutually exclusive, since a producer from h would not establish affiliates in more than one location i in order to supply the same market n. Therefore χ_{nih} is additive across production locations i.

[11] It is also possible to derive the volume of sales of h producers (manufacturing anywhere in the world) in n. Let $\chi_{nh} = \sum_s \chi_{nsh}$ be the probability that a producer from h (manufacturing anywhere in the world) sells in n. Therefore, $\chi_{nh} X_n$ is the volume of sales of h firms in n. The expression for χ_{nh} simplifies considerably. The second term in the expression for χ_{nih} disappears, and the probability that a producer from h (manufacturing anywhere) is the least-price supplier in n is simply $\chi_{nh} \equiv \Pr\left(p_{nh}(j) \leqslant \min_s \{p_{ns}(j), s \neq h\}\right)$.

[12] So $\sum_n \chi_{nih}$ is not a probability that a firm located in i has come from h (or a fraction of firms located in i that has come from h), because some affiliates may sell to more than one destination.

Equation (8) is a gravity-like equation for international trade because it relates trade to country characteristics and trade costs. Equation (11) is a gravity-like equation for FDI because it relates FDI to country characteristics and the implementation factors, which can be interpreted as barriers to investment.

3.2 Market clearing

Due to data limitations, only the manufacturing industries are modeled. Model closure follows the usual practice. In each country i, output must equal spending:

$$Q_i = \sum_{n=1}^{N} \pi_{ni} X_n. \tag{12}$$

Manufacturing goods can be used as either final or intermediate goods. Therefore, $X_n = Z_n + C_n$, where Z_n is the spending on the intermediate manufacturing goods and C_n is the spending on the final manufacturing goods. The latter is assumed to be a fixed portion of a country's income: $C_n = \varphi_n Y_n$. The former is given by the production function: $Z_n = (1 - \alpha - \beta)\, Q_n$. Putting these expressions together we obtain the equation for total spending:

$$X_n = (1 - \alpha - \beta)\, Q_n + \varphi_n Y_n. \tag{13}$$

Country income is the sum of capital income and labor income in manufacturing, and nonmanufacturing income. It is assumed that the profits are not repatriated to the headquarters. This assumption is made for two reasons: (a) to make the technology transfer the only transfer associated with FDI, so the focus stays on it and (b) to make the model more similar to Eaton and Kortum (2002) where income stays in the country of production.

The total income in n is

$$Y_n = w_n L_n + r_n K_n + Y_n^o, \tag{14}$$

where Y_n^o is the nonmanufacturing income. Following Eaton and Kortum (2002), the nonmanufacturing income is considered fixed.

Factor stocks K_n and L_n are specific to manufacturing. Capital and labor are not mobile between the manufacturing and nonmanufacturing sectors. Factor markets are perfectly competitive. Factor employments are given by

$$K_n = \alpha Q_n / r_n \text{ and } L_n = \beta Q_n / w_n. \tag{15}$$

3.3 Imposing distributional forms

As in Eaton and Kortum (2002), it is assumed that the productivity draws $z_h(j) > 0$ have the Fréchet distribution with the shaping parameter θ and location parameter Λ_h. The cdf of z_h is therefore $F_h^z(z) = e^{-\Lambda_h z^{-\theta}}$, where θ is common across countries while Λ_h is different.[13] Parameter Λ_h measures the state of the domestically-sourced technology in each country.

[13] The mean and variance of a Fréchet random variable are $E[z] = \Lambda^{1/\theta}\Gamma\left(1 - \frac{1}{\theta}\right)$, for $\theta > 1$ and $Var(z) = \Lambda^{2/\theta}\left[\Gamma\left(1 - \frac{2}{\theta}\right) - \Gamma^2\left(1 - \frac{1}{\theta}\right)\right]$, for $\theta > 2$, where Γ is the Gamma function.

It is assumed that implementation factors $\phi_{ih}(j) > 0$ are also distributed Fréchet.[14] The cdf of ϕ_{ih} is $F_{ih}^{\phi}(\phi) = e^{-\Psi_{ih}\phi^{-\mu}}$, where the shaping parameter μ is the same across country pairs while the location parameter Ψ_{ih} is different.

If ϕ_{ih} is distributed Fréchet, then $v_{nih} = c_i d_{ni}/\phi_{ih}$ has the Weibull distribution with cdf $F_{nih}^{v} = 1 - e^{-\tilde{\Psi}_{nih}v^{\mu}}$, where $\tilde{\Psi}_{nih} = \Psi_{ih}\left(c_i d_{ni}\right)^{-\mu}$. The probability that country i provides a producer from h with the lowest cost to market n (event C_{nih}) is

$$\Pr\left(C_{nih}\right) = \int_0^{\infty} \prod_{s\neq i}\left(1 - F_{nsh}^{v}(v)\right) dF_{nih}^{v}(v) = \frac{\Psi_{ih}\left(c_i d_{ni}\right)^{-\mu}}{\sum_{s=1}^{N}\Psi_{sh}\left(c_s d_{ns}\right)^{-\mu}} = \frac{\tilde{\Psi}_{nih}}{\sum_{s=1}^{N}\tilde{\Psi}_{nsh}} = \tilde{\Psi}_{nih}\breve{\Psi}_{nh}^{-1}, \tag{16}$$

where $\breve{\Psi}_{nh} = \sum_s \tilde{\Psi}_{nsh}$. The least cost-to-market v_{nh} is distributed with cdf $F_{nh}^{v} = 1 - \prod_i\left(1 - F_{nih}^{v}\right) = 1 - e^{-\breve{\Psi}_{nh}v^{\mu}}$.

The price $p_{nh}(j) = v_{nh}(j)/z_h(j)$ is the product of two independent (not necessarily identically distributed) Weibull random variables (v_{nh} and $\tilde{z}_h = 1/z_h$, since the inverse of a Fréchet r.v. is a Weibull r.v.). This product is itself a random variable with cdf $F_{nh}^{p}(p) = R\left(p;\mu,\theta,\breve{\Psi}_{nh},\Lambda_h\right)$ and pdf $f_{nh}^{p}(p) = r\left(p;\mu,\theta,\breve{\Psi}_{nh},\Lambda_h\right)$, where functions $R(\cdot)$ and $r(\cdot)$ will be defined below. The distribution of this random variable is derived by Sagias, Karagiannidis, Mathiopoulos and Tsiftsis (2006), Sagias and Tombras (2007), and Bithas, Sagias, Tsiftsis and Karagiannidis (2007).[15]

To make the numerical analysis workable, it is assumed that the shaping parameters of the distributions of v_{nih} and $\tilde{z}_h$ are the same. When $\mu = \theta$ the cdf and pdf of p_{nh} are

$$F_{nh}^{p}(p) = R\left(p;\theta,\theta,\breve{\Psi}_{nh},\Lambda_h\right) = 1 - 2\left(\breve{\Psi}_{nh}\Lambda_h\right)^{1/2} p^{\theta/2} K_1\left(2\left(\breve{\Psi}_{nh}\Lambda_h\right)^{1/2} p^{\theta/2}\right) \tag{17}$$

and

$$f_{nh}^{p}(p) = r\left(p;\theta,\theta,\breve{\Psi}_{nh},\Lambda_h\right) = 2\breve{\Psi}_{nh}\Lambda_h\theta p^{\theta-1} K_0\left(2\left(\breve{\Psi}_{nh}\Lambda_h\right)^{1/2} p^{\theta/2}\right), \tag{18}$$

where $K_q(\cdot)$ is the qth order modified Bessel function of the second kind.

The probability that an h producer located in i is the lowest-price supplier of j in n (event B_{nh}) is

$$\begin{aligned}\Pr\left(B_{nh}\right) &= \int_0^{\infty}\prod_{s\neq h}\left(1 - F_{ns}^{p}(p)\right) dF_{nh}^{p}(p) = \\ &= \int_0^{\infty}\prod_{s\neq h}\left(1 - R\left(p;\theta,\theta,\breve{\Psi}_{is},\Lambda_s\right)\right) dR\left(p;\theta,\theta,\breve{\Psi}_{nh},\Lambda_h\right). \end{aligned}\tag{19}$$

Therefore, the probability that a producer from h would establish production in i in order to supply n is given by the following integral equation:

$$\chi_{nih} = \tilde{\Psi}_{nih}\breve{\Psi}_{nh}^{-1}\int_0^{\infty}\left[\prod_{s\neq h}\left(1 - R\left(p;\theta,\theta,\breve{\Psi}_{is},\Lambda_s\right)\right)\right] r\left(p;\theta,\theta,\breve{\Psi}_{nh},\Lambda_h\right) dp. \tag{20}$$

[14] The technology being used to make good j and the implementation procedure for this technology both represent best available practices. Therefore, it is reasonable to represent them by extreme-value distributions.

[15] Note that a product of two Weibull random variables cannot be approximated by a Weibull random variable (Sagias and Tombras, 2007).

Plugging in the expressions for the cdf and pdf of p, this equation becomes

$$\begin{aligned}
\chi_{nih} &= \tilde{\Psi}_{nih}\breve{\Psi}_{nh}^{-1}\int_0^\infty \left[\prod_{s\neq h} 2\left(\breve{\Psi}_{is}\Lambda_s\right)^{1/2} p^{\theta/2} K_1\left(2\left(\breve{\Psi}_{is}\Lambda_s\right)^{1/2} p^{\theta/2}\right)\right]\times \\
&\quad \times 2\tilde{\Psi}_{nih}\Lambda_h\theta p^{\theta-1} K_0\left(2\left(\tilde{\Psi}_{nih}\Lambda_h\right)^{1/2} p^{\theta/2}\right) dp \\
&= 2^N\theta\tilde{\Psi}_{nih}^2\breve{\Psi}_{nh}^{-1}\Lambda_h\prod_{s\neq h}\left(\breve{\Psi}_{is}\Lambda_s\right)^{1/2}\times \\
&\quad \times\int_0^\infty p^{\theta(N+1)/2-1} K_0\left(2\left(\breve{\Psi}_{nh}\Lambda_h\right)^{1/2} p^{\theta/2}\right)\prod_{s\neq h} K_1\left(2\left(\breve{\Psi}_{is}\Lambda_s\right)^{1/2} p^{\theta/2}\right) dp, \quad (21)
\end{aligned}$$

that can be evaluated numerically. The integral converges, as explained below equation (7).

Prices in each country are distributed with cdf

$$F_n^p(p) = 1 - \prod_s 2\left(\breve{\Psi}_{ns}\Lambda_s\right)^{1/2} p^{\theta/2} K_1\left(2\left(\breve{\Psi}_{ns}\Lambda_s\right)^{1/2} p^{\theta/2}\right) \quad (22)$$

which has the corresponding pdf

$$f_n^p(p) = \sum_i \left\{2\breve{\Psi}_{ni}\Lambda_i\theta p^{\theta-1} K_0\left(2\left(\breve{\Psi}_{ni}\Lambda_i\right)^{1/2} p^{\theta/2}\right)\prod_{s\neq i}\left[2\left(\breve{\Psi}_{ns}\Lambda_s\right)^{1/2} p^{\theta/2} K_1\left(2\left(\breve{\Psi}_{ns}\Lambda_s\right)^{1/2} p^{\theta/2}\right)\right]\right\} \quad (23)$$

derived in the technical appendix (available upon request). The CES prices index in country n is given by equation (4).

3.4 Affiliate strategies

Section 2 described various strategies employed by producers in their quest to find the most cost-efficient ways to serve various markets. These strategies, summarized in Table 1, include exporting, offshoring, horizontal IP, and export-platform IP. How do various parameters of the model affect the incentives of producers to choose one strategy over another?

When deciding how to serve a particular market n, a producer considers the cost of implementing its blueprint, cost of production, and cost of delivering the manufactured good to market. A producer will be a domestic exporter if the domestic implementation factor is high, domestic production cost is low, and the trade cost to market n is low. On the other hand, if the trade cost to market n is high, the implementation factor in n is high (which is more likely if Ψ_{nh} is high), and the cost of production in n is low then the best strategy will be to set up a foreign affiliate in n and sell output locally, i.e. engage in horizontal IP.

It may be possible, though, that the trade cost from the home country to n is high, but the implementation factor in n is low or the cost of production there is high. In that case a producer will look for a country close to n with a high implementation factor and low production cost in order to establish production there and export output to n. This affiliate will then be engaged in export-platform IP.

Everything else equal, low trade costs d_{ni} will encourage imports into n, while high trade costs will encourage horizontal IP there ("tariff jumping"). High implementation factors in n (high Ψ_{nh}) and low production costs c_n will encourage producers to set up manufacturing in n. Low costs of shipping goods from n to other countries will encourage producers to use n as the platform for the export-oriented IP. Low costs of shipping goods from n to the producers' home countries will encourage offshoring.

How do producer characteristics relate to the producer's mode of operation (one of those listed in Table 1)? For example, which producers will engage in trade and IP and which will only sell on the domestic market? Both trade and IP involve additional costs compared to domestic production and sales. Therefore, more productive producers are more likely to be competitive in foreign markets. So, more productive producers are more likely to engage in trade and/or IP. Also, more productive producers will serve more markets than less productive ones.[16] These properties of the model match the observed producer facts.[17]

Of those producers that do serve foreign countries, which will engage in horizontal IP and which will be exporters? For a producer from h the decision whether to export to i or establish an affiliate there comes down to which option will give a lower price of its good in i. If a producer were to export to i, the price for its good in i would be $p_{ihh}^{export}(j) = c_h d_{ih}/\phi_{hh}(j)z_h(j)$.[18] If this producer were to set up an affiliate in i, the price for its good would be $p_{iih}^{IP}(j) = c_i/\phi_{ih}(j)z_h(j)$. The ratio of these prices is

$$\frac{p_{ihh}^{export}(j)}{p_{iih}^{IP}(j)} = \frac{c_h/\phi_{hh}(j)}{c_i/\phi_{ih}(j)} d_{ih}. \tag{24}$$

If this ratio is greater than one, then local production is a better option. If it is less than one, then trade is better. The ratio depends on the cost of production in h relative to i, implementation factor in i relative to h, and the cost of bringing a good from h to i.

Can we say something about the productivity of the producers that choose to export vs. those that choose IP? We can if we make an assumption that exporting is cheaper than IP for most producers and most destinations (Section 5.1 shows that this assumption holds for the countries in this paper's dataset). In this case, a producer is more likely to engage in exports than IP (and more producers engage in exports than IP). This means that a producer serving more destinations is more likely to serve some of them through IP than a producer serving fewer destinations.[19] Since more productive producers serve more destinations, they are more likely to engage in IP than less productive producers. This matches the observed fact that producers that engage in IP are, on average, more productive than those that only export.[20]

It is also interesting to consider the choice between domestic production and offshoring. If a producer from h wanting to supply its good to its home market were to manufacture the good domestically, its price would be $p_{hhh}^{dom}(j) = c_h/\phi_{hh}(j)z_h(j)$. If instead the manufacturing took place at an offshore affiliate in i, the price (in country h) would be $p_{hih}^{offshore}(j) = c_h d_{hi}/\phi_{ih}(j)z_h(j)$. The

[16] Because some markets n are more expensive to serve than others, more productive producers will be competitive in more markets than less productive producers.

[17] There is a large literature that looks at producer-level heterogeneity in trade. This literature finds that exporters are a minority and more productive than non-exporters. More productive exporters sell to more destinations than less productive exporters (Aw, Chung and Roberts, 1998; Clerides, Lach and Tybout, 1998; Bernard and Jensen, 1999; Eaton, Kortum and Kramarz, 2004).

[18] The superscript "export" is not necessary, but is added for convenience.

[19] Similarly, of the firms that serve a specific number of destinations, the fraction of pure exporters (not engaged in IP) declines as the number of destinations rises.

[20] There are several studies of producer heterogeneity in international production. They find that only a small fraction of firms engage in FDI and that these firms are more productive than the exporting firms (Helpman et al., 2004; Tomiura, 2007).

ratio of these prices is

$$\frac{p_{hhh}^{dom}(j)}{p_{hih}^{offshore}(j)} = \frac{c_h/\phi_{hh}(j)}{c_i/\phi_{ih}(j)}\frac{1}{d_{hi}}. \tag{25}$$

If this ratio is greater than one, then offshoring is a better option. Otherwise, domestic production is better. Similarly to (24), this ratio depends on cost of production in h relative to i and the implementation factor in i relative to h. However, the trade cost is now in the denominator rather than numerator. Therefore, it will always be the case that $p_{ihh}^{export}(j)/p_{iih}^{IP}(j) \geqslant p_{hhh}^{dom}(j)/p_{hih}^{offshore}(j)$. A producer that prefers offshoring to domestic production will also prefer local production (horizontal IP) to exporting. A producer that is actually engaged in offshoring (being a least-price supplier of j in h) will also engage in local production and sales of j in i. Section 5.1 continues this analysis in view of the estimated parameter values.

4 Data

The dataset includes 5 "countries": Canada, Europe (which includes France, Germany, Italy, Norway, Spain, Sweden, and UK), Japan, United States, and the rest of the world (denoted by ROW and dominated by China). Because of the availability of data, only the manufacturing sector is considered. The following data was collected: output, value added, total exports, total imports, employment, labor compensation, and bilateral trade from the World Bank's Trade and Production database, total country GDP from the World Bank's WDI database, and employment by foreign affiliates from the OECD's Globalization database (see Section 2 for a discussion on various measures of activity of foreign affiliates). Data is typically the average of several (2-3) years around 2000.

Table D1 shows the country-level data. Note that the ROW's manufacturing output is similar to that of the U.S. and Europe, but its employment is an order of magnitude higher and its wage is an order of magnitude lower.

Table D2 shows domestic and international trade, Π_{ni}. Domestic trade (domestic spending on domestic goods, shown on the diagonal of the table) is much larger than international trade (shown on the off-diagonal entries). Note that each row adds up to the total spending of the importer and each column to the total output of the exporter.

Table D3 shows the same data, but as a fraction of the total spending of the importer (so each row adds up to one), π_{ni}. The fraction of the domestic goods in total spending varies between 0.47 in Canada and 0.89 in Japan. Tables D4 also shows the same trade data, but as a fraction of the total output of the exporter. It clearly shows the significance of the U.S. market for Canadian firms: they sell 47% of their output on the domestic market and 45% on the U.S. market. Tables 3 and 4 show that Japan is the most closed economy of the five. The weight of its domestic trade in its total spending or output is greater than for any other country. We can also see that Canada is the most open economy of the five.

Table D5 shows the employment in each of the five countries classified by the country of ownership of the enterprise. This employment data shows the extent of the domestic and international production activities of the firms. Domestic production (measured by the number of workers employed by domestic firms, shown on the diagonal of the table) is much larger than international production (measured by the number of workers employed by foreign firms, shown on the off-diagonal entries). The sum of each row is the total employment in each country. The sum of each column is the total employment at all the firms from that country.

Table D6 shows the same data, but as a fraction of the total employment in each country (so that each row adds up to one). This is the ownership structure of each country's producers, previously defined as λ_{ih}. It shows that domestic firms employ between 71% (in Canada) and 98% (in Japan) of the labor force. There is a substantial presence of the U.S. firms in Canada: they employ 21% of the Canadian workers. The U.S. firms employ about 6% of all workers in Europe and European firms employ about 6% of all U.S. workers.

Very few Japanese workers are employed by foreign firms. For example, the U.S. firms employ only 0.8% of the Japanese workers. While a good number of workers are employed by foreign firms in the rest of the world, their number is small relative to the total workforce there. European firms employ 3% of the ROW's workforce, while the U.S. firms employ 2%.

Table D7 also shows the employment data, but this time as a fraction of the total employment by each country's firms (so that each column adds up to one). The table shows that for all the countries except the ROW, a significant part of the economic activity of their firms takes place outside the national borders. For example, only 77% of workers employed by the U.S. firms are American. The table also shows that the ROW's workers constitute a significant percentage of the workforce of each country's firms. For example, 14% of the workers employed by the U.S. firms are located in the ROW.

5 Parameter estimation

We begin by identifying parameters Ψ_{ih}, d_{ni}, and Λ_h. It was previously assumed that domestic trade is free, i.e. $d_{nn} \equiv 1$. It is also assumed that $\Psi_{hh} \equiv 1$. Therefore, there are $N \times (N-1)$ parameters d_{ni}, $N \times (N-1)$ parameters Ψ_{ih}, and N parameters Λ_h that need to be identified. The total number of these parameters is $2N^2 - N$.

The parameters are identified by fitting equations (8) and (11) to data:

$$\pi_{ni} = \sum_s \chi_{nis},\ n \neq i, \tag{26}$$

$$\lambda_{ih} = \frac{\sum_n (\chi_{nih} X_n)}{Q_i}, \tag{27}$$

with χ_{nih} given by (21):

$$\begin{aligned} \chi_{nih} &= 2^N \theta \tilde{\Psi}_{nih}^2 \breve{\Psi}_{nh}^{-1} \Lambda_h \prod_{s \neq h} \left(\breve{\Psi}_{is}\Lambda_s\right)^{1/2} \times \\ &\times \int_0^\infty p^{\theta(N+1)/2-1} K_0 \left(2\left(\breve{\Psi}_{nh}\Lambda_h\right)^{1/2} p^{\theta/2}\right) \prod_{s \neq h} K_1 \left(2\left(\breve{\Psi}_{is}\Lambda_s\right)^{1/2} p^{\theta/2}\right) dp, \end{aligned} \tag{28}$$

and the following variables as defined earlier: $\tilde{\Psi}_{nih} = \Psi_{ih}\left(r_i^\alpha w_i^\beta p_i^{1-\alpha-\beta} d_{ni}\right)^{-\theta}$ and $\breve{\Psi}_{nh} = \sum_s \tilde{\Psi}_{nsh}$. Note that the market clearing conditions $Q_i = \sum_{n=1}^N \pi_{ni} X_n$ are implied by equations (27).[21]

Equations (26) and (27) number $2N^2 - N$. Spending X_n, output Q_n, trade π_{ni}, ownership structure λ_{ih}, and wages w_n are taken from data. Capital share α is set to 0.105, labor share β to

[21] This can be see by taking the sum of (27) over h and remembering that $\pi_{ni} = \sum_h \chi_{nih}$, and $\sum_h \lambda_{ih} = 1$.

0.195, and (gross) rates of return r_n to 20% in every country.[22] The value of elasticity σ used to calculate the CES price index is set to 5.[23]

The value of the shaping parameter θ is set to 8. This is the value estimated in Eaton and Kortum (2002) using price data. Changing the value of θ affects the estimated parameter values in the manner similar to Eaton and Kortum (2002). Setting a lower θ increases estimated trade costs d_{ni} and decreases estimated parameters of the implementation factors' distributions Ψ_{ih} (so lower θ results in higher estimated trade and IP costs).[24,25] The next section presents the estimated values of Λ_h, Ψ_{ih}, and d_{ni} for $\theta = 8$.

5.1 Results

Since there are 5 countries, there are $2N^2 - N = 45$ parameters to be identified from the same number of equations. Table B1 shows each country's estimated mean blueprint productivity, normalized with respect to the U.S. This mean productivity is calculated as $(\Lambda_h/\Lambda_{US})^{1/\theta}$. We can see that Japan has a slightly higher state of technology than the U.S., while Europe and Canada have lower states. The ROW has a much lower state of technology than the other countries.

Table B2 shows the estimated mean implementation factors, calculated as $\Psi_{ih}^{1/\theta}$. The table shows owner countries in columns and host countries in rows. For example, the mean implementation factor for the U.S. firms operating in Canada is 0.74.

All mean international implementation factors are smaller than one, i.e. smaller than the mean domestic implementation factors. This indicates that producers are, on average, more efficient when they manufacture goods at home than abroad. Of course, cheaper costs of production and trade can still entice producers to move their operations abroad even when the implementation factors are less than one.

The producers from Canada, Europe, and the U.S. operating in the ROW have very small (0.3-0.4) mean implementation factors. Since the ROW is dominated by developing countries, especially China, producers operating there have to deal with poor infrastructure, unfriendly governments, etc., which make the implementation factors there very low. On the other hand, producers from the ROW operating in the other countries have implementation factors that are quite high. While they have to deal with all the usual issues of establishing production abroad, they often face more favorable business conditions in the foreign countries than at home.

[22] The share of intermediate goods in output is then 0.7. The implied shares of capital and labor in value added are 0.35 and 0.65. The 20% gross rate of return assumes a 10% net return and 10% depreciation rate.

[23] The value of parameter σ has a negligible effect on the parameter estimates or simulation results. For example, choosing a σ between 1.1 and 10 changes the relative price levels by less than 1%.

[24] Lower θ results in higher variance of the technology distribution, thus increasing the probability that a country has a producer that can be competitive in foreign markets. To fit the existing trade and IP values, the model offsets this effect by setting higher trade and IP costs.

[25] The simulation results presented in this paper are robust to the value of θ. Consider, for example, two cases: (a) a low θ and the corresponding high estimates of d_{ni}, $n \neq i$ and (b) a high θ and the corresponding low estimates of d_{ni}, $n \neq i$. Then, in each case, consider performing a counterfactual experiment that sets $d_{ni} = 1$, $\forall n, i$ (i.e. free trade). Such an experiment is performed in Section 7.1.2. As in Eaton and Kortum (2002), parameter θ determines the response of trade flows to changes in trade costs: higher θ means smaller response. So, moving to free trade results in approximately the same predicted changes of trade flows in both cases. In case (a), changes in trade costs are large, but trade flows are not sensitive to changes in trade costs. In case (b), changes in trade costs are small, but trade flows are very sensitive to changes in trade costs. Welfare changes are also approximately similar in both cases since they are a function of the changes in trade. The same logic applies to simulating free IP and autarky.

Besides the ROW producers, high implementation factors are enjoyed by the U.S. firms operating in Canada, and by European and Canadian firms operating in the U.S. The high implementation factors between the U.S. and Canada are not surprising since NAFTA contains many provisions designed to facilitate FDI. Comparing host countries, we can see that the highest implementation factors are in the United States, which means that it provides a good environment for foreign producers.

Producers trying to establish production in Japan and Japanese producers trying to establish production abroad face low implementation factors. Much has been written about the difficulties encountered by the non-Japanese firms trying to operate in Japan, so their low implementation factors are not surprising. The low implementation factors of the Japanese producers operating abroad are less expected. Perhaps they can be explained by management style differences or some other business culture-related factors.

Looking at the technology parameters and implementation factors, we can ask the following question: can the average producer from a country drawing the average implementation factor in a foreign country be competitive with the average producer of the host country? Both producers face the same production and transportation costs. The only difference is the productivity with which they operate.

For each country pair, Table B3 shows the production productivity of the average producer from country h (shown in columns) operating in country i (shown in rows), drawing the corresponding average implementation factor. This production productivity is equal to $(\Psi_{ih}\Lambda_h/\Lambda_{US})^{1/\theta}$. For example the average producer from Europe operating in Canada would draw the blueprint productivity of 0.95 and the implementation factor of 0.62 resulting in the productivity of $0.95 \times 0.62 \approx 0.58$. The diagonal entries show the productivities of the average domestic producers (since the average domestic implementation factors are one).

Table B3 shows that the production productivities are such that in every country the average domestic producer has an advantage over the average foreign producers drawing the average implementation factors. This implies that to be successful in a foreign country, a producer must either have a blueprint productivity that is better than his home country's average or draw an implementation factor that is better than average. The former can be achieved by having a better than average R&D department and the latter by having better than average managers.

Table B4 shows the estimated trade costs. The average trade cost across all 20 country pairs is 1.65 (the tariff equivalent of this cost is 65%). This is similar to a typical international trade cost roughly estimated by Anderson and van Wincoop (2004) to be 0.74%. The lowest trade costs are between the U.S. and Canada (17% and 35% tariff equivalents) and between Europe and the ROW (24% and 33%). The highest trade costs are faced by the Japanese producers selling to Europe and Canada (114% and 122%).

The rest of the model parameters: country labor and capital endowments L_i and K_i, share of manufacturing in country spending φ_i, and nonmanufacturing income Y_i^o, are easy to calculate. Because of the assumption of equal labor shares across countries, the labor stocks L_n are calculated as $L_n = \beta Q_n / w_n$ instead of being taken from data. These calculated labor stocks, shown in Table B5 are very similar to the ones in the data with the correlation being 0.998. The capital stocks are calculated as $K_n = \alpha Q_n / r_n$.

Preference parameters φ_n are calculated as $\varphi_n = C_n / Y_n$, where C_n is the spending on final goods and Y_n is the GDP. Spending on final goods is calculated as total spending minus spending on intermediate goods: $C_n = X_n - (1 - \alpha - \beta) Q_n$, while GDP is taken from data. The nonmanufacturing income is calculated as $Y_n^o = Y_n - w_n L_n - r_n K_n$. Table B5 presents the values of the preference parameters φ_n. It shows that manufacturing makes up about 10 to 15% of each country's spending.

5.1.1 Relationships between trade costs, implementation factors, and technology parameters

What are the relationships between the values of these key parameters? The trade costs d_{ni} and mean implementation factors $\Psi_{ni}^{1/\theta}$ are negatively correlated ($\rho = -0.58$).[26] They are plotted together on Figure B1. Since low implementation factors are a barrier to international production while high trade costs are a barrier to international trade, this result means that these two kinds of international barriers go hand-in-hand. The relatively high correlation between the two means that one can serve as a fairly accurate predictor of the other.[27]

A possible explanation for the high correlation between trade and investment barriers is that some of the factors that affect one also affect the other. For example, common language, physical proximity, free-trade agreements, and institutions are known to affect trade costs and likely also affect implementation factors. Government policy toward imports may be a subset of a more general policy toward openness that affects not only trade, but also foreign investment.

There is little or no correlation between the implementation factors and technology parameters of the owner and host countries. This means that high-technology countries do not offer better implementation factors as hosts or face lower implementation factors as investors than the low-technology countries.

5.1.2 Affiliate strategies revisited

Section 3.4 discussed the choice of producers between exporting to a destination vs. setting up production there. It was said that if exporting is cheaper than setting up production for most producers and most destination, then more producers will engage in exports than IP and those producers that engage in IP will, on average, be more productive than exporters. We can now check if exporting is indeed cheaper than IP for most producers and most destinations in the dataset.

We will calculate the price that a producer from h expects to receive if it exports its goods to i relative to the price that it expects to receive if it sets up production in i:

$$E\left[\frac{p_{ihh}^{export}}{p_{iih}^{IP}}\right] = \frac{c_h/E\left[\phi_{hh}\right]}{c_i/E\left[\phi_{ih}\right]} d_{ih} = \frac{c_h}{c_i}\Psi_{ih}^{1/\theta} d_{ih}. \tag{29}$$

This ratio depends on the relative cost of production in h and i, average implementation factor faced by an h producer in i, and the cost of bringing goods from h to i. The relative costs of production for each pair of countries are shown in Table B6, where i is a row and h is a column. It shows that for Canada, Europe, Japan, and the U.S. the relative costs of production are within 15% of each other. On the other hand, the costs of production in those countries are, on average,

[26] The correlation coefficient excludes the diagonal entries.

[27] The slope of the relationship between trade costs and implementation factors on Figure B1 is close to -1. The relationship between trade costs and implementation factors tightens significantly if the country pairs involving ROW are excluded (ρ becomes -0.77).

50% greater than in ROW. Average implementation factors were shown in Table B2 and trade costs in Table B4. We can see in Table B2 that the low cost of production in the ROW is offset by the low implementation factors there.[28]

Table B7 shows the ratio of the expected prices $E\left[p_{ihh}^{export}/p_{iih}^{IP}\right]$. Out of the 20 country pairs only 3 have this ratio greater than one. For those pairs of countries, IP gives a lower expected price than exporting. For example, the U.S. producers targeting the European market and the European producers targeting the U.S. market will, on average, find that setting up production in the target market gives them a lower price than exporting. The same is true for the Canadian producers targeting the European market. For the vast majority (17 out of 20) of country pairs, exporting to a destination will, on average, give a lower price than setting up production in the target market. Therefore, the assumption made in Section 3.4 that exporting is cheaper than setting up local production for most producers and most destination holds for the countries in the dataset.

Section 3.4 also discussed the choice between domestic production and offshoring. We can now calculate the price that a producer from h expects to receive if it produces a good domestically relative to the price that it expects to receive if it produces the good offshore:

$$E\left[\frac{p_{hhh}^{dom}}{p_{hih}^{offshore}}\right] = \frac{c_h/E\left[\phi_{hh}\right]}{c_i/E\left[\phi_{ih}\right]}\frac{1}{d_{hi}} = \frac{c_h}{c_i}\Psi_{ih}^{1/\theta}\frac{1}{d_{hi}}. \tag{30}$$

Table B8 shows this ratio for all country pairs. All the relative expected prices are significantly less than one, meaning that domestic production is on average much cheaper than offshoring for all countries. The best chance that offshoring may produce a lower price exists between the U.S. and Canada where NAFTA helps to make implementation factors high and trade costs low. Since the relative expected prices are less then one, producers will only engage in offshoring if their foreign implementation factor draw relative to their home implementation factor draw, $\phi_{ih}(j)/\phi_{hh}(j)$, is better (greater) than average.

5.1.3 Model vs. data

Section 2 presented the stylized facts on international production. One of the facts mentioned in that section is that the percentage of output of the U.S. foreign affiliates that is sold locally varies from country to country. This percentage for various countries around the world is shown on Figure D1.

We can now examine what the model has to say about the size of local sales. Remember that when parametrizing the model, we only used the data on the total employment of affiliates located in each country. We did not use the data on how much of the affiliates' output is sold locally. The

[28] While the labor compensation in Canada, Europe, Japan, and the U.S. is 7 to 10 times greater than in the ROW, it constitutes only 20% of the cost of production. Since the prices of capital and intermediate goods are fairly similar in all countries, the differences in the costs of production are not as great; There is certainly anecdotal evidence that operating in the U.S. is not much more expensive than operating in China (which dominates the ROW data). For example, an article in the L.A. Times (Lee (2008)) tells a story of a Chinese businessman opening a printing-plate factory in South Carolina. He explains that land costs less than 1/4 of what it does in southeast China, electricity rates are about 75% lower, and there are no blackouts. While the South Carolina labor costs are higher ($12-13/hr vs. $2/hr), they are partially offset by payroll tax credits from the state government (the differences in land costs, electricity costs, and tax incentives are captured in the model by the differences in the expected implementation factors). The bottom line? "I was surprised," said the businessman. "The gap is not as large as I thought."

model, however, can infer the percentage of output sold locally. It is equal to $\chi_{iih}X_i/\sum_n \chi_{nih}X_n$, where $n, i \neq h$.

Figure B2 shows the local sales of the U.S. affiliates predicted by the model as percentages their total sales (output) in each country. Similarly to Figure D1, this figure shows a good deal of variation across countries.

It would be interesting to compare these model predictions to data. Of all the countries in the dataset, there is only data on the size of the local sales for the U.S. affiliates in Canada and Japan.[29] The percentage of the U.S. affiliates's output sold locally in Canada is predicted by the model to be 61%, while the data shows it to be 55%. In Japan, the model predicts the fraction of output sold locally to be 96%, while it is 90% in the data. The numbers are close, but the model overpredicts the size of the local sales somewhat.[30]

6 Comparison with the Eaton-Kortum model

It is educational to compare the technology parameters Λ_h estimated above with the technology parameters of the Eaton-Kortum model. The Eaton-Kortum model assumes that there is no FDI or technology diffusion so that all producers in country i draw productivity from that country's technology distribution. Specifically, the producer of good j in country i draws its production productivity $z_i(j)$ from the productivity distribution of country i that has the Fréchet form with the location parameter T_i and shaping parameter θ (common to all countries).

As in the model of this paper, the producer of good j in country i can bring its good to country n at a cost d_{ni}. Of course, among all the producers of good j (in various countries), only the producer that offers the cheapest price succeeds in selling its good in country n. Given this setup, Eaton and Kortum derive the expression for bilateral trade:

$$\pi_{ni} = \frac{T_i \left(c_i d_{ni}\right)^{-\theta}}{\sum_s T_s \left(c_s d_{ni}\right)^{-\theta}}, \tag{31}$$

where π_{ni}, c_i, and d_{ni} have the same meanings as in this paper. Eaton and Kortum assume that labor is the only factor of production, but for compatibility purposes I will modify their model and assume that capital and labor are the factors of production, so that c_i is given by (1):

$$c_i = r_i^{\alpha} w_i^{\beta} p_i^{1-\alpha-\beta}, \tag{32}$$

Eaton and Kortum derive the price index for their model:

$$p_i = \gamma \left[\sum_s T_s \left(c_s d_{ni}\right)^{-\theta}\right]^{-1/\theta}, \tag{33}$$

where γ is a constant. The market clearing conditions in Eaton and Kortum and the model of this paper are the same, given by equations (12)-(15).

I can infer the parameter values of the Eaton-Kortum model from the same data used in the previous section to infer the parameters of the model of this paper. Of course, the data on the

[29] We cannot simply add up the local sales in the European or ROW countries to obtain the local sales of the U.S. affiliates in Europe and the ROW. Consider, for example, the sales of the U.S. affiliates located in France to Italy. These sales are local sales for Europe, but will be classified as sales to third countries in the BEA's data.

[30] Changing the value of parameter θ has a negligible effect on the percentages inferred by the model.

activity of foreign affiliates will not be needed since the Eaton-Kortum model does not have FDI. Also, since I want to focus on the estimates of the technology parameters, I will use the trade costs d_{ni} estimated in the previous section instead of using the Eaton-Kortum methodology of estimating them.[31] To infer the Eaton-Kortum's technology parameters, I will use the market clearing equation (12):

$$Q_i = \sum_{n=1}^{N} \pi_{ni} X_n \tag{34}$$

with π_{ni} given by (31), c_i by (32), and p_i by (33). Equations (34) constitute a system of N equations of N unknown T_i's. They are solved using data on output, spending, wages, and rates of return described in Section 4, and trade costs estimated in the previous section.

How would we expect T and Λ to be different? If there is no international production then T and Λ should be the same. For small volumes of international production, their values should be similar. On the other hand, if a country has a low Λ, but many producers from high-Λ countries operating on its territory, we would expect its T to be noticeably higher than its Λ. As the volume of international production increases, we would expect T's to become more and more similar across countries, while Λ's would of course remain the same. In an extreme case, when international production is as easy as the domestic production (i.e. $\Psi = 1$ for all pairs of countries), we would expect T's to be the same in all countries.

Table B9 presents each country's mean productivity inferred from the Eaton-Kortum model and normalized with respect to the United States. This mean productivity is calculated as $(T_i/T_{US})^{1/\theta}$.

The values of these mean productivities are very similar to the values of $(\Lambda_i/\Lambda_{US})^{1/\theta}$ shown in Table B1 with the exception of Canada, where T_{CAN} is higher than Λ_{CAN}. This result makes perfect sense in light of the discussion above.[32] As mentioned before, the present-day volumes of international production are fairly low for most countries. So for most countries the value of the parameter T is similar to the value of the parameter Λ. This is even the case for the ROW where own technology is low so the potential benefit from international production is high.

One notable exception in the dataset is Canada where, as shown on Table D6, 29% of the labor force is employed by foreign producers, mostly from the U.S. Therefore, T_{CAN} is noticeably higher than Λ_{CAN}. This difference implies a substantial technology transfer to Canada that we would expect to bring sizable welfare gains. Welfare gains from international production are analyzed in the Section 7.1.

As mentioned earlier, if international production is as easy as the domestic one, we would expect T's to be the same in all countries. So, an interesting experiment would be to use the model of this paper to simulate a world in which international production is as easy as the domestic one and then use the Eaton-Kortum model to infer the T parameters in such a world. This experiment is done in Section 7.1.2.

7 Counterfactual simulations

Having a fully parametrized model allows us to perform counterfactual simulations. To simulate a scenario means to solve for the endogenous variables π_{ni}, κ_{ih}, Q_n, X_n, w_n, r_n, and p_n given the

[31] They use a gravity-like equation to estimate the trade costs.

[32] This result also serves as a check of the model of this paper.

model parameters K_n, L_n, Y_n^o, Λ_n, Ψ_{ih}, θ, d_{ni}, α, β, σ, and φ_n. The endogenous variables are found using equations (8), (11)-(15), and (4) reproduced below for convenience:

$$\pi_{ni} = \sum\nolimits_h \chi_{nih},\ n \neq i, \tag{35}$$

$$\kappa_{ih} = \frac{\sum_n \left(\chi_{nih} X_n\right)}{Q_i},\ i \neq h, \tag{36}$$

$$Q_i = \sum\nolimits_{n=1}^{N} \pi_{ni} X_n, \tag{37}$$

$$X_n = \left(1 - \alpha - \beta\right) Q_n + \varphi_n \left(w_n L_n + r_n K_n + Y_n^o\right), \tag{38}$$

$$r_i = \alpha Q_i / K_i,\ w_i = \beta Q_i / L_i, \text{ and} \tag{39}$$

$$p_n = \left[\int_0^\infty p^{1-\sigma} dF_n^p(p)\right]^{1/(1-\sigma)}, \tag{40}$$

where χ_{nih} is given by (21):

$$\begin{aligned}\chi_{nih} \quad = \quad & 2^N \theta \tilde{\Psi}_{nih}^2 \breve{\Psi}_{nh}^{-1} \Lambda_h \prod\nolimits_{s \neq h} \left(\breve{\Psi}_{is} \Lambda_s\right)^{1/2} \times \\ & \times \int_0^\infty p^{\theta(N+1)/2-1} K_0 \left(2 \left(\breve{\Psi}_{nh} \Lambda_h\right)^{1/2} p^{\theta/2}\right) \prod\nolimits_{s \neq h} K_1 \left(2 \left(\breve{\Psi}_{is} \Lambda_s\right)^{1/2} p^{\theta/2}\right) dp,\end{aligned} \tag{41}$$

with $\tilde{\Psi}_{nih} = \Psi_{ih} \left(r_i^\alpha w_i^\beta p_i^{1-\alpha-\beta} d_{ni}\right)^{-\theta}$, $\breve{\Psi}_{nh} = \sum_s \tilde{\Psi}_{nsh}$ as defined earlier, and the cdf of prices given by (22):

$$F_n^p(p) = 1 - \prod\nolimits_s 2 \left(\breve{\Psi}_{ns} \Lambda_s\right)^{1/2} p^{\theta/2} K_1 \left(2 \left(\breve{\Psi}_{ns} \Lambda_s\right)^{1/2} p^{\theta/2}\right). \tag{42}$$

7.1 Trade, international production, and welfare

This section will investigate the welfare effects of international trade and production in manufactures. It will start by quantifying the welfare effects of the current levels of trade and international production. It will then investigate a counterfactual world in which there are no barriers to trade and international production is as easy as the domestic one.

7.1.1 Autarky

First, we will consider how much the current level of international trade in manufactures contributes to welfare. For this purpose, a counterfactual experiment will simulate an increase in trade costs d_{ni} (while holding all the other parameters constant at their baseline levels) to the point where international trade disappears. Welfare will be measured by real income.

The results of the experiment, presented in the first column of Table S1, show that the contribution of the current level of international trade to the current level of welfare varies between 0.5% in Japan and 4% in Canada. It is not surprising that the contribution of trade is the greatest in Canada: it currently spends a half of its income on foreign goods and sends a half of its output abroad. By comparison, Japan spends only 10% of its income on foreign goods and sends 20%

of its output abroad. The numbers reported in the first column of Table S1 are similar to those presented in the fourth column of Table IX in Eaton and Kortum (2002).[33]

Next, we will consider how much the current level of international production in manufactures contributes to welfare. For this purpose, we will perform a counterfactual experiment that will simulate a decrease in implementation factors $\Psi_{ih,i\neq h}$ (while holding all the other parameters, including trade costs, constant at their baseline levels) to the point where international production disappears.[34]

The results of this experiment are presented in the second column of Table S1. As with trade, Japan has the distinction of having the smallest contribution of international production to welfare at 0.05%, while Canada has the largest at 2.1%. It is not surprising that the contribution of IP is the largest in Canada, since it has the greatest presence of foreign producers on its soil. As discussed in Section 4, about 30% of Canadian labor force is employed by foreign producers (mostly from the U.S.) that make a noticeable contribution to the average productivity in Canada.

The contribution of international production to welfare is smaller than the contribution of trade by a factor of two for Canada, Europe, and the U.S., factor of six for the ROW, and factor of nine for Japan. This result is not unexpected given that the current levels of international production are fairly modest for most countries. For example, only 1.5% of Japanese workers are employed by foreign producers.

Finally, we will consider how much the current levels of both trade and international production in manufactures (jointly) contribute to welfare. For this purpose, a counterfactual experiment will simulate a simultaneous increase in trade costs d_{ni} and decrease in implementation factors $\Psi_{ih,i\neq h}$ to the point where both international trade and production disappear.

The combined welfare effects of international production and trade, i.e. the effects of openness, are presented in the third column of Table S1. The model predicts that Canada would see its welfare reduced by about 7% if its manufacturing sector were to become closed to trade and international production. Canada being a small fairly open economy, this result is not surprising. Europe, the U.S., and ROW would see their welfare reduced by 1.7-2.5%, Japan by 0.6%.

The welfare effect of both trade and international production is greater than the sum of the welfare effect of trade and the welfare effect of international production (i.e. column three of Table S1 is greater than the sum of columns one and two). This occurs because trade and IP are, to some degree, substitutes. For example, when international trade is stopped, international production increases. Similarly, when international production is stopped, international trade increases.

7.1.2 Open world

It is also interesting to quantify the potential benefits to having free trade and international production. Free trade exists when all international trade costs d_{ni} are equal to one, i.e. the same as the domestic trade costs. Free international production exists when all mean implementation factors $\Psi_{ih}^{1/\theta}$ are equal to one, i.e. the same as the domestic mean implementation factors. With free IP, technology is freely mobile across countries.

This section will simulate several scenarios: (a) a world in which trade is free, but the implementation factors are same as in the today's world, (b) a world in which international production

[33] Arkolakis, Costinot and Rodríguez-Clare (2010) show that these gains from trade can be obtained from a large class of trade models.

[34] Trade costs are held at their base values, presented in Table B4.

is free, but the trade costs are the same as in the today's world, and (c) a fully open world in which both trade and international production are free.

The last three columns of Table S1 show the welfare changes that are predicted by these simulations. We note that the potential gains from free trade and international production are much greater than the welfare gains from the current levels of trade and international production.[35] All countries are predicted to reap substantial rewards from more openness.

Gains from free trade depend on country size and current trade magnitude. Canada, as a small country, has the most to gain from free trade. Japan, as the currently least-open country, also stands to gain substantially. The size of gains from free international production are related to the current level of domestic technology. The ROW, having domestic technology that is much less productive than the other countries', stands to gain by far the most. Free international production gives it a very large 90% increase in welfare. This shows that technology diffusion can be a source of significant economic growth. This is especially true for less developed countries, such as the ROW, that have low productivities of domestically-sources technologies.

Comparing the gains from free trade and international production, we can see that for the U.S., the gains are similar. For countries with productive domestic technologies, such as Japan, free trade is more beneficial than fully integrated international production. For countries with less productive domestic technologies, such as Europe and especially the ROW, free international production is more beneficial. Being a small country, Canada benefits greatly from free trade. However, having relatively less productive domestic technologies, it also benefits significantly from free international production.

The last column of Table S1 shows the predicted benefits of a completely open world, with free trade and international production. The numbers are quite large. The U.S. is predicted to see a 26% increase in its real income, Japan and Europe - 40-45% increase. Canada and the ROW are predicted to benefit the most: Canada stands to gain 110% while the ROW 118%. To put these numbers in perspective, consider that a 26% increase in real income can also be obtained from 8 years of a 3% annual economic growth. A 40-45% increase in real income can be obtained from 11.5-12.5 years of a 3% annual economic growth and a 110% increase - from 25 years.

Similarly to the case of autarky simulations of the previous section, the welfare effect of both free trade and international production is greater than the sum of the welfare effect of free trade and the welfare effect of free international production. As in those simulations, this occurs because trade and IP are, to some extent, substitutes. For example, when international trade becomes free, international production decreases. Therefore, the liberalization of international production has a greater effect on the size of international production when trade is free than when it is costly. Similarly, when international production becomes free, international trade drops. Therefore, trade liberalization has a greater effect on the size of trade when international production is free than when it is costly.

Table S2 shows what happens to the activity of foreign affiliates when international production becomes free (i.e. fully internationally integrated).[36] The ownership structure of producers becomes the same in all countries. Producers from more productive countries get a bigger slice of production, those from less productive countries get a smaller slice. Japanese producers become responsible for 38% of total employment, the U.S. producers for 30%. On the other hand, Canadian producers get 8% of labor in each country and the ROW producers get 2%. Still, even 8% represents big gains

[35] Eaton and Kortum (2002) reach the same conclusion for international trade.

[36] Regardless of whether the international trade is free or not.

for Canadian producers, as can be seen by comparing Tables S2 and D6.

Since with free international production the ownership structure is the same in all countries, the production productivities are also the same everywhere. This can be verified by using the Eaton-Kortum model to infer the technology parameters T_i in the world with free international production. The parameters are inferred using the procedure described in Section 6 and the simulated data on output, spending, wages, and rates of return for the world with free international production. As expected, the estimated technology parameters T_i are *exactly* the same in all countries. Therefore, the world with free international production is the world where technology has diffused completely throughout the world.

7.2 Free trade agreements and offshoring

It is often suggested that implementing a free-trade agreement between a developed and developing country would result in more offshoring by the developed country's firms. Given cheap labor in the developing country and cheap costs of bringing the goods back to the developed country, firms would have an incentive to move their production to the developing country.

This section looks for the maximum size of this effect by forecasting the consequences of removing all trade costs between the U.S. and ROW. This is accomplished by solving the model with $d_{US,ROW}$ and $d_{ROW,US}$ set to one. Of course free-trade agreements do not result in free trade. They only remove the policy-related trade barriers. However, since the current levels of the policy-related trade barriers between the U.S. and ROW are not known, I will estimate the upper bound of the effects of a free-trade agreement by simulating completely free trade.

The model predicts all the usual consequences of a free trade agreement: higher volume of trade, greater welfare in both countries. However, we are specifically interested in what happens to offshoring by the U.S. producers. There are several ways to measure the volume of offshoring. One is to look at $\chi_{US,ROW,US}$ which is the fraction of the U.S. spending that goes towards goods made by the U.S. firms in the ROW. This number increases from 0.07% to 0.56%. Another way to measure offshoring is to look at the value of goods sold in the U.S. by the ROW-located U.S. producers relative to the total output in the ROW. This number increases from 0.06% to 0.5% as the consequence of the free-trade agreement.

Both measures show significant, 8-fold increases. However, 0.56% or 0.5% are still small numbers. The main obstacles to the U.S. producers trying to establish production in the ROW are the low implementation factors they encounter there. Consider for example the world with free trade and fully integrated international production that was simulated in the previous section. In that world, fully 15.2% of the U.S. spending goes towards goods made in the ROW by the U.S. firms.[37]

8 Conclusion

The paper develops a general equilibrium model of international production and trade. Producers develop technology at the headquarters in their home countries and can implement this technology in any country around the world. When searching for the location of production, producers consider the costs of production and the proximity to goods markets. Important features of the model include

[37] Another way to measure offshoring is to look at the value of goods sold in the U.S. by ROW-located U.S. producers. This value grows more than 10-fold as the result of the free-trade agreement because not only the fraction of these goods in total U.S. spending increases, but the total U.S. spending increases as well.

technological differences across producers, technology transfer through international production, and the presence of trade costs. Technology transfer means that the technology used in production in each country is endogenous. The model produces two gravity-like equations: one for international trade and the other for international investment.

The model is parametrized using data for five countries. Model parameters describe the states of technology in different countries, barriers to international investment, and trade costs. The estimated states of technology are compared and contrasted with the states of technology of the Eaton-Kortum model.

The model is used to quantify the welfare effects of the current level of international production and trade. The current level of international production contributes between 0.05 and 2.1% to the current level of welfare, depending on the country, while the current level of trade contributes between 0.5 and 4%. The model is also used to quantify the welfare effects of moving to a world with trade free trade and free international production. Free trade is estimated to increase welfare by 9-36% while free international production by 8-90%.

The model is used to study the effects of a free-trade agreement between the U.S. and ROW on offshoring. The model predicts that such a free-trade agreement will cause offshoring to increase significantly in percentage terms while remaining small in absolute terms. Welfare is predicted to increase in both countries.

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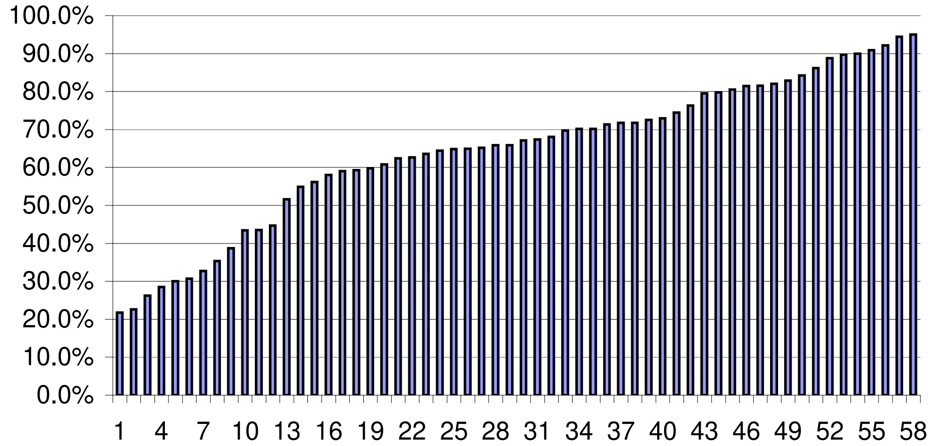
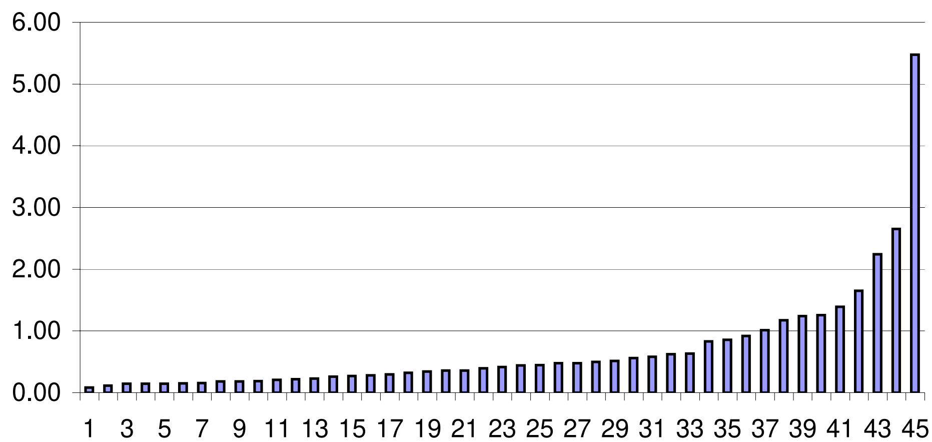
Figure D1 Local sales as a percentage of the total sales of the U.S. MOFAs, 1999



Data source: BEA

Figure D2 U.S. exports to a country as a fraction of the local sales of the U.S. MOFAs located there



Data source: BEA

Table D1 Country data

	units	Canada	Europe	Japan	US	ROW
Manuf. imports	Bil. USD	193	782	220	895	1,308
Manuf. exports	Bil. USD	194	885	424	651	1,243
Manuf. output	Bil. USD	366	3,511	2,300	3,466	4,421
Spending on manufactures[(1)]	Bil. USD	365	3,408	2,096	3,709	4,485
Total GDP	Bil. USD	738	6,774	4,676	9,839	8,938
Compensation per worker	USD	34,367	33,234	39,236	48,201	4,861

[(1)]Spending is calculated as output plus imports minus exports

Table D2 Trade (billions USD)

	Canada	Europe	Japan	US	ROW
Canada	172	15	8	140	29
Europe	9	2,626	52	105	617
Japan	4	30	1,876	52	133
U.S.	164	146	122	2,815	464
ROW	17	694	242	354	3,178

Note: importing countries are in rows while exporting countries are in columns.
Table entries show how much the importing country spends on goods from each of the exporting countries. Spending on domestic goods is shown on the diagonal.

Table D3 Trade (as a fraction of importer's spending)

	Canada	Europe	Japan	US	ROW
Canada	0.471	0.041	0.022	0.384	0.081
Europe	0.003	0.771	0.015	0.031	0.181
Japan	0.002	0.014	0.895	0.025	0.064
U.S.	0.044	0.039	0.033	0.759	0.125
ROW	0.004	0.155	0.054	0.079	0.708

Note: importing countries are in rows while exporting countries are in columns.
Table entries show how much the importing country spends on goods from each of the exporting countries as a fraction of its total spending. Spending on domestic goods is shown on the diagonal. By design, each row adds up to one.

Table D4 Trade (as a fraction of exporter's output)

	Canada	Europe	Japan	US	ROW
Canada	0.470	0.004	0.004	0.040	0.007
Europe	0.024	0.748	0.023	0.030	0.140
Japan	0.012	0.009	0.815	0.015	0.030
U.S.	0.447	0.042	0.053	0.812	0.105
ROW	0.047	0.198	0.105	0.102	0.719

Note: importing countries are in rows while exporting countries are in columns.
Table entries show how much the exporting country sends to each of the importing countries as a fraction of its total output. Revenue from domestic sales is shown on the diagonal. By design, each column adds up to one.

Table D5 Employment by location and ownership

	Canada	Europe	Japan	US	ROW
Canada	1,412	122	18	414	21
Europe	72	19,547	127	1,216	884
Japan	2	44	8,806	69	19
U.S.	167	946	355	13,643	533
ROW	192	3,694	1,501	2,451	113,549

Note: host countries are in rows while owner countries are in columns.

Table D6 Employment by location and ownership
(as a fraction of total employment in each country)

	Canada	Europe	Japan	US	ROW
Canada	0.711	0.062	0.009	0.208	0.011
Europe	0.003	0.895	0.006	0.056	0.040
Japan	0.000	0.005	0.985	0.008	0.002
U.S.	0.011	0.060	0.023	0.872	0.034
ROW	0.002	0.030	0.012	0.020	0.935

Note: host countries are in rows while owner countries are in columns.
By design, each row adds up to one.

Table D7 Employment by location and ownership
(as a fraction of total employment by each country's firms)

	Canada	Europe	Japan	US	ROW
Canada	0.765	0.005	0.002	0.023	0.000
Europe	0.039	0.803	0.012	0.068	0.008
Japan	0.001	0.002	0.815	0.004	0.000
U.S.	0.091	0.039	0.033	0.767	0.005
ROW	0.104	0.152	0.139	0.138	0.987

Note: host countries are in rows while owner countries are in columns.
By design, each column adds up to one.

Table B1 Mean blueprint productivities, $(\Lambda_b/\Lambda_{US})^{1/\theta}$

	Value
Canada	0.80
Europe	0.95
Japan	1.05
U.S.	1
ROW	0.65

Table B2 Mean implementation factors, $(\Psi_{ih})^{1/\theta}$

	Canada	Europe	Japan	U.S.	ROW
Canada	1	0.62	0.43	0.74	0.73
Europe	0.49	1	0.42	0.61	0.95
Japan	0.37	0.49	1	0.49	0.67
U.S.	0.64	0.69	0.54	1	0.96
ROW	0.31	0.42	0.32	0.37	1

Note: host countries are in rows, owner countries are in columns

Table B3 Production productivities of producers that draw mean productivities and mean implementation factors, $(\Psi_{ih}\Lambda_b/\Lambda_{US})^{1/\theta}$

	Canada	Europe	Japan	U.S.	ROW
Canada	0.80	0.58	0.44	0.74	0.47
Europe	0.39	0.95	0.44	0.61	0.62
Japan	0.30	0.46	1.05	0.49	0.43
U.S.	0.51	0.66	0.57	1.00	0.62
ROW	0.24	0.40	0.34	0.37	0.65

Note: host countries are in rows, owner countries are in columns

Table B4 Trade costs (d_{ni})

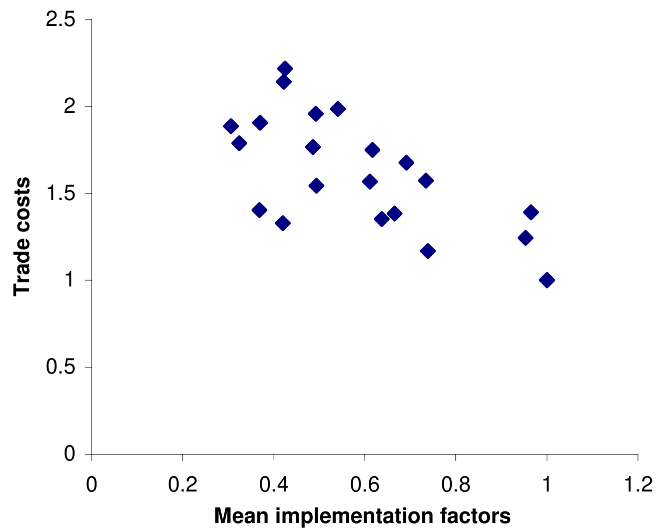
	Canada	Europe	Japan	U.S.	ROW
Canada	1	1.75	2.22	1.17	1.57
Europe	1.96	1	2.14	1.57	1.24
Japan	1.91	1.77	1	1.54	1.38
U.S.	1.35	1.68	1.99	1	1.39
ROW	1.89	1.33	1.79	1.40	1

Note: importer countries are in rows, exporter countries are in columns

Table B5 Calculated macroeconomic variables

	Canada	Europe	Japan	U.S.	ROW
Labor force, L_i, mil.	2.08	20.60	11.43	14.02	177.34
Capital stock, K_i, tril. USD	0.19	1.84	1.21	1.82	2.32
Share of manufacturing in country spending, φ_i	0.15	0.14	0.10	0.13	0.16

Figure B1 Trade costs vs. mean implementation factors



Note: the correlation is -0.58 and the slope is close to -1. The correlation becomes -0.77 if the country pairs involving ROW are excluded.

Table B6 Relative costs of production, c_h/c_i

	Canada	Europe	Japan	U.S.	ROW
Canada	1	0.92	0.89	1.03	0.64
Europe	1.09	1	0.97	1.12	0.70
Japan	1.12	1.03	1	1.15	0.72
U.S.	0.98	0.90	0.87	1	0.62
ROW	1.56	1.44	1.39	1.60	1

Note: host countries (*i*) are in rows, owner countries (*h*) are in columns

Table B7 Expected price from exporting relative to international production

	Canada	Europe	Japan	U.S.	ROW
Canada	1	0.99	0.84	0.89	0.74
Europe	1.05	1	0.88	1.07	0.82
Japan	0.79	0.89	1	0.88	0.66
U.S.	0.84	1.04	0.93	1	0.84
ROW	0.90	0.80	0.81	0.83	1

Note: host/importing countries are in rows, owner/exporting countries are in columns

Table B8 Expected price from domestic production relative to offshoring

	Canada	Europe	Japan	U.S.	ROW
Canada	1	0.29	0.20	0.56	0.25
Europe	0.31	1	0.23	0.41	0.50
Japan	0.19	0.23	1	0.29	0.27
U.S.	0.53	0.40	0.30	1	0.43
ROW	0.30	0.49	0.33	0.43	1

Note: offshore hosting countries are in rows, owner (home) countries are in columns

Figure B2 Local sales as a precentage of the total sales of the U.S. affiliates

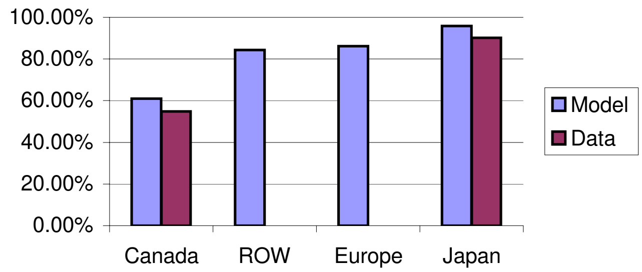


Table B9 Mean productivities inferred using the Eaton-Kortum model, $(T_h/T_{US})^{1/\theta}$

	Value
Canada	0.88
Europe	0.95
Japan	1.04
U.S.	1
ROW	0.65

Table S1 Welfare effects

	Autarky			Open world		
	No trade	No IP	Complete	Free trade	Free IP	Both
Canada	-4.03%	-2.09%	-7.14%	35.63%	22.94%	109.50%
Europe	-1.50%	-0.66%	-2.48%	12.85%	17.61%	45.18%
Japan	-0.51%	-0.05%	-0.62%	17.69%	8.93%	40.48%
U.S.	-1.05%	-0.55%	-1.73%	9.14%	7.98%	26.23%
ROW	-1.94%	-0.34%	-2.53%	9.89%	89.98%	118.11%

Table S2 Employment by location and ownership with free IP
(as a fraction of total employment in each country)

	Canada	Europe	Japan	US	ROW
Canada	0.08	0.22	0.38	0.30	0.02
Europe	0.08	0.22	0.38	0.30	0.02
Japan	0.08	0.22	0.38	0.30	0.02
U.S.	0.08	0.22	0.38	0.30	0.02
ROW	0.08	0.22	0.38	0.30	0.02

Note: host countries are in rows, owner countries are in columns.
By design, each row adds up to one.