Innovation and Production in the Global Economy

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One consequence of globalization, and in particular the rise of multinational production (MP), is that goods are increasingly being produced far from where ideas are created. International specialization in innovation and production is clearly evident in the aggregate data. Figure 1 shows that the most innovative OECD countries, as measured by R&D expenditures in manufacturing relative to local value-added, are home to multinationals whose foreign affiliate sales exceed the sales of foreign multinational affiliates in their country. With increasing globalization, this pattern has become more pronounced over time. Figure 2 shows that R&D expenditures relative to manufacturing value-added in the United States has grown from 8.7 percent in 1999 to 12.7 percent in 2009. Over the same period, U.S. firms have increased the share of their total global employment that is located in their foreign affiliates from 22 to 31 percent. This is thanks in large part to an increasing presence in China, which now accounts for one in eight employees of the foreign affiliates of U.S. firms.

Being a recent phenomenon, specialization in production or innovation raises a host of concerns. Countries that specialize in production worry that low innovation will dam-

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age their growth prospects, while countries that specialize in innovation worry that this specialization pattern will reduce the availability of good middle-income jobs. Viewed from the perspective of the standard two-sector trade theory, concerns about specialization in production may seem misguided, since specialization would reflect comparative advantage and bring about efficiency gains. But there are two reasons why it is legitimate to worry about specialization in production as opposed to innovation. First, the expansion of production could trigger a deterioration of a country's terms of trade. Second, innovation is an increasing-returns-to-scale activity, so that standard reasoning based on comparative advantage is insufficient. In particular, the combination of fixed costs of innovation and frictions to the movement of ideas across borders leads to home-market effects (HMEs) in innovation, and, as shown by Venables (1987), specialization induced by HMEs could lead to non-standard welfare effects.

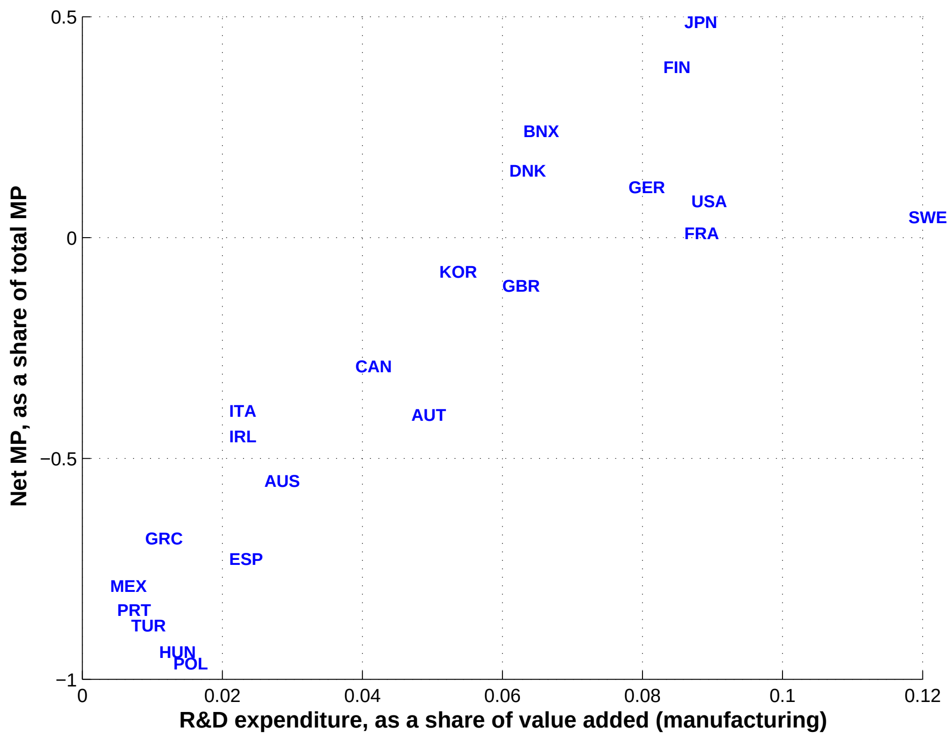
In this paper we develop a quantifiable, multi-country general-equilibrium model of trade and MP that captures these forces in a rich geographic setting. We use the model to quantify the welfare implications of shocks driving increased specialization in innovation and production, including a generalized reduction in the cost of transferring technologies across borders, the integration of China into the global economy, and the impact of selective integration or breakups between countries.

Following Melitz (2003), we model innovation as the creation of heterogeneous firms that sell differentiated goods in monopolistically competitive markets separated by fixed and variable trade costs. We depart from the Melitz model by assuming that firms can locate production outside of their home market and assume that firm productivity levels across locations are drawn from a multivariate distribution. Firms face a tradeoff in choosing where to produce for any particular market: they could locate production close to their customers to avoid trade costs or they could locate where production costs are lower. By allowing firms to produce outside of their home country, MP allows some countries to specialize in innovation and others to specialize in production, with profits flowing from producing to innovating countries to compensate for the cost of innovation.[1] Loosely speaking, innovative countries export ideas and import goods.

The model provides a natural framework to explore the implications of openness to trade and MP. We find that countries that specialize in innovation tend to realize larger gains from openness than implied by current models (e.g. Ramondo & Rodríguez-Clare

[1] In the absence of MP, the share of labor devoted to innovation would be the same in all countries. This is consistent with the version of the Melitz model presented in Arkolakis, Demidova, Klenow & Rodríguez-Clare (2008), where entry is endogenous, but not affected by trade costs. An equivalent result is derived by Eaton & Kortum (2001) in a setting with Bertrand competition.

Figure 1: R&D and Net Multinational Production.



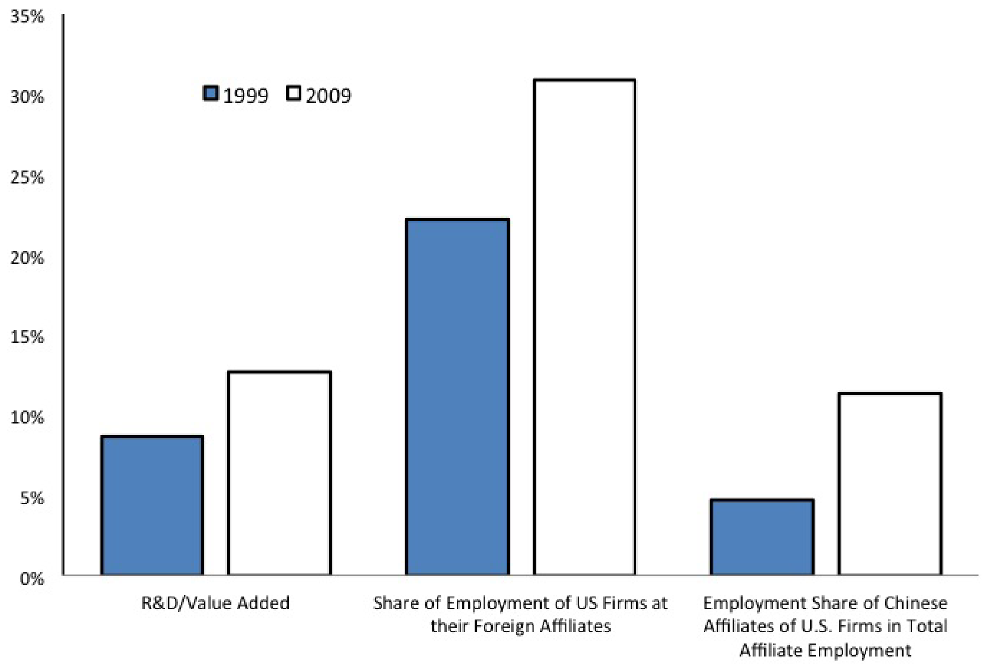
Notes: R&D expenditure in manufacturing, as a share of value-added, is from OECD STAN for 1999. Net MP is defined as outward affiliate sales - inward affiliate sales divided by their sum, an average over 1996-2001, from Ramondo, Rodríguez-Clare & Tintelnot (2015).

(2013)), while countries that are most at risk from adverse welfare effects are those that experience a contraction of innovation. In addition, by allowing for worker heterogeneity in their skills for innovation and production as in Roy (1951), openness to trade and MP not only alters the distribution of income in intuitive ways but can lead to a loss of welfare for some workers even as the country's aggregate real income increases. This result resonates with the popular fear that the real wage of production workers in innovative countries such as the United States may fall as multinational firms move production abroad.

The quantitative analysis starts by deriving and testing a novel implication of our model, namely that trade flows restricted to the parents and affiliates of firms from a given country are more sensitive to trade costs than overall trade flows. Using high-quality data from the Bureau of Economic Analysis (BEA) on the sales of U.S. firms and their foreign affiliates, we estimate restricted and standard gravity equations and find that the trade elasticities are consistent with this prediction. These two elasticities will also serve as key targets in our calibration.

The model is calibrated using trade, MP, and production data for 26 countries. We identify the full set of trade and MP frictions between countries and a vector of parame-

Figure 2: Manufacturing R&D and Employment of U.S. Multinational Firms.



Notes: R&D data are from OECD STAN and U.S. multinational firms data are Bureau of Economic Analysis. The employment share for U.S. affiliates abroad is defined as total employment of U.S. majority-owned manufacturing affiliates abroad, divided by total U.S. manufacturing employment, plus U.S. majority-owned manufacturing affiliates abroad, minus the employment of the affiliates of foreign-owned manufacturing affiliates operating in the United States.

ters that govern comparative advantage by fitting aggregate bilateral trade and MP data under the assumptions that all trade and MP frictions are symmetric between pairs of countries. Intuitively, specialization in innovation or production that cannot be explained by geography is due to comparative advantage.[2]

We use the calibrated model to perform several counterfactual exercises. First, we consider a five-percent reduction in all MP costs from their calibrated levels. This reduction results in greater specialization across countries in innovation and production and real incomes rise on average by about two percent. Only one of the countries that experience a decline in innovation suffers welfare losses, and they are very small. Contrary to popular fears, we find that production workers gain everywhere, and it is innovation workers who experience losses in countries that face a contraction in their innovation sector. Second, we explore the implications of the integration of China to the world economy. The result is that countries with good ties to China such as Japan and the United States follow

[2]In this paper we focus on MP as the vehicle through which international specialization takes place, but there are alternative arrangements, such as the licensing of technology and other contractual relationships such as outsourcing that do not involve ownership. Our model is consistent with these mechanisms, but because there is little data on arm's length offshoring we can only measure the offshoring done within multinational firms.

what we could refer to as the "Apple model": they specialize in innovation while China becomes their manufacturing hub. Countries that specialize further in innovation experience overall gains, and production workers share in those gains, although by much less than innovation workers. Finally, to explore the consequences of "Brexit", we consider an increase in trade and MP costs between the U.K. and the European Union, and to explore President Trump's suggestion of increasing taxes on firms that move part of their production abroad, we consider an increase in outward MP costs for U.S. firms.

The mechanisms at work in our model have antecedents in the classic work on trade and MP (see Markusen (2002)). This literature highlights four key ideas: (i) MP allows innovation (entry) to be geographically separated from production; (ii) countries differ in their relative costs of innovation and production, which leads to specialization in one of these two activities; (iii) the non-rivalry of technology within the firm allows multi-plant production; and (iv) trade costs encourage, while MP costs discourage, multi-plant production. The incorporation of these features into a general-equilibrium trade model dates back to Helpman (1984) and Markusen (1984).[3] By modeling firm-level productivity in different countries as coming from a multivariate distribution and by replacing plant-level fixed costs with marketing fixed costs, we gain the ability to construct a tractable, quantifiable, and multi-country general equilibrium model that incorporates the most important mechanisms found in this earlier work. Although adding plant-level fixed costs to our model is beyond the scope of this paper, in the robustness Section we argue that their presence should not substantially affect our qualitative results (i.e., cross country patterns) and we offer some thoughts on the implications they would have for the quantitative effects (i.e., cross-country averages).

Our paper is closely related to a recent literature on trade and MP. Ramondo & Rodríguez-Clare (2013) also have a probabilistic representation of multi-country productivity and a large number of countries, allowing for counterfactual analysis in a rich geographic setting. The key difference is that there is no innovation in their perfectly-competitive model. Our monopolistic-competition framework is also related to a recent paper by Irarrazabal, Moxnes & Opromolla (2013), which is the quantitative application of Helpman, Melitz & Yeaple (2004). They focus on understanding the frictions that rationalize the export versus MP decisions of Norwegian firms, but abstract from "export-platform MP"

[3] Examples of work that most closely resembles our own are Markusen & Venables (1998) and Markusen & Venables (2000) in which the authors analyze the interaction between comparative advantage in production and innovation, trade costs, and plant and corporate fixed costs in a two-country, Heckscher-Ohlin-like setting. Grossman & Helpman (1991) extend this framework to an endogenous growth setting in which the more efficient use of the world's resources made possible by MP may affect the long-run growth rate in rich and poor countries. Non-homothetic preferences together with home market effects determine specialization and foreign investment patterns in high-quality or low quality goods in Fajgelbaum, Grossman & Helpman (2015).

(any market can be served only from a local affiliate or by exports from the firm's home country) and fix firm innovation locations and country wages by assumption. With a probabilistic structure similar to ours, Tintelnot (2017) allows for export-platform MP in a general-equilibrium model, although again in this setting there is no innovation as firm entry is exogenous.

Our paper is also related to a literature that considers the movement of managerial or knowledge capital from one country to another, interpreted as MP, while trade takes place only as a way to transfer the returns to capital (see, for example, Burstein & Monge-Naranjo (2009), McGrattan & Prescott (2010), McGrattan (2012), and Ramondo (2014)).[4] The simplification on the trade dimension in these papers allows for a more detailed modeling of the effect of specific policies, such as taxes on profits of foreign owned firms, as well as the transition path as countries open up to MP. Because they do not allow for increasing returns and frictions to trade and MP, these papers have nothing to say about bilateral trade and MP flows or about the role of HMEs and their related welfare implications.

Finally, by distinguishing between innovation and production activities, we make contact with a body of theory that emphasizes the effect of offshoring on the set of activities done within a country and on real wages (e.g. Feenstra & Hanson (1999), Grossman & Rossi-Hansberg (2008) and Rodríguez-Clare (2010)). By considering the impact of China's integration into world markets, our paper also makes contact with an empirical literature that has documented the negative effect of Chinese manufacturing exports on the employment and wages of manufacturing workers in developed countries (e.g. Autor, Dorn & Hanson (2013)).

I The Model

We consider a world economy comprised of $i = 1, ..., N$ countries; one factor of production, labor; and a continuum of goods indexed by $\omega \in \Omega$. Preferences are Constant Elasticity of Substitution (CES) with elasticity of substitution $\sigma > 1$. The associated price index is given by

$$P_i = \left(\int_{\omega \in \Omega} p_i(\omega)^{1-\sigma} d\omega \right)^{\frac{1}{1-\sigma}}, \tag{1}$$

where $p_i(\omega)$ is the price of good ω in country i.

[4] Recent papers that present stylized models of innovation versus production are Eaton & Kortum (2007) and Rodríguez-Clare (2010). In principle, these models could be adapted for quantitative analysis but this task has not been undertaken so far.

Each good ω is potentially produced by a single firm under monopolistic competition. Firms can produce anywhere in the world with varying productivity levels as specified below. To the extent possible, we use index i to denote the firm's country of origin (the source of the *idea*), index l to denote the *location* of production, and index n to denote the country where the firm sells its product. Firms that export from l to country n incur a marketing fixed cost F_n in units of labor in the destination country, and an iceberg transportation cost $\tau_{ln} \geq 1$ with $\tau_{nn} = 1$. Firms originated in country i that produce in country l incur a productivity loss that we model as iceberg bilateral MP costs, $\gamma_{il} \geq 1$, with $\gamma_{ll} = 1$. These costs are meant to capture various impediments that multinationals face when operating in a different economic, legal or social environment, as well as the various costs of technology transfer incurred by multinationals in different production locations.

A firm from origin i can serve destination n by (i) producing in i and exporting to country n, by (ii) opening an affiliate in country $l \neq i, n$ and exporting from there to country n, or by (iii) opening an affiliate in n and selling the good locally. Firms use constant returns to scale technologies, with the marginal product of labor being firm and location specific. Formally, a firm is characterized by a productivity vector $\boldsymbol{z} = (z_1, z_2, ..., z_N)$, where z_l determines the firm's productivity if it decides to produce in country l. These productivity vectors are allowed to vary across firms, leading firms to make different choices regarding their production locations. Note that all heterogeneity across firms is associated with differences in the productivity vector $\boldsymbol{z}$, while the trade and MP costs, $\{\tau_{ln}\}$ and $\{\gamma_{il}\}$, as well as wages (introduced below), are common across firms.

We think of innovation as the process of creating differentiated goods, each one produced by a single-product firm, and assume that doing so requires f_i^e units of labor. If L_i^e units of labor are allocated to the innovation sector in country i, then the measure of goods created in that country is $M_i = L_i^e / f_i^e$. Although this entails only product innovation, it is easy to extend the model to allow for process innovation in such a way that none of the results that we focus on are affected. As we show in the Online Appendix, if entrants can augment the expected productivity of the firms they create by a proportion a at a cost that is a power function of a, then part of the total innovation investment will be devoted to good creation, and part to making firms more productive, with this breakdown of innovation into product and process innovation being invariant to trade and MP.[5]

[5]Our model ignores innovation performed by multinationals' foreign affiliates (see Fan (2017) for an extension of our model to R&D offshoring). This assumption seems reasonable given that most of the R&D is still done in the multinationals' home country. For example, according to BEA data for 2009, the parents of U.S. multinationals accounted for 85 percent of its total R&D expenditure but only 70 percent of its value-added. See also Bilir & Morales (2016), which concludes that the parent R&D is a substantially

There are $\bar{L}_i$ workers in country i. Workers are immobile across countries but mobile across different activities (i.e., innovation, production and marketing) within each country. We assume that workers are heterogeneous in their abilities across these activities. Each worker is characterized by a productivity vector $\boldsymbol{v} \equiv (v^e, v^p)$, where v^e represents the number of units of labor that the worker can supply to innovation and v^p represents the number of units of labor that the worker can supply to production or marketing. Workers can choose to work in innovation, where the wage per efficiency unit of labor is w_i^e, or production/marketing, where the wage per efficiency unit of labor is w_i^p. A worker with productivity vector $\boldsymbol{v}$ would work in the innovation sector if and only if $v^e w_i^e \geq v^p w_i^p$.

A Firm's Optimization

In this environment, firms face a simple optimization problem. First, for each market n, a firm finds the cheapest location from where to serve that market. Second, the firm decides what price to charge. Given our assumption on preferences, firms simply set prices equal to mark-up $\widetilde{\sigma} \equiv \sigma/(\sigma-1)$ over marginal cost. Letting $\xi_{iln} \equiv \gamma_{il} w_l^p \tau_{ln}$, the marginal cost of a firm from i producing in location l to serve market n is $C_{iln} \equiv \xi_{iln}/z_l$, and hence the price charged in market n by a firm from i is

$$p_{in} = \widetilde{\sigma} \min_l C_{iln}. \tag{2}$$

In Figure 3, we summarize how the price charged by a firm is determined by factors that are firm specific, i.e. the firm's productivity vector $\boldsymbol{z}$, and by factors that depend on the country of origin, location of production, and final sales. Third, the firm calculates the associated profits. If those profits are higher than the fixed marketing cost then the firm chooses to serve the market. Letting X_n be total expenditure in country n, the maximum unit cost under which variable profits in market n are enough to cover the fixed cost $w_n^p F_n$ is defined by

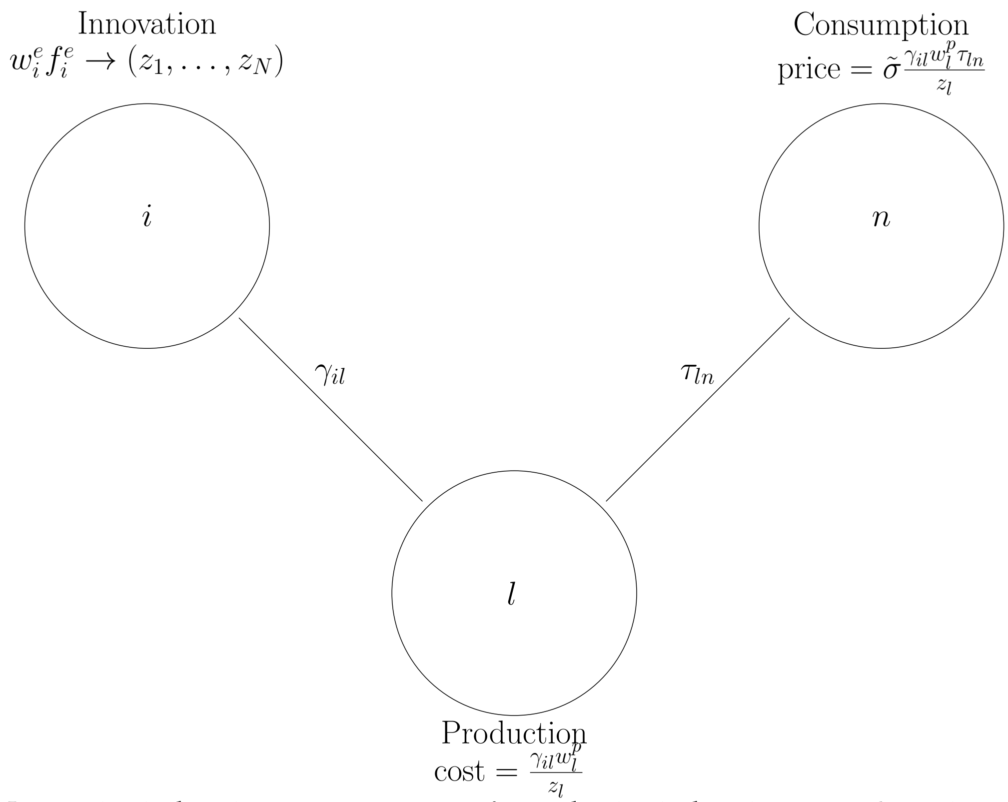
$$c_n^* \equiv \left(\frac{\sigma w_n^p F_n}{X_n}\right)^{1/(1-\sigma)} \frac{P_n}{\widetilde{\sigma}}. \tag{3}$$

B Aggregation

Although the problem for each firm is simple, our goal is to obtain analytic expressions for the aggregate variables that we can relate to the data while retaining key features of

more important determinant of firm performance than affiliate R&D.

Figure 3: Firm Costs and Pricing Behavior.



Notes: Innovation is done in country i at cost $w_i f_i^e$; production is done in country l at unit cost $\gamma_{il} w_l / z_l$; and consumption is done in country n at price $\widetilde{\sigma} \times \gamma_{il} w_l \tau_{ln} / z_l$.

previous theories of international trade. To do so, we consider a multivariate extension of the univariate Pareto distribution used in the Chaney (2008) version of Melitz (2003).

We assume that the productivity vector of firms in country i is randomly drawn from the multivariate distribution given by

$$\Pr(Z_1 \leq z_1, ..., Z_N \leq z_N) = G_i(z_1, ..., z_N) = 1 - \left(\sum_{l=1}^{N} \left[T_{il} z_l^{-\theta} \right]^{\frac{1}{1-\rho}} \right)^{1-\rho}, \tag{4}$$

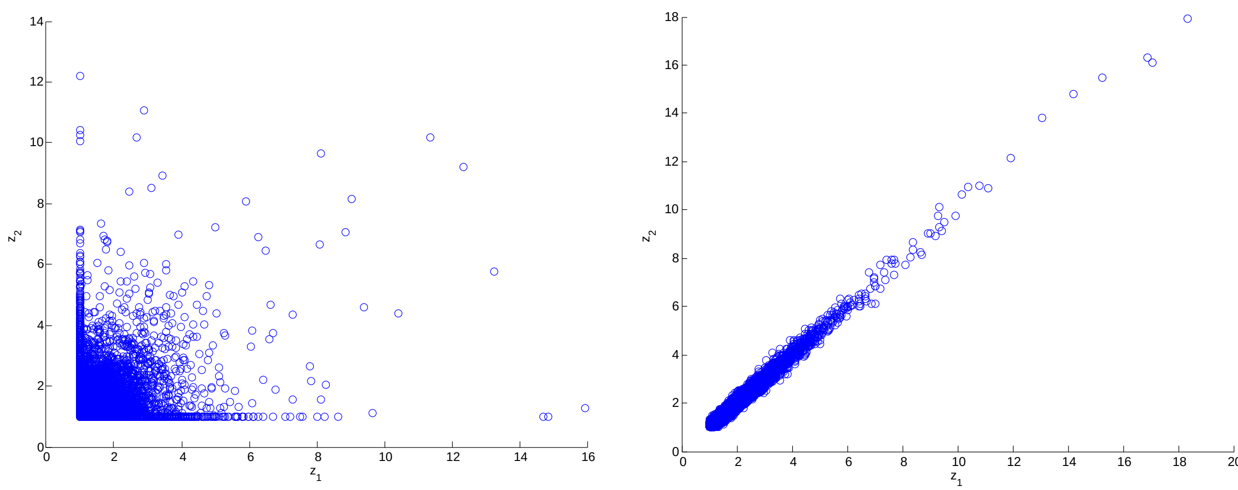
with support $z_l \geq \widetilde{T}_i^{1/\theta}$ for all l, where $\widetilde{T}_i \equiv \left[\sum_l T_{il}^{1/(1-\rho)} \right]^{1-\rho}$, $\rho \in [0, 1)$, and $\theta > \max(1, \sigma - 1)$.[6] Several comments are in order regarding the properties of this distribution. First, the

[6]This distribution can be seen as a reformulation of an Archimedean copula of Pareto distributions. Specifically, the Archimedean copula 4.2.2 in Nielsen (2006) leads to the same function for the distribution as (4) in the two-dimensional case if z_1 and z_2 are each distributed Pareto, except that the support would be implicitly defined by $(T_1 z_1^{-\theta})^{\frac{1}{1-\rho}} + (T_2 z_2^{-\theta})^{\frac{1}{1-\rho}} \leq 1$. This distribution cannot be directly extended to $N \geq 3$ because the copula is not strict (see Nielsen (2006)). Instead, we modify the support of the distribution to make it an N-box defined by $z_l \geq \widetilde{T}_i^{1/\theta}$ for all l. For a proof that (4) satisfies the requirements to be a distribution function as well as a detailed discussion of its properties see Arkolakis, Rodríguez-Clare & Su (2017).

marginal distributions have Pareto tails – that is, for $z_l \geq a > \widetilde{T}_i^{1/\theta}$ we have $\Pr(Z_l \geq z_l \mid Z_l \geq a) = (z_l/a)^{-\theta}$. Second, $\max(Z_1, ..., Z_N)$ is distributed Pareto with shape parameter θ and scale parameter $\widetilde{T}_i^{1/\theta}$, while the joint probability that $\arg\max_j Z_j = l$ and $Z_l \geq z$ for $z > \widetilde{T}_i^{1/\theta}$ is given by $\left(T_{il}/\tilde{T}_i\right)^{1/(1-\rho)} \tilde{T}_i z^{-\theta}$. Third, if $\rho \to 1$ the elements of $(Z_1, Z_2, ..., Z_N)$ are pairwise perfectly correlated. Finally, the case with $\rho = 0$ is equivalent to simply having the production location l chosen randomly with probabilities $T_{il}/\widetilde{T}_i$ among all possible locations $l = 1, ..., N$, and the productivity Z_l drawn from the Pareto distribution $1 - \widetilde{T}_i z_l^{-\theta}$ with $z_l \geq \widetilde{T}_i^{1/\theta}$. Figure 4 illustrates how the distribution depends on the value of ρ.

Figure 4: Multivariate Pareto: Simulated Draws.

(a) $\rho = 0.1$ (b) $\rho = 0.9$



Notes: Simulation for 100,000 draws, $N = 2$, $\theta = 4$, and $T_1 = T_2$.

For the reminder of the paper, we make the following assumption.

Assumption 1. $T_{il} = T_i^e T_l^p$.

This assumption is without loss of generality because variation in MP flows across country pairs can be equivalently generated by T_{il} or by γ_{il} – we simply choose to load all of this on γ_{il}. The assumption implies that $\widetilde{T}_i = \left(\sum_l (T_l^p)^{1/(1-\rho)}\right)^{1/(1-\rho)} T_i^e$, so that we can think of T_i^e as a measure of the quality of ideas in country i, or *productivity in innovation*. In turn, T_l^p determines country l's *productivity in production*.[7] We will continue to write T_{il}

[7]This setup easily allows for splitting countries without affecting the equilibrium. For example, we could split country l into two countries, l_1 and l_2, with $T_{l_j}^e = T_l^e$ and $\left(T_{l_j}^p\right)^{1/(1-\rho)} / \bar{L}_{l_j} = (T_l^p)^{1/(1-\rho)} / \bar{L}_l$ for $j = 1, 2$. One can show that if there are no costs to trade and MP between l_1 and l_2 then the equilibrium is not affected by the split (the proof is available upon request).

rather than $T_i^e T_l^p$ for notational convenience. Since T_i^e and f_i^e will have equivalent effects on all relevant equilibrium variables, we henceforth assume that $f_i^e = f^e$ for all i.

To guarantee that for all pairs $\{i, n\}$ there are firms from i that will decide not to serve market n, we assume that the parameters of the model (e.g., marketing costs) are such that the level of c_n^* is low enough. Formally, we make the following assumption, which we maintain throughout the rest of the paper:

Assumption 2. *$\xi_{iln} > \widetilde{T}_i^{1/\theta} c_n^*$, for all i, l, n.*

The multivariate Pareto distribution together with this assumption allows us to characterize several important objects in the model, starting from the probability that a firm serves a particular market from a certain production location at a unit cost below some c, and the probability that firms from i serving market n decide to do so from production location l.

Lemma 1. The (unconditional) probability that a firm from i will serve market n from l at cost lower than c, for $c \leq c_n^*$, is

$$\Pr\left(\arg\min_k C_{ikn} = l \ \cap \min_k C_{ikn} \leq c\right) = \psi_{iln} \Psi_{in} c^{\theta}, \tag{5}$$

where

$$\Psi_{in} \equiv \left[\sum_k \left(T_{ik} \xi_{ikn}^{-\theta}\right)^{\frac{1}{1-\rho}}\right]^{1-\rho} \text{ and } \psi_{iln} \equiv \left(T_{il} \xi_{iln}^{-\theta} / \Psi_{in}\right)^{\frac{1}{1-\rho}},$$

while the (conditional) probability that firms from i serving market n will choose location l for production is

$$\Pr\left(\arg\min_k C_{ikn} = l \ \mid \min_k C_{ikn} \leq c_n^*\right) = \psi_{iln}. \tag{6}$$

Proof: See Appendix A.

We use this Lemma to analyze the model's implications for aggregate trade and MP flows. Let M_i denote the measure of firms in country i, M_{iln} denote the measure of firms from i that serve market n from location l, and X_{iln} denote the total value of the associated sales. Using the pricing rule in (2) and the cut-off rule in (3), we can compute X_{iln} by using (5) to obtain

$$X_{iln} = \psi_{iln} \lambda_{in}^E X_n, \tag{7}$$

where

$$\lambda_{in}^E \equiv \frac{\sum_l X_{iln}}{X_n} = \frac{M_i \Psi_{in}}{\sum_k M_k \Psi_{kn}} \tag{8}$$

is the share of total expenditure in country n devoted to goods produced by firms from i (irrespective of where they are produced). The measure of firms behind these sales is

$$M_{iln} = \frac{\theta - \sigma + 1}{\sigma\theta} \frac{X_{iln}}{w_n^p F_n}. \tag{9}$$

Aggregate flows X_{iln} can be used to construct trade and MP shares. In particular, trade shares are given by expenditure shares across production locations, $\lambda_{ln}^T \equiv \sum_i X_{iln} / \sum_{i,k} X_{ikn}$, while MP shares are given by production shares across firms from different origins, $\lambda_{il}^M \equiv \sum_n X_{iln} / \sum_{j,n} X_{jln}$. Letting $Y_l \equiv \sum_{i,n} X_{iln}$ denote the value of all goods produced in country l, recalling that $X_n \equiv \sum_{i,l} X_{iln}$ is total expenditure by consumers in country n, and using expression (7), trade and MP shares can be written more succinctly as

$$\lambda_{ln}^T \equiv \sum_i \frac{X_{iln}}{X_n} = \sum_i \psi_{iln} \lambda_{in}^E, \tag{10}$$

and

$$\lambda_{il}^M \equiv \sum_n \frac{X_{iln}}{Y_l} = \frac{\sum_n \psi_{iln} \lambda_{in}^E X_n}{Y_l}. \tag{11}$$

Let Π_{iln} denote aggregate profits associated with sales X_{iln}, net of fixed marketing costs, but gross of entry costs. Given CES preferences, variable profits associated with X_{iln} are X_{iln}/σ. The total fixed marketing costs paid by these firms are $w_n^p F_n M_{iln}$. Using these two expressions and (9), we obtain

$$\Pi_{iln} = \eta X_{iln}, \tag{12}$$

where $\eta \equiv 1/(\theta\tilde{\sigma})$. Therefore, total profits made in country l are a constant share of the value of production in country l, i.e. $\sum_{i,n} \Pi_{iln} = \eta Y_l$.

We now turn to the aggregation across heterogeneous workers' choices regarding their labor supply. We assume that each worker's endowment of units of labor in innovation and production/marketing, v^e and v^p, are obtained as transformations of an independently and identically distributed random variable drawn from a Fréchet distribution, similar to Lagakos & Waugh (2013) and Hsieh, Hurst, Jones & Klenow (2013). More specifically, $v^e = u^e/\Gamma(1 - 1/\kappa)$ and $v^p = u^p/\Gamma(1 - 1/\kappa)$, with u^e and u^p both drawn independently from the distribution $\exp\left[-u^{-\kappa}\right]$, where $\kappa > 1$ and where $\Gamma(.)$ is the Gamma function.[8] From the properties of the Fréchet distribution, this implies that the supply of

[8] We divide by $\Gamma(1 - 1/\kappa)$ so that when we take the limit when $\kappa \to 1$ the aggregates defined below do not blow up to infinity.

labor units to innovation and production/marketing activities in country i are given by

$$L_i^e = \bar{L}_i \left[1 + \left(\frac{w_i^e}{w_i^p} \right)^{-\kappa} \right]^{1/\kappa - 1}, \tag{13}$$

and

$$L_i^p = \bar{L}_i \left[1 + \left(\frac{w_i^e}{w_i^p} \right)^{\kappa} \right]^{1/\kappa - 1}, \tag{14}$$

respectively. For future purposes, note that L_i^e and L_i^p depend on the ratio w_i^e/w_i^p. The parameter κ captures the extent to which workers differ in their relative productivities in the two activities. The case of perfect mobility—or, homogeneous workers—obtains in the limit as $\kappa \to \infty$, while the case of no mobility across sectors obtains in the limit as $\kappa \to 1$, as discussed further below.

The following remark is important for the interpretation of our quantitative exercises. Changes in w_i^e and w_i^p are fully reflected in the income levels for workers that stay in their sectors. For instance, if w_i^e/w_i^p increases, workers in the innovation sector will all stay and they will gain according to the change in w_i^e/P_i, while the workers in the production sector that decide to stay in their sector will gain (or lose) according to the change in w_i^p/P_i. The workers that switch from the production to the innovation sector will gain more —-in particular the marginal worker will gain according to changes in w^e/P_i. In our quantitative exercises, we implicitly focus on the workers that do not switch sectors, which implies that we focus on the workers with the worst outcome.[9]

C Equilibrium

We start by considering the labor market clearing conditions in production/marketing and then in innovation. Labor demand (in value) for production and marketing in country l is $Y_l/\widetilde{\sigma}$ and $(1 - \eta - 1/\widetilde{\sigma})\, X_l$, respectively. Using $Y_l = \sum_n \lambda_{ln}^T X_n$, we can then write the labor market clearing condition for workers in production/marketing in country i as

$$\frac{1}{\widetilde{\sigma}} \sum_n \lambda_{ln}^T X_n + \left(1 - \eta - \frac{1}{\widetilde{\sigma}} \right) X_l = w_l^p L_l^p. \tag{15}$$

To write the labor market clearing condition in innovation, note that profits net of marketing costs but gross of entry costs in country i are $\sum_{l,n} \Pi_{iln}$. Since the cost of entry is

[9] Note that we do not want to use the actual average income of workers in a sector to compute welfare of workers originally in one sector or another, because the group of workers changes, making the comparison meaningless.

simply given by labor hired for innovation, the zero-profit condition implies that we can think of $\sum_{l,n} \Pi_{iln}$ as labor demand (in value) for innovation. Using (8) and (12) we can then write the labor-market clearing condition for workers in innovation in country i as

$$\eta \sum_{n} \lambda_{in}^{E} X_n = w_i^e L_i^e. \tag{16}$$

We allow for aggregate trade and MP imbalances via *exogenous* international transfers Δ_i as in Dekle, Eaton & Kortum (2008), with $\sum_i \Delta_i = 0$.[10] Together with zero profits, the budget balance condition is

$$w_i^p L_i^p + w_i^e L_i^e + \Delta_i = X_i. \tag{17}$$

Using (13) , (14) and (17) to substitute for L_i^e, L_i^P, and X_i in terms of wages, (15) and (16) constitute a system of $2N$ equations that can be used to solve for the equilibrium wages $\boldsymbol{w}^p$, $\boldsymbol{w}^e$ (up to a constant determined by the numeraire).

It is worth noting that marketing fixed costs, F_n, do not enter the equilibrium equations (assuming that they are high enough that Assumption 2 holds). The reason is that they affect all origins equally and hence do not affect labor demand for production or innovation across countries. Of course, although these fixed costs do not affect relative wages, they do affect variety and welfare in each country.

Equation (17) is one of the basic National Income and Product Accounts (NIPA) identities, namely that (in the absence of current-account imbalances, as we are assuming here) income equals expenditure adjusted by trade and MP imbalances. The other NIPA identity is that income equals output – this is obtained by adding up (15) and (16), which yields

$$w_l^p L_i^p + w_i^e L_i^e = \frac{1}{\tilde{\tilde{\sigma}}} Y_i + \left(1 - \eta - \frac{1}{\tilde{\tilde{\sigma}}}\right) X_i + \eta \sum_{n} \lambda_{in}^{E} X_n. \tag{18}$$

The first term on the right-hand-side is the value of domestic production net of the associated variable profits, the second term is the value of marketing services, and the last term denotes profits gross of entry cost – the sum of these three terms is national output. Note also that from (15), (16) and (17), and using (12), we see that

$$\Delta_i = X_i - Y_i + \left(1 - \eta - \frac{1}{\tilde{\tilde{\sigma}}}\right)(Y_i - X_i) + \sum_{j,n} \Pi_{jin} - \sum_{l,n} \Pi_{iln}. \tag{19}$$

[10] We use the expression "aggregate trade and MP imbalances" rather than current account imbalances for two reasons. First, because international transfers are included in the current account and hence would not lead to current account imbalances in equilibrium. Second, and more importantly, because in the quantitative analysis below we do *not* use data on current account imbalances to measure Δ_i and instead do so by using the calibrated model combined with net trade and MP flows.

This says that the aggregate trade and MP deficit (Δ_i) equals the goods trade deficit plus the deficit in marketing services plus net profit outflows.

A key concept in the rest of the paper is the share of income earned in the innovation sector (henceforth simply denoted as the *innovation share*) $r_i \equiv w_i^e L_i^e / \left(w_i^p L_i^p + w_i^e L_i^e\right)$, which is also equal to $r_i = \sum_{l,n} \Pi_{iln}/(X_i - \Delta_i)$. Rearranging (15) and using (17) we get

$$r_i\left(1 - \frac{\Delta_i}{X_i}\right) - \eta = \frac{1}{\widetilde{\sigma}}\left(\frac{X_i - Y_i}{X_i}\right) - \frac{\Delta_i}{X_i}. \tag{20}$$

Therefore, the innovation share is directly related to the trade deficit, $X_i - Y_i$ and the aggregate trade and MP deficit. With no deficits (i.e., $\Delta_i = 0$) this collapses to the simple expression

$$r_i - \eta = \frac{1}{\widetilde{\sigma}}\left(\frac{X_i - Y_i}{X_i}\right). \tag{21}$$

In the two extreme cases of infinite MP costs or infinite trade costs, we must have $X_i = Y_i$ and, thus $r_i = \eta$. The first case is discussed in more detail below.

For future reference, note also that, from (13) , (14), we must have

$$\frac{w_i^e}{w_i^p} = \left(\frac{r_i}{1 - r_i}\right)^{\frac{1}{\kappa}}. \tag{22}$$

This is intuitive: a higher innovation share requires a higher wage in innovation relative to production/marketing to induce the necessary reallocation of workers.[11] Moreover, plugging this relative wage into (13) yields $L_i^e = r_i^{1-1/\kappa}\bar{L}_i$ and hence

$$M_i = r_i^{1-1/\kappa}\bar{L}_i / f^e, \tag{23}$$

so that the measure of firms created is an increasing function of the innovation share.

D Special Cases

In this Subsection, we explore a number of special cases of the model that we can characterize analytically. These cases illustrate how, in the presence of MP, comparative advantage and home market effects (HME) determine whether countries specialize in innovation or production. They also shed light on the basic forces behind the results of our quantitative analysis in Section III. For the rest of this Section, we assume no international

[11] In the case of homogeneous workers (i.e., $\kappa \to \infty$), an interior equilibrium (i.e., with $r_i \in (0, 1)$) requires wage equalization between innovation and production/marketing, $w_i^e = w_i$.

transfers, i.e., $\Delta_i = 0$ for all i.

D.1 Infinite MP costs - a world without MP

It is instructive to consider the case in which MP costs are infinite, i.e., $\gamma_{il} \to \infty$ for all $i \neq l$. This restriction implies that expenditure shares are equal to trade shares, $\lambda^E_{in} = \lambda^T_{in}$, and that

$$\lambda^T_{in} = \frac{M_i T_{ii} \left(w^p_i \tau_{in}\right)^{-\theta}}{\sum_k M_k T_{kk} \left(w^p_k \tau_{kn}\right)^{-\theta}}, \tag{24}$$

which is the same expression as in the Chaney (2008) version of the Melitz model. The equilibrium conditions further imply that $r_i = \eta$ for all i, that relative wages are given by $\frac{w^e_i}{w^p_i} = \left(\frac{\eta}{1-\eta}\right)^{\frac{1}{\kappa}}$, that the total amount of labor supplied to innovation is $L^e_i = \bar{L}_i \eta^{1-1/\kappa}$, and that

$$M_i = \widetilde{M}_i \equiv \eta^{1-1/\kappa} \bar{L}_i / f^e.$$

This implies that innovation is proportional to country size. Note that if $\kappa \to \infty$ then $L^e_i = \eta \bar{L}_i$, so that a share η of (homogenous) workers are employed in innovation – this is the same expression as the one derived by Arkolakis et al. (2008) in a Melitz model with endogenous entry.[12]

D.2 A frictionless world - the role of comparative advantage

We now discuss the role of comparative advantage in leading to specialization in innovation or production. To make the analysis tractable, we focus on the case with homogenous workers (i.e., $\kappa \to \infty$) in a frictionless world (i.e., $\tau_{ln} = 1$ and $\gamma_{il} = 1$, for all i, l, n). Let $A_i \equiv \left(T^p_i\right)^{1/(1-\rho)} / \bar{L}_i$ be an index for a country's productivity in production and $\delta_i \equiv \bar{L}_i T^e_i / \sum_k \bar{L}_k T^e_k$ be a measure of relative country size. The equilibrium conditions for this case lead to the following result:

Proposition 1. Consider a frictionless world with homogenous workers (i.e., $\kappa \to \infty$). Assume that, for all i,

$$1 - (1-\eta)\,\widetilde{\sigma} < \frac{A_i / \left(T^e_i\right)^{\theta/(1-\rho)+1}}{\sum_k \delta_k A_k / \left(T^e_k\right)^{\theta/(1-\rho)+1}} < 1 + \eta \widetilde{\sigma}, \tag{25}$$

so that no country is completely specialized in innovation or production. The share of

[12] An equivalent result is derived by Eaton & Kortum (2001) in a setting with Bertrand competition.

labor devoted to innovation in country i is

$$r_i = \frac{L_i^e}{\bar{L}_i} = \frac{1}{\tilde{\tilde{\sigma}}} \left(1 - \frac{A_i / \left(T_i^e\right)^{\theta/(1-\rho)+1}}{\sum_k \delta_k A_k / \left(T_k^e\right)^{\theta/(1-\rho)+1}} \right) + \eta. \tag{26}$$

Proof: See Online Appendix.

The proposition states that countries with a relatively high ratio of productivity in innovation to production (i.e., countries that have a comparative advantage in innovation) will (partially) specialize in innovation, as reflected in $r_i > \eta$.

D.3 A two-country world - the role of home market effects

Our model exhibits HMEs, according to which the location of innovation and production across countries is affected by country size, as well as trade and MP costs. To illustrate these effects we consider a world with two countries, homogenous workers (i.e., $\kappa \to \infty$) and frictionless trade (i.e., $\tau_{ln} = 1$ for all l, n).

Proposition 2. Consider a two-country world, homogenous workers (i.e., $\kappa \to \infty$) and frictionless trade. Assume further that $A_1 = A_2$ and $T_1^e = T_2^e$. If either (i) $\bar{L}_1 > \bar{L}_2$ and $\gamma_{12} = \gamma_{21} = \gamma > 1$ or (ii) $\bar{L}_1 = \bar{L}_2$ and $\gamma_{12} < \gamma_{21}$ then in an interior equilibrium $r_1 > r_2$.

Proof: See Online Appendix.

The proposition shows the existence of a home market effect (HME) in innovation. Since MP costs are positive but trade is frictionless, it makes sense to innovate in the country with the larger labor force or with the higher inward MP costs.[13]

E Welfare Implications

We now turn to the model's implications for how trade and MP affect welfare in each country. We are interested both in a country's overall welfare, as measured by aggregate real income, as well as real wages of workers in innovation and production.

[13]In a previous version of this paper we also studied the case in which MP is frictionless but trade is costly, showing the existence of an "anti-HME" according to which the country that is larger or has a higher inward trade cost tends to specialize in production rather than innovation – see the Online Appendix. We labeled this effect a anti-HME because it runs counter to the logic of the HME, whereby the larger country specializes in the activity with increasing returns, which here is innovation. We have chosen not to highlight the anti-HME here because it turns out to be much weaker than the HME. For example, our numerical simulations show that in the presence of both trade and MP costs, the large country tends to specialize in innovation. In particular, the large country specializes in innovation whenever $\tau = \gamma > 1$ and only specializes in production if γ is much smaller than τ.

E.1 Gains from Openness

We start by considering the overall gains from openness, defined as the change in aggregate real income as we move from a counterfactual equilibrium with no trade and no MP to the observed equilibrium. As shown in the Online Appendix, the gains from openness as a function of equilibrium trade and MP flows (and the implied innovation share r) are

$$GO_n = \underbrace{\left[\left(\frac{X_{nnn}}{X_n}\right)^{-\frac{1-\rho}{\theta}}\left(\frac{\sum_l X_{nln}}{X_n}\right)^{-\frac{\rho}{\theta}}\right]}_{\text{Direct Effect}}\underbrace{\left[\left(\frac{1-\eta}{1-r_n}\right)^{\frac{1}{\kappa}\left(\frac{\sigma}{\sigma-1}-\frac{1}{\theta}\right)}\left(\frac{r_n}{\eta}\right)^{\frac{\kappa-1}{\kappa\theta}}\right]}_{\text{Indirect Effect}}. \tag{27}$$

With no MP, this equation collapses to $GO_n = \left(\lambda_{nn}^T\right)^{-1/\theta}$, as in Arkolakis, Costinot & Rodríguez-Clare (2012). With MP, the gains from openness are composed of a direct and an indirect effect, which we discuss in turn.

To understand the direct effect, consider first the simple case with $\rho = 0$, under which the direct effect collapses to $(X_{nnn}/X_n)^{-1/\theta}$. The term X_{nnn}/X_n is an inverse measure of the degree of openness to trade and MP of country n. As one would expect, this measure implies more openness than the typical measure of trade openness, since $X_{nnn}/X_n < \lambda_{nn}^T = \sum_i X_{inn}/X_n$. Turning to the case with $\rho > 0$, note that

$$\left(\frac{X_{nnn}}{X_n}\right)^{-\frac{1-\rho}{\theta}}\left(\frac{\sum_l X_{nln}}{X_n}\right)^{-\frac{\rho}{\theta}} = \left(\frac{\sum_l X_{nln}}{\sum_{i,l} X_{iln}}\right)^{-\frac{1}{\theta}}\left(\frac{X_{nnn}}{\sum_l X_{nln}}\right)^{-\frac{1-\rho}{\theta}}. \tag{28}$$

The first term on the right-hand-side captures the gains for country n from being able to consume goods produced with foreign technologies (independently of where production takes place), while the second term captures the gains for country n from being able to use its own technologies abroad and import the goods back for domestic consumption. Given the equilibrium flows X_{iln}, $\rho > 0$ leads to lower gains than $\rho = 0$ since correlated productivity draws imply that the gains associated with the second term are not as important.

The indirect effect captures the gains or losses triggered by the net flow of profits due to MP. Countries with net outward MP flows have a net inward flow of profits and $r_n > \eta$—see (20), implying a positive indirect effect; the opposite occurs in countries with net inward MP flows. The indirect effect has two components. The term $\left(\frac{1-\eta}{1-r_n}\right)^{\frac{1}{\kappa}\left(\frac{\sigma}{\sigma-1}-\frac{1}{\theta}\right)}$ captures how a net inflow of profits from MP implies a higher total income and a lower price index thanks to the effect of higher expenditures on the variety of goods available for domestic consumption.[14] The term $(r_n/\eta)^{\frac{\kappa-1}{\kappa\theta}}$ captures how a net inflow of profits is associated with higher entry (i.e., higher M_n), which increases welfare by inducing a better selection of varieties in the domestic market.

It is useful to compare our result for gains from openness with those in the perfectly competitive setting of Ramondo & Rodríguez-Clare (2013), where the gains from openness are equal to the direct effect in (27).[15] Thus, given trade and MP flows, the difference between the two models is captured entirely by the indirect effect. Our monopolistic competition setup then implies larger gains from openness than the perfect competition model of Ramondo & Rodríguez-Clare (2013) for countries with a net outflow of MP, while the opposite is true for countries with a net inflow of MP.

E.2 Gains from Trade and Gains from MP

In addition to the gains from openness, we are also interested in the separate welfare effects of trade and MP. The *gains from trade*, GT, are defined as the ratio of real income (X_i/P_i) between the calibrated equilibrium and a counterfactual equilibrium where there is no trade, computed by letting $\tau_{ln} \to \infty$ for $l \neq n$. Analogously, the *gains from MP*, GMP, are defined as the ratio of real income between the calibrated equilibrium and a counterfactual equilibrium with no MP, computed by letting $\gamma_{il} \to \infty$ for $i \neq l$. In the counterfactual analysis with the calibrated model in Section III we find that some countries (e.g., Turkey) lose from MP, $GMP < 1$, while some countries (e.g., Brazil and China) lose from trade, $GT < 1$. We now use simple cases of our model to shed light on these possibilities.

To understand how a country could lose from MP, it is useful to start by discussing a simpler result, namely that a country can lose from *unilateral* MP liberalization (i.e., a decline in inward MP costs). Consider a perfectly symmetric two-country world with fric-

[14] Everything else equal, a higher income X_n implies lower productivity cutoffs for domestic sales and a lower price index P_n. More specifically, note that the elasticity of GO_n w.r.t. $\left(\frac{1-\eta}{1-r_n}\right)$ in (27) can be written as $\frac{1}{\kappa}\left[1+\frac{1}{\theta}\left(\frac{\theta}{(\sigma-1)}-1\right)\right]$. The 1 inside the square parenthesis comes from the direct effect of a higher income on welfare, whereas the term $\frac{1}{\theta}\left(\frac{\theta}{\sigma-1}-1\right)$ captures selection effects according to which P_n falls with an increase in X_n/w_nF_n with an elasticity $\frac{1}{\theta}\left(\frac{\theta}{\sigma-1}-1\right)$, as can be seen from (A.6) in the Appendix (for more on this "selection" elasticity, see Costinot & Rodríguez-Clare (2014)). The term $1/\kappa$ outside the square parenthesis comes from the relationship between $1-r_n$ and X_n/w_nF_n – see (O.12) in the Online Appendix.

[15] Ramondo & Rodríguez-Clare (2013) did not derive this result explicitly, but it can be easily obtained from the equilibrium equations of their model in the special case with only tradable goods and no intermediate goods. The parameters θ and ρ in Ramondo & Rodríguez-Clare (2013) play analogous roles as in our model, except that in their case those parameters are associated with a multivariate Fréchet distribution rather than a multivariate Pareto distribution.

tionless trade and homogeneous labor. As per Proposition 2, unilateral MP liberalization leads to a decline in innovation, and – as shown in the Online Appendix – this leads to a decline in welfare in the liberalizing country. This resonates with the well-known result of Venables (1987) that unilateral liberalization can decrease welfare in a Krugman (1980) model with a homogeneous-good sector, but the mechanisms are different. The welfare effect in Venables (1987) is caused by the de-location of firms away from the liberalizing country and the resulting increase of its differentiated-goods price index. In contrast, in our model the price index falls in the liberalizing country, but its welfare declines because of a deterioration in its terms of trade caused by the expansion of employment in the production sector.

Can a country lose from *multilateral* MP liberalization? Resorting to numerical examples in the simple case of two countries we find that this is indeed possible.[16] The logic is the same as the one outlined above: if MP liberalization triggers home market effects that push innovation in country i below its no-MP level, i.e. $r_i < \eta$, the deterioration of country $i's$ terms of trade may dominate the direct MP gains from the use of foreign ideas, implying losses from MP, $GMP_i < 1$.

To understand how a country could lose from trade, we turn again to the simple two-country numerical example discussed above, and study the consequences of multilateral trade liberalization in a setting where everything is symmetric except for MP costs. Assume that inward MP costs are lower than outward MP costs for country 2 ($\gamma_{12} < \gamma_{21}$), so that (from Proposition 2) country 1 specializes in innovation and country 2 specializes in production ($r_1 > \eta > r_2$). Compared to trade autarky, the equilibrium with finite and symmetric trade costs entails a lower real wage in country 2. Interestingly, the relative wage of country 2 increases as we open up trade, but prices increase even more. Reminiscent of Venables (1987), the de-location of innovation from country 2 to country 1 leads to an increase in the price index in country 2 as it must now incur in MP costs for more of the ideas used domestically.

The previous discussion may suggest the possibility that a country loses from openness, $GO_i < 1$. While we cannot rule out this possibility for all parameter values, we prove in the Online Appendix that for the important case of $\kappa \to \infty$ the gains from openness in the multi-country setting must be positive for all countries. Moreover, for other parameter values, our numerical simulations for two countries never lead to such a result: even if openness leads to a decline in innovation below its autarky value, i.e. $r_i < \eta$, the direct gains from openness always outweigh the indirect losses through a decline in

[16] For the numerical example we set θ, σ and ρ as calibrated in Section B, together with $\kappa \to \infty$, $\tau_{12} = \tau_{21} = 3$ and $\gamma_{12} = 3$ and $\gamma_{21} = 4$.

innovation. The key insight is that trade and MP are substitutes in the sense that, if one of these channels is present, adding the other channel leads to small additional direct gains (see Ramondo & Rodríguez-Clare (2013)) which may not be enough to compensate for the losses arising from the fall in innovation.

E.3 Multinational Production and Real Wages in Production and Innovation

As mentioned in the Introduction, there is popular concern that globalization of production may have a detrimental effect on production workers in rich countries. We use our model to explore this possibility by looking at the effect of MP on the real wage of production workers in a country that has a comparative advantage in innovation. To make the analysis tractable, we focus on the comparative statics of moving from a situation with frictionless trade but no MP to a situation with both frictionless trade and frictionless MP. The proposition below establishes that there are indeed conditions under which production workers would be hurt by such a move.

The proposition considers a special case in which productivity in production is the same across countries, $A_i \equiv \left(T_i^p\right)^{1/(1-\rho)}/\bar{L}_i = A$ for all i, so a "rich" country here is one with a relatively high T_i^e and hence a comparative advantage in innovation. We also assume that $\rho \to 1$, so that the gains from MP arising from differences in firm productivity across countries are not present in this case, making it more likely that MP will hurt production workers. Finally, and most importantly, we assume that $\kappa \to 1$, so that production workers are stuck in production.

Proposition 3. Consider a world with no worker mobility across sectors (i.e., $\kappa \to 1$), and $\rho \to 1$. Consider a switch from frictionless trade but no MP to frictionless trade and MP. (i) Suppose that $A_i = A$ for all i, $T_j^e = T^e$ for all $j \neq i$ and $T_i^e = T^e + \varepsilon$ for ε small enough. In country i, the switch increases the real wage for innovation workers and aggregate real income, but it increases real production wages if and only if $\sigma < \bar{\theta} \equiv \frac{(1+\theta)^2}{1+\theta+\theta^2}$. (ii) Suppose that $A_i = 0 < A_j$ for all $i \neq j$ and $T_i^e = T^e$ for all i. The switch increases aggregate real income, but it decreases the real wage for innovation workers in country j.

Proof: See Online Appendix.

Consider the first part of the proposition. By giving firms the ability to locate production in low-production wage countries, MP exerts downward pressure on production wages in rich countries. The same forces lead to an increase in innovation wages and total income, and this increases the variety of goods available for consumption and decreases the price index. If the elasticity of substitution is low enough, this increase in variety will have a large downward effect on the price index, which more than compensates for the decrease in nominal wages, allowing real production wages to increase.

Now consider the second part of the Proposition. MP liberalization that leads the innovation labor from a country to lose its monopoly power over an abundant supply of production workers can have dramatic implications for innovation labor's real wage. Intuitively, innovation labor is not differentiated by country and thus moving from no MP to free MP causes innovation worker's wages to equalize across countries while having less dramatic effects on the cost of less substitutable production worker labor. The fall in the relative wage of innovation worker relative to production workers in the production worker abundant country must swamp the efficiency gains associated with production reallocation is guaranteed by the parameter restriction because of the required parameter restriction that $\theta > \sigma - 1$.

As we will see below, even with the low value of $\kappa = 2$, our calibrated model implies that production workers actually gain from MP liberalization in countries that further specialize in innovation. Instead, the losers are the innovation workers in some of the countries that deepen their specialization in production as a consequence of MP liberalization. Not surprisingly, low worker mobility is a key assumption for the result above. As we show in the Online Appendix, with perfect worker mobility (i.e., $\kappa \to \infty$), and assuming that condition (25) holds so that the equilibrium in a frictionless world is an interior equilibrium, then a move from frictionless trade but no MP to frictionless trade and frictionless MP increases the common real wage paid to workers employed in the innovation and production sectors.

II Model's Calibration

The model's calibration proceeds in two parts. In the first part we estimate two different specifications of the gravity equation to obtain trade elasticities that are used as targets to calibrate θ and ρ. In the second part we estimate trade and MP costs, as well as the parameters related to productivity in production and innovation, T_i^P and T_i^e. For trade and MP costs, for which we assume they are symmetric, we target the bilateral trade and MP shares in the data and implement a generalized version of the Head & Ries (2001) procedure. For the productivity parameters, we calibrate T_i^e by targeting a model-based measure of innovation and T_i^p by targeting a measure of gross production in manufacturing, for each country.

A Gravity Estimates

We use data on production, trade, and multinational sales to estimate two different gravity equations – the estimated trade elasticities will serve as targets for calibration. The first gravity equation is defined over X_{iln}, the aggregate sales of firms that originate in country i, produce in country l, and sell in country n. Because this gravity equation is defined over trade flows conducted by firms that originate from a single origin, we refer to this equation as "restricted gravity." The second gravity equation is defined over $X_{ln} \equiv \sum_i X_{iln}$, the sales to n from *all* firms operating in country l (as in the standard analysis). Because this gravity equation is defined over trade flows by firms from all countries, we refer to this equation as "unrestricted gravity."

Details about the construction of the data and sources are in Appendix B.

A.1 Restricted Gravity

To estimate the restricted gravity equation, we use expression (7) and take logarithms to obtain

$$\ln X_{iln} = \alpha^r_{il} + \mu^r_{in} - \frac{\theta}{1-\rho} \ln \tau_{ln}, \tag{29}$$

where α^r_{il} and μ^r_{in} are fixed effects.[17] We rely on a measure of trade costs that is directly related to a critical component of τ_{ln}: the different tariffs applied to goods across production locations. Specifically, we parameterize trade costs so that

$$\ln X_{iln} = \alpha^r_{il} + \mu^r_{in} + \beta^r \ln(1+t_{ln}) + \sum_k \delta^r_k [1|d_{ln} \in d_k] + \Theta^r H_{ln} + \varepsilon_{iln}, \tag{30}$$

where t_{ln} is the simple average tariff applied by n on goods from l, $[1|d_{ln} \in d_k]$ is an indicator variable for distance between n and l—whose marginal effect on trade costs is given by δ^r_k—, and H_{ln} is a vector of standard gravity controls, including distance dummies, dummies for shared language and border, and an indicator variable that is equal to one if $l = n$ to control for the variation in τ_{ln} that is due to unmeasured trade costs, such as administrative and information frictions, that local production avoids. The estimated coefficient $\hat{\beta}^r$ has the structural interpretation of the parameter ratio $\theta/(1-\rho)$ under the assumption that our measure of t_{ln} captures some of the variation in trade costs between countries.

[17] Given i, the fixed effect captured by α^r_{il} varies by location of production and corresponds (in the model) to $\alpha^r_{il} = \ln\left(M_i \left[T^e_i T^p_l (w^p_l \gamma_{il})^{-\theta}\right]^{\frac{1}{1-\rho}}\right)$, while the fixed effect captured by μ^r_{in} varies by country of destination and corresponds (in the model) to $\mu^r_{in} = \ln\left(X_n \Psi_{in}^{\frac{-\rho}{1-\rho}} / \sum_k M_k \Psi_{kn}\right)$.

The data for X_{iln} with $l \neq U.S. = i$ was constructed from the 1999 Benchmark Survey of the Bureau of Economic Analysis (BEA) on the operations of U.S. multinationals abroad. Specifically, for each country $l \neq U.S.$ we observe sales of U.S. multinationals in their host country and their exports to the United States, Canada, Japan, the United Kingdom, and a composite of fourteen European Union countries. The data for X_{iln} with $l = U.S. = i$ was constructed using a mixture of publicly available data and a confidential survey conducted by the BEA on the activities of the U.S. affiliates of foreign firms.

In our sample on the global operations of U.S. multinationals, there are two forms of variation in t_{ln} that identify β^r. The first type of variation is due to the fact that firms that open a local affiliate avoid all trade costs (i.e. $t_{nn} = 0$), while firms from another country generally must pay the applied MFN tariff rate. A second source of variation in t_{ln} is due to the fact that some l and n belong to common preferential trade agreements (so that $t_{ln} = 0$), while others do not (so that exports from l pay country n's MFN tariff rates).[18] Because in our data there are multiple observations for each production location l and for each destination country n, we can estimate (30) via ordinary least squares (OLS), as well as Poisson pseudo-maximum-likelihood estimation (PPML).

A.2 Unrestricted Gravity

The "unrestricted" gravity equation has the same form as the "restricted" gravity equation, but it is estimated on the bilateral sales of *all* firms located in country l selling to country n. Specifically, we estimate

$$\ln X_{ln} = \alpha_l^u + \mu_n^u + \beta^u \ln(1 + t_{ln}) + \sum_k \delta_k^u [1 | d_{ln} \in d_k] + \Theta^u H_{ln} + v_{iln}. \tag{31}$$

We estimate (31) by OLS and PPML using data for manufacturing on trade volumes from Feenstra, Romalis & Schott (2002), and total expenditure from various sources, for 1999. To ensure comparability between the coefficients, we restrict the sample so that the country pair coverage in the restricted and unrestricted samples is the same.

The coefficient estimate $\hat{\beta}^u$ does not have a structural interpretation, but it still provides information on the relative magnitudes of θ and ρ. When MP is not possible, all exports are done by local firms so that the correlation of the firm productivity shocks determined by ρ is irrelevant, and the coefficient on tariffs is equal to θ, as can be seen in (24). In the data most exports are done by domestic firms so that X_{ln} disproportionately

[18]There is also some variation in constructed tariff measures due to the fact that developed countries extend Generalized System of Preference tariffs to a number of developing countries.

contains information on the operations of domestic firms. This fact suggests that $\hat{\beta}^u$ is closer to θ than $\hat{\beta}^r$, which in turn is equal to $\theta/(1-\rho)$. In summary, the model implies the following restriction on parameters: $\hat{\beta}^r = -\theta/(1-\rho) < \hat{\beta}^u < -\theta < 0$.

A.3 Results

The coefficient estimates $\hat{\beta}^r$ and $\hat{\beta}^u$ are reported in the first and second rows of Table 1, respectively – the estimates for the other coefficients all have the expected signs and are reported in the Online Appendix. The first two columns report the results using OLS and differ only in the way that bilateral tariffs t_{ln} are computed. The raw data is for tariffs at the industry level, and we need to aggregate up to a single tariff without using endogenous country-level trade shares as weights. In the first column the tariff is computed as a simple average of the applied tariff across industries, while in the second column we use common weights given by the value of global trade in the industry divided by the value of total global trade.[19] Finally, the third and fourth columns report results using PPML. Using PPML avoids possible bias in OLS estimates because of heteroscedasticity, as explained by Silva & Tenreyro (2006), and also allows us to use the dependent variable in levels, and hence, to include zero flows.

Consistent with the model, the four specifications yield a more negative trade elasticity for the restricted regression relative to the unrestricted regression. A Wald test of the cross equation restriction that the trade elasticity is the same for the restricted and unrestricted gravity equations reveals that the difference is statistically significant at standard levels for both of the OLS regressions but not for the PPML regressions. Based on the results in Table 1, we set targets of $\hat{\beta}^r = 10$ and $\hat{\beta}^u = 5$ in the calibration below. This estimate for the unrestricted trade elasticity is in the range of estimates obtained by the trade literature (such as Romalis (2007), Simonovska & Waugh (2013), and Caliendo & Parro (2015)). Additionally, Head & Mayer (2014) survey estimates of trade elasticities and concluded that their "preferred estimate is -5.03, the median coefficient obtained using tariff variation, ...".

A.4 Robustness using instrumental variables

One concern that arises when tariffs are used to estimate trade elasticities is that tariffs are endogenous. The exporter and importer fixed effects included in our baseline grav-

[19]The tariff data is from the World Integrated Trade Solution (WITS) data provided by the World Bank and calculated at the H.S. six-digit level for the year closest to 1999 for which data were available.

Table 1: Restricted and Unrestricted Gravity.

	OLS		PPML	
Tariffs:	unweighted avg	weighted avg	unweighted avg	weighted avg
Restricted	-10.9	-11.1	-8.4	-11.6
	(3.5)	(3.5)	(2.6)	(4.0)
Unrestricted	-4.3	-5.3	-5.4	-8.6
	(1.8)	(1.9)	(1.7)	(2.6)

Notes: Unweighted avg refers to a simple average across industry tariffs; weighted avg refers to an average across industry tariffs using as weights the share of the industry in total trade. The number of observations is 317 in the OLS specification and 384 in the PPML specification. Robust standard errors in parenthesis.

ity equations ease this concern with respect to the absolute tariff level, but the concern remains that the propensity for firms to export from country l to country n is correlated with the likelihood that l and n enter into a free trade agreement. Some trade agreements (e.g. US-Israel, US-Colombia) are driven by political rather than commercial concerns, while others (e.g. US-Canada) are driven by the volumes of trade between the involved countries that are in turn driven by geography. The gravity controls in (30) proxy for this affinity. If, however, other determinants of preferential trade agreements are excluded from (30), the trade elasticity may be biased. Given the importance of these trade elasticities for our calibration, we consider an alternative instrumental-variable estimation.

Following Brainard (1997) and Helpman et al. (2004), we measure trade barriers as the product of tariffs and freight and insurance costs (c.i.f./f.o.b), and consider as our dependent variable the Head-Ries measure of unrestricted and restricted bilateral trade and MP flows between the United States and those of its trade partners for which we have the necessary freight-cost data.[20] To address the endogeneity concern, we instrument trade costs with the logarithm of distance, dummies for a border with the United States and for English as a main language, and an index of infrastructure quality. A bivariate OLS regression produces trade elasticities of -11.8 and -6.9 for the restricted and unrestricted gravity equations. In the instrumental-variable regression, we obtain trade elasticities that are moderately higher at -14.4 and -9.7, respectively. These estimates are not statistically different in magnitude from those obtain in our baseline specifications.

[20]We choose to use these indices, rather than the trade flows (in logs) directly, because the data on bilateral freight costs are available only for the United States, impeding the inclusion of two sets of country fixed effects in the gravity equations.

B Calibration Procedure

We restrict our analysis to 26 countries for which we have good data for both trade, output and MP. For trade we use the World Input-Output Database (WIOD) on manufacturing trade flows from any country l to country n, including home sales, as the empirical counterpart of bilateral trade in the model.[21] Using this information, we construct the $N \times N$ matrix of trade shares, λ_{ln}^{T}, and the $N \times 1$ vector of aggregate (manufacturing) expenditures, X_n.

We use data from Ramondo et al. (2015) on the gross value of production for multinational affiliates from country i in country l to construct the empirical counterpart of bilateral MP flows and obtain an $N \times N$ matrix of production shares, λ_{il}^{M}. Since our quantitative analysis is restricted to the manufacturing sector, while our MP data includes all MP flows, we rely on the following approximation. We observe that, for the United States, MP flows in manufacturing account for approximately one half of overall MP flows, while manufacturing gross output is approximately one half of overall GDP (according to our own calculations using BEA data, an average over 1996-2001). Thus, we take overall MP flows divided by GDP as an approximation of manufacturing MP flows as a share of gross production in manufacturing.[22]

We measure the $N \times 1$ vector of labor endowments, $\bar{L}_i$, as equipped labor, from Klenow & Rodríguez-Clare (2005), multiplied by the share of employment in the manufacturing sector, from UNIDO. This is also the variable we refer to as country size. All the data refer to an average over 1996-2001.

Table 2 summarizes the calibrated parameters and each of the targeted moments in the data. We set $\theta/(1-\rho) = 10$ to match the restricted gravity elasticities shown in Table 1. To disentangle ρ from θ, we use the predictions of the model regarding the unrestricted gravity regression coefficient. As described below, this leads to $\theta = 4.5$ and $\rho = 0.55$. We set $\sigma = 4$, a common value in the literature that implies a markup of 33 percent, which is on the high end of the range of estimates for markups in manufacturing across the OECD – see Martins, Scarpetta & Pilat (1996) and Domowitz, Hubbard & Petersen (1988) The calibrated values for θ and σ imply that $\eta = 16.7$, which under no MP is also the innovation share. As discussed further below, this is not far above an estimate of the

[21] See Timmer (2012) and Costinot & Rodríguez-Clare (2014) for the description of the WIOD database.

[22] Is this a plausible approximation for the remaining countries in our sample? We can check it for a sub-sample of 14 countries in our sample using data assembled by Alviarez (2015) containing the share of manufacturing (inward) MP for the period 2003-2011, and data for gross output in manufacturing as a share of GDP for the years 1995, 2000 and 2005 from the OECD Inter-Country Input-Output Tables. The average ratio of these two shares is 0.94, with a standard deviation of 0.16. We thank Vanessa Alviarez for kindly sharing her calculations with us.

Table 2: Calibrated Model Parameters and Data Targets.

Parameters Notation	Value	Description	**Moments** Description
σ	4	elasticity of substitution	mark-up (OECD)
κ	2	Fréchet shape parameter	literature
$\theta/(1-\rho)$	10	restricted trade elasticity	restricted gravity equation
θ	4.5	MVP shape parameter	unrestricted gravity equation (U.S.)
ρ	0.55	MVP correlation parameter	implied from restr. gravity and θ
η	0.167	profit share	implied from θ and σ
T_i^P	0.38 (0.44)	avg productivity in production in i	gross mfg. production in i
T_i^e	1.77 (1.13)	avg productivity in innovation in i	innovation rate in i
$\hat{\tau}_{ln}^{hr}$	2.9 (0.8)	trade cost from l to n	trade share from l to n
$\hat{\gamma}_{il}^{hr}$	4.4 (3.5)	MP cost from i to l	MP share from i to l

Notes: Trade elasticity refers to the elasticity of exports of firms from i located in l and selling to n to trade costs from l to n. Parameter values for T_i^P and T_i^e refer to averages across N countries, relative to values for the United States. Parameter values for τ_{ln} and γ_{il} refer to averages across the $N \times (N-1)$ country pairs. Standard deviations are in parenthesis.

returns to intangible capital as a share of GDP in the U.S.

We also need a value for κ, which determines the elasticity of labor supply to innovation vs production with respect to the relative wage w^e/w^p. We have some guidance from recent quantitative work for the value of this parameter in related contexts. In a model where κ determines the wage elasticity of labor supply for workers across occupations, Hsieh et al. (2013) estimate a value of 2, while Burstein, Morales & Vogel (2016) estimate a lower value of 1.8. Using data from the United States and a model where κ determines the wage elasticity of labor supply across manufacturing sub-sectors, Galle, Rodríguez-Clare & Yi (2015) also find a value of 2. We thus set $\kappa = 2$ in our baseline calibration, and experiment with an alternative high value of 5 in Section A.

The calibration of the rest of the parameters proceeds in three steps. The first step computes the matrices of τ's and γ's by using the trade and MP shares from the data. Our procedure is an extension of the approach in Head & Ries (2001) to a setting with MP. Head & Ries (2001) show that in a gravity model of trade, if one assumes that trade costs are symmetric, $\tau_{nl} = \tau_{ln}$, and there are no domestic trade costs (i.e., $\tau_{nn} = 1$ for all n) then trade costs can be obtained as $\hat{\tau}_{ln}^{hr} = \left[(\lambda_{ln}^T \lambda_{nl}^T)/(\lambda_{ll}^T \lambda_{nn}^T)\right]^{-1/2\theta}$. For $\rho = 0$ the Head-Ries method can be used in our model to estimate trade and MP costs, but for $\rho > 0$ this is no longer the case. However, as we show in Appendix C, given data on bilateral trade and MP flows, our model determines all trilateral flows, X_{iln}. Imposing symmetry on trade and MP costs as well as $\tau_{ll} = \gamma_{ll} = 1$ for all l, and given values for ρ and θ, we can then use these trilateral flows to construct estimates of τ_{ln} and γ_{il}.[23]

The second step of the calibration procedure involves calibrating the productivity parameters T_l^p and T_i^e. We normalize $T_i^e = T_i^p = 1$ for $i = USA$ and then pick T_i^e and T_i^p so that the model-implied values for innovation shares r_i and observed gross manufacturing output levels Y_i (both relative to the U.S.) exactly match the corresponding values computed using (20) and our data on trade, MP, and aggregate expenditures (all for manufacturing). Table 3 shows the calibrated values for T_i^p and T_i^e.[24]

The third and final step of the algorithm requires estimating an unrestricted gravity regression in which the dependent variable is the model-generated trade share from l to n and the regressors are the calibrated trade costs from l to n, as well as exporter and importer fixed effects. For $\theta = 4.5$ and $\rho = 0.55$, which satisfy our target of $\theta/(1-\rho) = 10$, this regression yields an unrestricted trade elasticity of 5.7 (s.e. 0.15), just slightly above the targeted 5 in the data.

C Calibration Results

C.1 Fit of Calibrated Model

We next assess the fit of the calibrated model. Figure 5 plots inward and outward trade and MP flows, respectively, at the country level. Trade flows are normalized by absorption in manufacturing in country n, both in the model and the data, while MP flows are normalized by gross output in the model and GDP in country n in the data. Note that aggregate shares were not directly targeted by our calibration procedure. The figure reveals that the model delivers slightly higher MP outward shares and export shares than the ones observed the data.[25]

[23] One source of asymmetry in trade costs that we are ignoring here, and that we used for the estimation of trade elasticities in Section A, is tariffs. We can extend our generalized Head-Ries procedure to allow for tariffs and calculate the symmetric part of trade costs as a residual. The results are virtually unchanged relative to those in our baseline, a result that is not surprising given the very low bilateral tariffs prevailing between the countries in our sample.

[24] The identification strategy we use is in some aspects related to the one in Burstein & Monge-Naranjo (2009). Our distinction between T_i^p and T_i^e is related to their notion of country-embedded productivity that affects any firm producing in country l, and firm-embedded productivity that affects all firms from country i, respectively. One difference stems from the fact that, whereas in Burstein & Monge-Naranjo (2009) there are only one-way MP flows, in our case we have two-way MP flows. Thus, instead of using something like $\sum_{i \in R} \lambda_{il}^M$, with R being the set of rich countries, we use net MP flows as one of the key moments for calibrating T^e and T^p. Additionally, while Burstein & Monge-Naranjo (2009) use data on taxation of foreign profits to disentangle MP costs from T_i^e, we impose symmetry and compute $\gamma' s$ using the generalized Head-Ries procedure.

[25] On average, outward MP shares are 0.23 in the model, and 0.19 in the data, while inward shares are, respectively, 0.35 and 0.30. For export and import shares, the model delivers averages of 0.26 and 0.26,

Figure 6 plots bilateral trade and MP shares, model vs data. These variables in the data are an input into the model's calibration, but given the symmetry assumption on trade and MP costs, it is not the case that the model exactly matches all the elements of the bilateral flow matrices; in other word, ours is an "over-identified" procedure, with more targeted moments ($2 \times N \times (N-1)$) than parameters ($2 \times N \times (N-1)/2$) to estimate. The figure reveals that the calibrated model overall does a good job in matching the bilateral data: The model captures more than 90 percent of the variation observed in the data in bilateral trade and MP shares, respectively. Overall, the average bilateral MP share in the data is 0.012 against 0.014 in the model, while the average for bilateral trade share in the data is 0.013 against 0.010 in the model.[26]

C.2 Innovation, Comparative Advantage and HMEs.

We next discuss the role of comparative advantage and HMEs in explaining the cross-country variation in innovation shares. Our assumption that trade and MP costs are symmetric becomes critical here – without such an assumption, we could not identify T_i^e relative to $A_i \equiv (T_i^p)^{1/(1-\rho)} / \bar{L}_i$.

The difference between r_i in column 3 in Table 3 and $\eta = 0.167$ tells us the specialization pattern for each country according to our baseline calibration: countries with $r_i > \eta$ are specialized in innovation (such as the United States, Denmark, and Benelux), and countries with $r_i < \eta$ are specialized in production (such as China, Ireland, and Mexico).

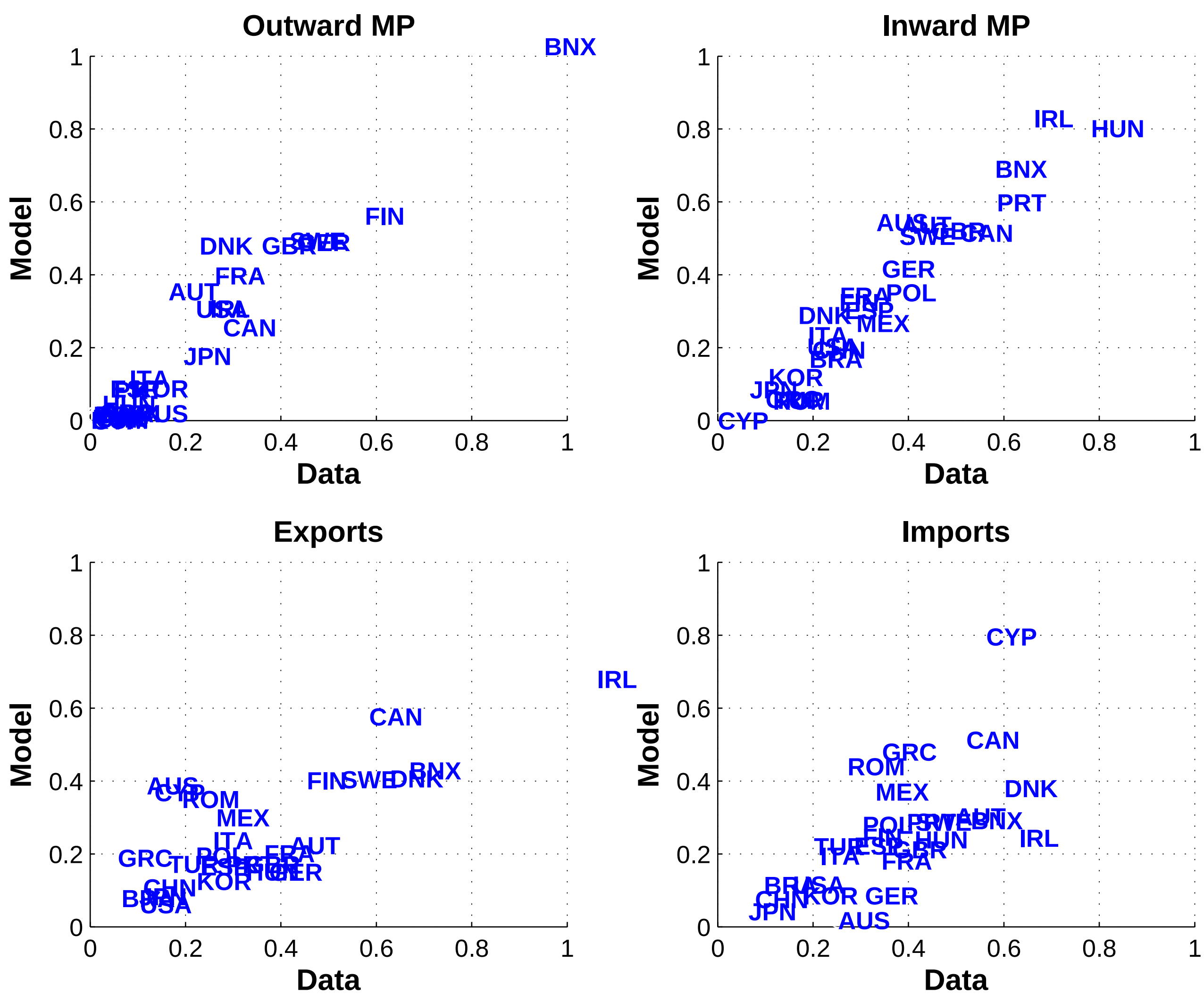
To isolate the role of HME, vis-a-vis the role of comparative advantage, we use the calibrated model and shut down comparative advantage by setting $T_i^e = 1$ and $T_i^p = \bar{L}_i^{1-\rho}$ for all i. Column 4 in Table 3 shows the resulting innovation share, r_i, and compares it with the one from our baseline calibration in column 3, in both cases shutting down trade and MP deficits by setting $\Delta_i = 0$ for all i. The difference between r_i in column 4 and η isolates the effects of HMEs on innovation in country i, with the difference between r_i in columns 3 and 4 revealing the effects of comparative advantage.

In general, HMEs push small countries such as Hungary and Ireland towards specialization in production, while they push large countries such as the United States to spe-

respectively, while the data delivers average of around 0.32 and 0.33, respectively.

[26] We should note that we do not evaluate the quantitative predictions of our model with respect to income distribution across and within countries as the necessary data are not available for the large number of countries in our dataset. A methodology for computing model-consistent measures of wages by occupation can be found in Burstein et al. (2016), who document a rise in the relative wages of occupations that are likely associated with innovation and firm entry.

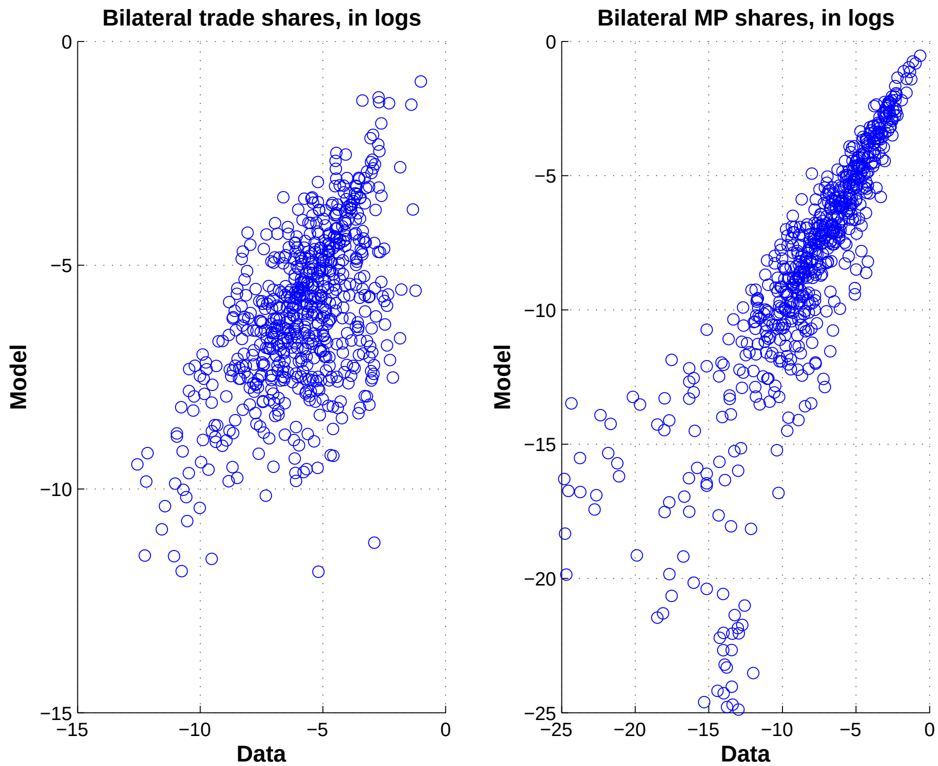
Figure 5: Aggregate Trade and MP Shares: Model vs Data.



Notes: Imports and exports for country n are normalized by manufacturing absorption in country n. Outward (inward) MP shares refer to total sales of foreign affiliates from (into) country n normalized by gross production in country n in the model (GDP in country n in the data).

cialize in innovation. But the neighborhood also matters and HMEs still lead to specialization in innovation in some small countries (e.g., Benelux). Of course, small countries with adverse HMEs may nevertheless be specialized in innovation thanks to comparative advantage (i.e., a relatively high T_i^e/A_i) – we can see that this is the case for Denmark and Finland by comparing columns 3 and 4. On the contrary, and quite surprisingly, the United States is revealed to have a comparative advantage in production – if it had a comparative advantage in innovation r should be higher in column 3 than in 4; it is the strong HME that pushes the United States towards specialization in innovation, resulting in r in column 3 higher than η.

Figure 6: Bilateral Trade and MP Shares: Model vs Data.



Notes: Imports and exports from country l to n are normalized by manufacturing absorption in country n. MP flows from i to l are normalized by gross production in country n in the model (GDP in country n in the data).

It is important to note that our symmetry assumption on trade and MP costs is only necessary to disentangle the role of comparative advantage and HMEs in driving countries to specialize in innovation or production – this assumption is not necessary for counterfactual analysis. In fact, in a previous version of this paper (see Arkolakis, Ramondo, Rodríguez-Clare & Yeaple (2013)) we developed a version of the "just-identified" calibration procedure as in Dekle et al. (2008) that does not rely on the symmetry assumption. This alternative calibration procedure does not identify the productivity parameters T^e and T^p, but its counterfactual implications are similar to those we get from our symmetry-based calibration.[27]

[27]For instance, the correlation between the gains from openness obtained under each procedure is 0.92, with gains of 24.6 and 25.8 percent, respectively, for the average country in the over- and just-identified procedure. Additionally, for the counterfactual exercise in Table 7 for which we fully liberalize MP from the United States to China, the just-identified calibration implies that U.S. production workers would gain one percent, rather than two percent as in our current calibration, and U.S. innovation workers would gain12 percent, rather than16 percent.

Table 3: Comparative Advantage vs Home-Market Effects

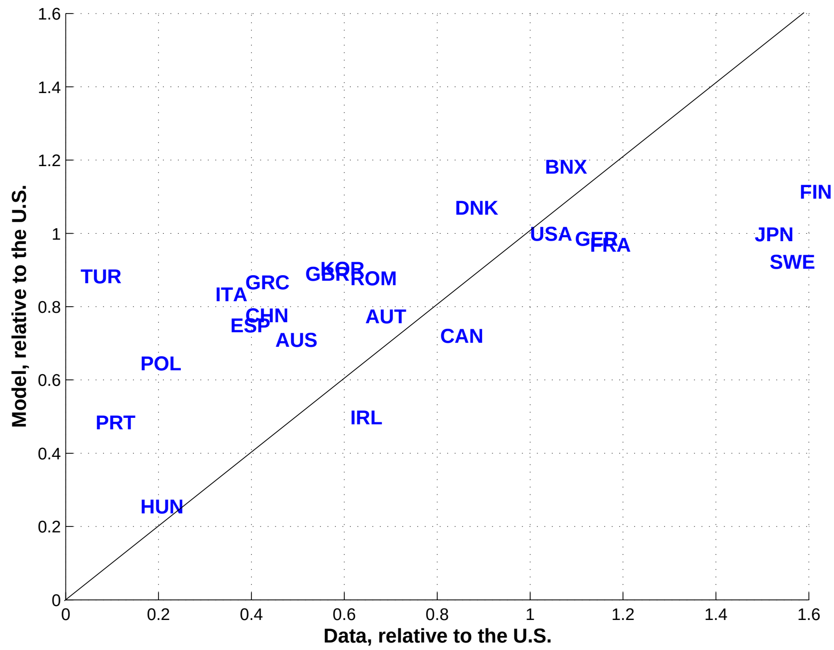
Country Name (Code)	T_i^P	T_i^e	Innovation share, r_i baseline	$T_i^e = A_i = 1$
	(1)	(2)	(3)	(4)
Australia (AUS)	0.175	0.695	0.067	0.086
Austria AUT)	0.226	2.626	0.147	0.073
Benelux (BNX)	0.600	1.549	0.203	0.183
Brazil (BRA)	0.206	0.745	0.145	0.154
Canada (CAN)	0.403	1.371	0.129	0.097
China (CHN)	0.003	0.140	0.139	0.167
Cyprus (CYP)	0.036	3.826	0.167	0.167
Denmark (DNK)	0.162	3.573	0.193	0.097
Spain (ESP)	0.568	1.660	0.137	0.125
Finland (FIN)	0.247	4.136	0.195	0.084
France (FRA)	0.589	1.740	0.175	0.138
United Kingdom (GBR)	0.523	1.465	0.159	0.131
Germany (GER)	0.480	1.132	0.174	0.184
Greece (GRC)	0.178	3.832	0.160	0.131
Hungary (HUN)	0.051	1.247	0.059	0.050
Ireland (IRL)	0.240	2.104	0.078	0.033
Italy (ITA)	1.176	2.007	0.151	0.130
Japan (JPN)	1.963	1.931	0.178	0.159
Korea (KOR)	0.242	1.689	0.162	0.144
Mexico (MEX)	0.006	0.460	0.133	0.147
Poland (POL)	0.001	0.371	0.121	0.151
Portugal (PRT)	0.142	1.565	0.097	0.086
Romania (ROM)	0.0001	0.301	0.159	0.165
Sweden (SWE)	0.332	2.708	0.162	0.091
Turkey (TUR)	0.091	1.163	0.159	0.159
United States (USA)	1.000	1.000	0.182	0.202

Notes: Columns 1 and 2 shows the values for T^p and T^e, respectively, from the baseline calibration. Columns 3 and 4 show innovation shares, r_i, coming from the model's equilibria with T_i^e and T_i^p set to their baseline values, and $T_i^e = A_i = 1$, with $A_i \equiv (T_i^p)^{1/(1-\rho)}/\bar{L}_i$, respectively. Equilibria calculated without trade and MP imbalances, $\Delta = 0$.

C.3 Additional Implications

Innovation shares. Figure 7 shows the innovation share in the model and in the data relative to the United States. The innovation share in the model is r_i from Table 3, while in the data this share corresponds to employment in R&D as a share of total employment, from UNIDO, as an average over the nineties.

Figure 7: Innovation Shares: Model vs Data.



Notes: Innovation shares refer to R&D employment shares: in the model, the (equilibrium) variable r, calculated with exogenous current account imbalances, $\Delta \neq 0$ (the variable in column 3 of Table 3); in the data, manufacturing R&D employment as a share of total manufacturing employment, closest year available to 1999, from OECD (data on total manufacturing employment for China are from Lardy (2015)) — Brazil, Mexico, and Cyprus do not have data. Shares are relative to the United States.

There is a strong positive association between the two variables in spite of the fact that R&D data was not used in the calibration of the model (correlation coefficient of 0.67). On the one hand, this positive association suggests that the model does a good job in capturing the observed relationship between trade, MP, and innovation. On the other hand, the innovation shares in the data and the model are quite different in levels – the observed share of labor employed in R&D is an order of magnitude lower than the model's implied share, which revolves around 17 percent. One reason for this discrepancy is that R&D in the data captures only a small part of what constitutes innovation in the model. The innovation share implied by the model is of the same order of magnitude to the 15 percent share of income accrued to intangible capital—which includes not only

Table 4: Trade Costs, MP Costs, and Gravity. Baseline calibration.

	Distance Dummies					Other Gravity Controls		
	D2	D3	D4	D5	D6	Border	Language	R-sq.
Bilateral trade costs	0.966	0.954	1.112	1.159	1.149	0.035	-0.091	0.61
	(0.10)	(0.10)	(0.08)	(0.09)	(0.06)	(0.04)	(0.05)	
Bilateral MP costs	0.702	0.882	1.049	1.091	1.235	-0.065	-0.154	0.93
	(0.09)	(0.1)	(0.09)	(0.09)	(0.06)	(0.04)	(0.03)	

Notes: Coefficients are estimated through OLS. Robust standard errors in parenthesis.

R&D expenditures, but also marketing expenditures—in the United States (average for 2000-03), as calculated by Corrado, Hulten & Sichel (2009).[28]

Trade and MP costs. The estimated trade and MP costs should correlate to geographic variables such as bilateral distance. To evaluate this relationship we regress the logarithm of estimated trade and MP costs on an indicator variable for distance bins, as in the gravity regressions above, border and language dummies, and origin and destination fixed effects. Except for the estimates of the border dummy on trade costs, the coefficients are all significant at the one-percent level and have the expected signs: Trade and MP costs increase with distance and are lower for country pairs that share a language.

Bridge MP. As discussed above, our calibration procedure implies a unique mapping from observed bilateral trade and MP shares to simulated trilateral flows, X_{iln}. We now assess the ability of our model to predict these trilateral flows for the United States ($i = USA$), which is the only case for which we have the necessary data. Notice that this data was *not* used in the calibration of trade and MP costs, except of course as part of the aggregate bilateral trade flows.

Following Ramondo & Rodríguez-Clare (2013), we refer to MP sales sold outside of the local market as bridge MP (BMP) flows, since firms from i use l as a bridge to reach another location n. In turn, BMP shares are defined as the ratio of BMP to total MP flows from i in l ($\sum_{n \neq l} X_{iln} / \sum_n X_{iln}$). The BMP shares predicted by the model are lower than the ones in the data. Across all production locations for U.S. multinationals, the average BMP share in the model is 0.054, while this is 0.36 in the data.[29] Predicted BMP flows are

[28]Corrado, Haskel, Lasinio & Iommi (2014) extend their analysis of the income share of intangible capital to other OECD countries besides the U.S. For a subset of 18 countries that are in both our sample and in theirs, the correlation between our innovation share and their computed income share of intangible capital is 0.46.

[29]We use the data published by the BEA website on local sales, sales to the United States, and sales to

low because in the calibrated model multinationals tend to serve foreign markets mostly through exports or MP rather than BMP. This is a consequence of the relatively high value of ρ in our calibration (i.e., $\rho = 0.55$), which is dictated by the large gap between the estimated trade elasticities in the restricted and unrestricted gravity equations. Results are very different if we simply imposed $\rho = 0$, as we explain in detail in Section A.

Digging deeper into the variation in BMP, we find that the correlation between predicted BMP by country and destination for U.S. firms (i.e. X_{iln} for $i = U.S.$) is nearly one when compared with the actual data. A large part of this is due to gravity: sales from large countries to large countries tend to be large. To control for gravity we compare $\log(X_{iln}/Y_l X_l)$ as predicted by the model and as observed in the data. For $\rho = 0.55$, the correlation is roughly 0.45, whereas for $\rho = 0$ the correlation falls to roughly 0.40. The better fit of the data to the micro patterns of BMP is to be expected as the trade elasticities in the aggregate data imply a ρ that is greater than zero.

III Counterfactual Experiments

Armed with our calibrated model, we perform a series of counterfactual experiments to understand the effects of openness on innovation and welfare across and within countries. All our counterfactuals are performed assuming that the aggregate trade and MP deficits are zero (i.e. by setting $\Delta_i = 0$).

We first calculate the gains from openness as well as the gains from trade and the gains from MP, according to the definitions in Section E. We then compute the effect of a decline in MP costs on innovation, real income, and real wages of workers in the innovation and production sectors. Next, motivated by its recent emergence as a key location for manufacturing production, we analyze the effects of the integration of China to the world economy through various exercises. We finish with a couple of exercises designed to explore the likely implications of Brexit and a tax on U.S. firms that set up production locations abroad.

Before presenting our results, we acknowledge that the absence of non-tradable and intermediate goods in our calibrated model is likely to bias the overall magnitude of our quantitative results on welfare. As shown in Alvarez & Lucas (2007) the inclusion of non-tradable goods lowers, while the inclusion of tradable intermediate goods increases, the gains from trade, with the overall effects reducing the gains from trade by half. The effect

third countries of affiliates in manufacturing, by country. We choose the year 1999 for consistency with the BMP data used for the gravity estimates and because this is a benchmark survey year for which less data are imputed.

Table 5: Gains from Openness, Trade, and MP. Selected countries. Baseline calibration.

in percent change	Gains from Openness overall	direct	indirect	Gains from Trade	Gains from MP
	(1)	(2)	(3)	(4)	(5)
Australia	20.7	42.2	-15.2	-7.6	11.7
Benelux	60.2	52.9	4.8	9.7	27.8
China	3.4	7.4	-3.7	-2.2	0.04
Germany	18.2	17.1	0.9	2.5	10.2
Hungary	44.0	73.0	-16.7	-5.2	16.3
Ireland	89.5	118.2	-13.2	-1.0	27.7
Mexico	16.7	22.4	-4.7	1.8	1.0
Turkey	5.8	6.8	-1.0	2.6	-0.5
United States	9.8	7.6	2.0	3.2	5.3
Average (all sample)	24.6	29.0	-2.9	3.6	7.0

Note: The gains from openness refer to changes in real expenditure between autarky and the calibrated equilibrium. The direct and indirect effects refer to the first and second terms,respectively, on the right-hand side of (27). The gains from trade (MP) refer to changes in real expenditure between an equilibrium with only MP (trade) and the calibrated equilibrium with both trade and MP. Changes are with respect to the baseline calibrated equilibrium without trade and MP imbalances, $\Delta = 0$.

should be milder for the gains from MP since MP is feasible in the non-tradable sector (see Ramondo & Rodríguez-Clare (2013)). Although these considerations will affect the levels of welfare gains, we conjecture that, under standard assumptions, they should not affect our results on the distribution of trade and MP gains (and loses) across countries, the impact of trade and MP on innovation, and the distribution of gains between production and innovation workers within countries.

A The Gains from Openness

Table 5 presents the gains from openness decomposed into the direct and indirect effects, as discussed in Section E, as well as the gains from trade and MP, for a list of selected countries – the table with all countries is in the Online Appendix. All countries gain from openness, and these gains are mostly driven by the direct effect. For countries that specialize in production, the direct effect is partially offset by a negative indirect effect – for example, Ireland has direct gains of 118 percent but indirect losses of 13 percent, resulting in a net overall gain of 90 percent.

The gains from MP and trade tend to be low, relative to the gains from openness, because trade and MP are substitutes: once an economy has access to either trade or MP,

Table 6: MP Liberalization. Selected countries. Baseline calibration.

percent change in:	r	X/P	w^p/P	w^e/P
	(1)	(2)	(3)	(4)
Australia	-11.49	3.40	3.83	-2.72
Benelux	10.63	5.61	4.17	11.08
China	-5.33	0.26	0.70	-2.45
Germany	1.29	2.71	2.57	3.37
Hungary	-14.80	3.76	4.24	-4.23
Ireland	7.52	4.94	4.60	8.81
Mexico	-8.26	0.81	1.45	-3.44
Turkey	-2.14	-0.01	0.20	-1.08
United States	0.75	1.32	1.23	1.70
Average (all sample)	-2.00	1.93	2.01	0.88

Note: MP liberalization refers to a five-percent decrease in all MP costs with respect to the baseline calibrated values. The variables are: the innovation share, r; real expenditure, X/P; real wage per efficiency unit in the production sector, w^p/P; real wage per efficiency unit in the innovation sector, w^e. Percentage changes are with respect to the baseline calibrated equilibrium without trade and MP imbalances, $\Delta = 0$.

then adding the other channel does not generate large additional gains. Table 5 shows that some countries with $r_i < \eta$ actually lose from trade or MP. Focusing again on Ireland, we see that it experiences loses from trade of one percent, but gains from MP of 28 percent. The fact that some countries lose from trade or MP stands in contrast to Ramondo & Rodríguez-Clare (2013), where gains from trade and gains from MP were always positive. As explained in Section E.2, if inward MP costs are low relative to outward MP costs, lowering trade costs from infinity to their calibrated values (while leaving MP costs at their calibrated levels) would lead to a reallocation of resources from innovation to production, a de-location effect that may increase prices as more ideas used in production must now bear the MP costs. Similarly, lowering MP costs from infinity to their calibrated values (while leaving trade costs at their calibrated levels) would lead to a decline in innovation, triggering a deterioration in the country's terms of trade.

B The Gains from MP Liberalization

We now quantify the overall gains and distributional effects from lowering all MP barriers by five percent. Table 6 shows the percentage changes for each country in innovation shares (r_i), real expenditure (X_i/P_i), real wage in production (w_i^p/P_i), and real wage in innovation (w_i^e/P_i).

MP liberalization generates a large reallocation of innovation across countries. For example, r increases more than ten percent in Benelux, but falls by more than 11 percent in Australia. These changes result from a combination of forces. When trade and MP costs decrease, we should see countries specializing according to their comparative advantage, but with positive trade and MP costs, HMEs are magnified, or weakened, as barriers decrease. In addition, there are third country effects: When a country is close to another country that has strong comparative advantage, MP liberalization may lead to a decline in its innovation share. In general, we should observe reallocation towards innovation in countries with $r > \eta$, and the opposite in countries with $r < \eta$. However, it is also important to consider whether innovation shares are low because of comparative advantage or HMEs. For instance, Ireland has $r < \eta$, but when MP gets liberalized, it reallocates resources toward the innovation sector. This is because Ireland has a comparative advantage in innovation.

It is worth noting that effects of MP liberalization are highly non-linear. For instance, the strong increase in innovation in Benelux is caused by the fact that γ is already low in that country; effects would be weaker if γ were high.[30]

As measured by changes in aggregate real expenditure, countries experience average welfare gains of 1.93 percent from MP liberalization. The top winner is Benelux, with gains of 5.6 percent, while Turkey experiences a small loss. As explained in Section E, aggregate loses arise because of the reallocation of resources from innovation to production and the associated terms of trade, or de-location, effects.

The distributional impact of MP liberalization are also shown in Table 6. The real wage for production workers increases with MP liberalization in all the countries in our sample. In contrast, changes in the real wage for innovation workers tend to fall with MP liberalization in countries which are net recipients of MP (i.e., with $r < \eta$). For example, real wages in innovation decrease by 3.4 percent in Mexico and by around 2.5 percent in China. More broadly, real wages in innovation tend to increase by more than real wages in production in countries with net MP outflows (i.e., with $r > \eta$), whereas the opposite happens in countries with net MP inflows (i.e., with $r < \eta$).

C The Rise of the East

Arguably the single most important recent event relevant to the questions addressed in this paper is the emergence of China as a major center for manufacturing production. We

[30] In a symmetric world, we would not observe this non-linear effects; the gains from MP liberalization would be, as a first-order approximation, the product of the decline in γ and MP flows.

Table 7: The Rise of of the East. Baseline calibration.

	China	United States	Japan	Mexico	Ireland
		percent changes			
China in autarky					
innovation rate, r	19.55	-2.53	-1.81	0.34	-0.79
real expenditure, X/P	-3.29	-0.76	-0.76	-0.11	-0.37
real production wage, w^p/P	-4.84	-0.48	-0.57	-0.14	-0.33
real innovation wage, w^e/P	5.74	-2.03	-1.67	0.06	-0.76
Unilateral MP liberalization into China					
innovation rate, r	-11.95	1.34	1.21	-0.25	0.58
real expenditure, X/P	0.75	0.31	0.26	0.013	0.14
real production wage, w^p/P	1.73	0.16	0.13	0.03	0.12
real innovation wage, w^e/P	-5.45	0.98	0.86	-0.11	0.43
Frictionless MP into China from USA					
innovation rate, r	-92.25	21.87	-0.86	-3.36	-5.56
real expenditure, X/P	34.20	4.85	0.0004	0.33	0.68
real production wage, w^p/P	43.88	2.27	0.09	0.59	0.92
real innovation wage, w^e/P	-62.65	15.75	-0.43	-1.36	-2.16

Note: China in autarky refers to the counterfactual scenario in which trade and MP costs from/to China are set to infinity; unilateral MP liberalization into China refers to the counterfactual scenario in which MP costs into China are decreased by ten percent; frictionless MP into China from USA refers to the counterfactual scenario in which MP costs from the United States into China are set to one. The real wage in each sectors refers to the real wage per efficiency units. Percentage changes are with respect to the baseline calibrated equilibrium without trade and MP imbalances, $\Delta = 0$.

analyze how this may have affected innovation patterns across countries, as well as its overall welfare effects and distributional implications. Following up on the theoretical discussion in Section E, we pay particular attention to the possibility of a negative effect on production workers in rich countries.

We consider three counterfactual exercises: (i) China reverting to autarky ($\tau'_{l,CHN}$, $\tau'_{CHN,l}$, $\gamma'_{i,CHN}$, $\gamma'_{CHN,i} \longrightarrow \infty$ for all $l \neq CHN$, and all $i \neq CHN$); (ii) unilateral MP liberalization of ten percent into China (i.e., $\gamma'_{i,CHN}/\gamma_{i,CHN} = 0.9$ for all $i \neq CHN$); and (iii) frictionless MP from the United States into China (i.e., $\gamma'_{USA,CHN} = 1$). Table 7 presents the results for China, the United States, Japan, Mexico and Ireland, using the baseline calibrated model.[31]

[31]Before proceeding, It is worth noting that our calibrated model matches well the trade and MP data for China. The values for inward MP shares, export and import shares, are virtually the same in the data and model; a discrepancy is observed in outward MP shares (0.005 versus 0.01 in the model and data, respectively).

China in autarky. Moving China back to autarky implies a reduction in the innovation share for countries that are specialized in innovation. For example, r falls by 2.5 percent in the United States and almost two percent in Japan. On the contrary, Mexico experiences an increase in r. This might seem counterintuitive: if Mexico and China compete for inward MP, then it would be natural to expect China's disappearance from the scene to lead to *more* MP towards Mexico, causing deeper specialization in production and a decline in r. The positive effect arises because innovation is a *non-rival* activity, so that its decline in the United States leads to the creation of fewer U.S. firms and lower MP flows to China and other locations.

Aggregate welfare falls everywhere and, as implied by the theory, the relative wage of innovation workers (i.e., w^e/w^p) increases wherever there is an increase in the innovation share. In fact, the large increase in w^e/w^p in China implies that innovation workers benefit from moving to autarky. The real wage for production workers falls even in countries that experience a decline in r, such as the United States.

Unilateral MP liberalization into China. The second counterfactual exercise involves a ten-percent decline in MP costs from all countries into China. This leads China to specialize even more in production while the United States and Japan further specialize in innovation. In turn, higher innovation in the United States increases outward MP to Mexico, which deepens its specialization in production.

China experiences gains of 0.75 percent, and the other countries in Table 7 also gain, but some countries experience modest aggregate losses, such as Austria and Turkey (not shown). These are countries for which innovation activities decline, and hence, by the results in Section E, they are candidates for welfare losses caused by the strengthening of HMEs due to MP liberalization in China. Specifically, countries that are initially well linked to China benefit disproportionally from the new MP opportunities generated by China's liberalization, leading to a reallocation of innovation toward these countries and away from countries with weak links to China, who may then suffer welfare losses.

Turning to the distributional implications, the gains from MP liberalization in China are captured by production workers, who see their real wage increased by almost two percent, while innovation workers actually experience losses of more than five percent. Contrary to popular fears, production workers gain in the United States, but their gains are less than one fifth of those of workers in the innovation sector.

Frictionless MP from the United States into China. The complete removal of MP frictions from the United States into China has major effects all over the world. First, there is a dramatic reallocation of innovation from China to the United States. Second, the increase in innovation in the United States leads to a strong displacement of innovation away from countries with strong links to the United States, such as Ireland and Mexico. Third, there is a decline in innovation activities (and the real wage for innovation workers) in other high-innovation countries, such as Japan, for two reasons: these countries face much worse conditions for doing MP in China as production wages there increase by almost 45 percent thanks to the higher demand for labor by U.S. multinational firms; and the increase in innovation activities in the United States leads their multinational firms to open foreign subsidiaries everywhere, extending the upward pressure in production wages to—and reducing the incentives for innovation in—the rest of the world.

Importantly, although there is a large reallocation of production by U.S. multinational firms to China, the fear that this may hurt U.S. workers does not materialize in our calibrated model: both production and innovation workers in the United States experience increases in their real wage.

D The Fall of the West

Motivated by Brexit, we first use our model to quantify the effects of a five-percent increase in bilateral trade and MP costs between the United Kingdom and the countries in our sample that belong to the European Union. To highlight the separate role of the increase in MP costs, we perform the exercise in two steps: we first increase only trade costs by five percent, and then we increase simultaneously trade and MP costs by five percent. We find that while increasing barriers to trade with the EU would reduce real expenditure in the U.K. by a percentage point, also increasing barriers to MP would more than triple the real expenditure losses. The innovation share would fall by 2.5 percent, and workers in the production and innovation sector would experience decreases in their real wage of 1.4 and 2.7 percent, respectively. All EU members would lose from Brexit—particularly Ireland—except for Italy that would experience small welfare gains.

Next, motivated by the idea of imposing taxes on U.S. firms that reallocate (parts of) their production process to foreign locations, we consider a unilateral increase of 20 percent in outward MP costs from the United States (i.e., $\gamma'_{USA,l}/\gamma_{USA,l} = 1.20$, for all $l \neq USA$). As shown in the Online Appendix, this causes a reduction in the U.S. innovation share of almost 20 percent. Both workers in the production and innovation sectors would lose, but the losses of workers in the latter sector would be more than six-time larger. Ireland and Mexico would both experience increases in their innovation shares but suffer aggregate welfare losses. Overall, countries with net positive MP flows (i.e., $r > \eta$) tend to gain, while net recipients of MP (i.e., $r < \eta$) tend to lose.

IV Sensitivity Analysis

In this Section we present results for alternative calibrations with values for ρ and κ that differ from our baseline calibration, and discuss the sensitivity of our results to the inclusion of fixed costs of operating plants in additional locations.

A Alternative Calibrations

Two parameters have outsized roles in shaping the model's quantitative implications. The parameter ρ governs the heterogeneity of firms' productivity draws across production locations and so determines the efficiency gains associated with the relocation of production internationally. The parameter κ governs the heterogeneity of a worker's efficiency draws across innovation and production and so determines the extent to which countries can be induced to specialize. In this section, we contrast the fit and the welfare implications of alternative parameterizations of ρ and κ with those of our benchmark calibration. The supporting tables can be found in the Online Appendix.

To illustrate the role of ρ we reconsider the model's fit and counterfactual predictions when $\rho = 0$. Under this parameterization, it is easy to show that $X_{iln} = \lambda_{il}^{M} \lambda_{ln}^{T} X_n$, i.e., the aggregate export behavior of the foreign affiliates mimics the export behavior of domestic firms. There are two immediate implications for the model fit under this parameterization. First, the model will not generate trade elasticities that differ between restricted and unrestricted gravity (they are both equal to θ), so it cannot match the target estimates from Section A. Still, upon recalibrating trade and MP costs, the model calibrated with $\rho = 0$ does as well as that calibrated with $\rho = 0.55$ in matching the observed trade and MP flows. Second, the average BMP share predicted by the model rises from 5.5 to 27 percent, bringing it much closer to the 36 percent observed in the data.[32] As explained in Section C.3, however, the cross-country pattern of BMP is better captured by the model with $\rho = 0.55$, as also implied by our aggregate estimates of the gravity elasticities.

The cross-country pattern of the various effects we have focused on are not significantly different across the calibrations with $\rho = 0$ and $\rho = 0.55$. Specifically, the correlation between the two calibrations in the country-level gains from openness, gains from trade and gains from MP are 0.93, 0.85 and 0.92, respectively, while the analogous correlation in the percentage change in r , X/P, w^p/P and w^e/P, are 0.88, 0.96, 0.96, and 0.86,

[32] This difference in the average BMP share between data and model is close to the difference in fit obtained by Tintelnot (2017) in the baseline calibration of his model with plant-level fixed costs (50 percent in the data vs 39.4 percent in the model).

respectively. Some differences emerge in cross-country averages: the average gains from openness are 13 percent under $\rho = 0$, lower than the 25 percent for the case with $\rho = 0.55$, the average gains from MP are slightly lower (6 rather than 7 percent), the average gains from trade are slightly higher (5 rather than 4 percent), and the average gains from MP liberalization are lower (1.4 vs 1.9 percent).

Why is it that the calibration with $\rho = 0$ delivers lower gains from openness than with $\rho = 0.55$? Since the difference arises almost entirely from the direct gains, we can focus on the expression on the right-hand side of (28). Even with $\rho = 0$ the calibrated model implies that $\sum_l X_{nln} \approx X_{nnn}$, and hence

$$\left(\frac{\sum_l X_{nln}}{\sum_{i,l} X_{iln}}\right)^{-\frac{1}{\theta}} \left(\frac{X_{nnn}}{\sum_l X_{nln}}\right)^{-\frac{1-\rho}{\theta}} \approx \left(\frac{X_{nnn}}{X_n}\right)^{-\frac{1}{\theta}}.$$

Thus, we can focus on the implied value of the share X_{nnn}/X_n under $\rho = 0$ and $\rho = 0.55$ to understand the difference in the gains from openness between the two calibrations. Since BMP shares tend to be higher under $\rho = 0$ but both models are calibrated to be consistent with the same trade and MP shares, it must be that domestic firms tend to export less and produce more for the domestic market, implying a higher X_{nnn}/X_n and lower gains from openness.

To illustrate the role of the parameter κ, we consider the alternative value of $\kappa = 5$.[33] Not surprisingly, as κ increases countries respond to shocks by becoming more specialized. The results for Benelux illustrate the point clearly: the increase in the innovation share triggered by MP liberalization increases from 11 percent with $\kappa = 2$ to almost 20 percent with $\kappa = 5$.

B Plant-Level Fixed Costs

As mentioned in the Introduction, we have departed from the literature by assuming that there are no fixed costs involved in setting up plants in additional locations. This approach has important advantages: firm decisions aggregate up nicely so that we have analytical results for comparative statics and welfare; the model generates a gravity equation for trade flows by firms from one home country – our *restricted gravity equation*; and the calibration is transparent, as we can recover key restrictions on parameters with our restricted gravity equation and compute trade and MP costs from our extended Head

[33]Because this case differs only in the specification of the labor market, the implied trade and MP costs, T^e's, and T^p's, as well as the goodness of fit of the calibrated model, and the values of ρ and θ, are common across specifications.

and Ries approach. Still, it is important to discuss how the absence of a proximity-concentration tradeoff (i.e. incurring trade costs, but concentrating production in one location, or incurring a plant-level fixed cost to replicate production in another location closer to consumers) may be affecting our results.

As we show in the Online Appendix, under the special case with $\rho = 0$ and if plant-level fixed costs are not too high relative to marketing costs (a generalization of a condition imposed by Helpman et al. (2004)), then allowing for such fixed costs would not affect any of the conclusions we have derived in this paper. In essence, in this case, all that the plant-level fixed costs do is to increase the productivity cutoff for selling in the market where the plant is located, exactly as if the marketing cost for selling there were higher. Since marketing costs have no effect on our counterfactuals, it follows that adding fixed costs does not affect them either. We acknowledge that the case with $\rho = 0$ is quite special, but the isomorphism is important because it shows that the magnitude of any possible change caused by introducing plant-level fixed costs depends on how far ρ is from zero.

For $\rho > 0$ the isomorphism breaks down and one must deal with firms facing a discrete choice problem with 2^N combinations of production locations to choose from. Such firm-level decisions do not aggregate up into a set of equilibrium equations that we can directly use to conduct comparative statics, and the analysis must be done through simulation methods. Tintelnot (2017) addresses this challenging problem in the context of a model with a probabilistic structure that is similar to ours, but without innovation or marketing costs.[34] He calibrates the model to match moments associated with German firm-level data as well as aggregate trade and MP flows. One key result of that paper is that BMP increases with plant-level fixed costs. This is because those fixed costs lead to fewer and larger firms, with a lower average number of production plants and higher BMP.

Adding plant-level fixed costs to our model, computing the equilibrium by following the techniques in Tintelnot (2017), and calibrating the model to make it consistent with the restricted and unrestricted trade elasticities as well as the average BMP shares is an important issue for future research. Here we can only offer the following conjecture: since either the case of positive plant-level fixed costs or the case with no such costs and $\rho = 0$ imply higher BMP shares relative to our baseline calibrated model with $\rho = 0.55$ and no fixed costs, then their effect on counterfactual implications may be similar. In that sense, the results discussed above for the alternative calibration with $\rho = 0$ may be informative

[34] In the Online Appendix, we formally show that the probabilistic setup in our model is isomorphic to the one in Tintelnot (2017) and Sun (2017), where each firmÕs productivity in a location is the product of a Pareto-distributed core productivity and a location-specific Fréchet-distributed efficiency shock, and market-entry decisions are made before observing the location-specific efficiencies.

about the effect of adding plant-level fixed costs.

V Conclusion

The decline in the costs of multinational production (MP) has allowed some countries to specialize in innovation and others to specialize in the production of goods and services created elsewhere. To quantify the implications of this phenomenon, we develop a quantifiable general equilibrium model where firms can serve a market by exporting from their home country, by producing in the foreign market, or by exporting from a third location. In making their location decisions, firms face a proximity-comparative advantage tradeoff: trade costs may induce firms to open foreign affiliates near to their foreign customers, but this proximity may imply not minimizing production costs. In the aggregate, countries that have a high productivity in innovation relative to production tend to specialize in innovation, but home market effects create forces to concentrate production in countries with large "market potential" while drawing innovation towards countries with large "production potential." The model yields simple structural expressions for bilateral trade and MP that we use in our calibration across a set of OECD countries. We use the calibrated model to perform a series of counterfactual exercises designed to study the welfare implications of shocks driving increased specialization in innovation and production across countries. We find that countries that specialize in production due to HMEs may experience aggregate losses, although these losses tend to be very small. Contrary to popular fears, we find that production workers gain even in countries that further specialize in innovation.

A Theory

A Properties of the Multivariate Pareto.

(i) We show that with $\rho \to 1$ the elements of $\boldsymbol{z}$ are perfectly correlated, i.e. $\lim_{\rho\to 1} G_i(z_1,...,z_N) = 1 - \max_l T_{il} z_l^{-\theta}$. Let $x \equiv \max_l T_{il} z_l^{-\theta}$ and note that $G_i(z_1,...,z_N) = 1 - x\left(\sum_{l=1}^N \left(T_{il} z_l^{-\theta}/x\right)^{\frac{1}{1-\rho}}\right)^{1-\rho}$. As $\rho \to 1$ then $\sum_{l=1}^N \left(T_{il} z_l^{-\theta}/x\right)^{\frac{1}{1-\rho}} \to 1$, proving the result.

(ii) We also show that $\rho = 0$ is equivalent to the case of the production location l chosen randomly with probabilities $T_{il}/\widetilde{T}_i$ among all possible locations $l = 1,...,N$, and the productivity Z_l chosen from the Pareto distribution $1 - \widetilde{T}_i z_l^{-\theta}$ with $z_l \geq \widetilde{T}_i^{1/\theta}$. We simply need to prove that for $l \neq k$ we have $\Pr(Z_l > \widetilde{T}_i^{1/\theta} \cap Z_k > \widetilde{T}_i^{1/\theta}) = 0$, and $\Pr(Z_l \leq z_l \cap Z_k = \widetilde{T}_i^{1/\theta}$ for all $k \neq l) = \left(T_{il}/\widetilde{T}_i\right)\left(1 - \widetilde{T}_i z_l^{-\theta}\right)$. Note that with $\rho = 0$ the density associated with the distribution above is zero, if it is evaluated at a point with $Z_v > \widetilde{T}_i^{1/\theta}$ for two or more v, while $\Pr(Z_l \leq z_l \cap Z_k = \widetilde{T}_i^{1/\theta}$ for all $k \neq l) = 1 - \left[\sum_{k\neq l}^N T_{ik}/\widetilde{T}_i + T_{il} z_l^{-\theta}\right] = \left(T_{il}/\widetilde{T}_i\right)\left(1 - \widetilde{T}_i z_l^{-\theta}\right)$ proving the result.

B Proof of Lemma 1

The (unconditional) probability that a firm from i will serve market n from l is

$$\Pr\left(\arg\min_k C_{ikn} = l \ \cap \min_k C_{ikn} \leq c_n^*\right).$$

To compute this probability, note that,

$$\Pr\left(C_{i1n} \geq c_{i1n}, ..., C_{iNn} \geq c_{iNn}\right) = \Pr\left(Z_1 \leq \frac{\xi_{i1n}}{c_{i1n}}, ..., Z_N \leq \frac{\xi_{iNn}}{c_{iNn}}\right).$$

Assuming that $c_{ikn} \leq \xi_{ikn}\widetilde{T}_i^{-1/\theta}$ for all k, then our assumption regarding the distribution of $\boldsymbol{z}$ for firms in country i implies that

$$\Pr\left(Z_1 \leq \frac{\xi_{i1n}}{c_{i1n}}, ..., Z_N \leq \frac{\xi_{iNn}}{c_{iNn}}\right) = 1 - \left(\sum_{k=1}^N \left[T_{ik}\left(\frac{\xi_{ikn}}{c_{ikn}}\right)^{-\theta}\right]^{\frac{1}{1-\rho}}\right)^{1-\rho}. \tag{A.1}$$

But we know that

$$\Pr\left(C_{i1n} \geq c_{i1n}, ..., C_{iln} = c_{iln}, ..., C_{iNn} \geq c_{iNn}\right) = -\frac{\partial \Pr\left(C_{i1n} \geq c_{i1n}, ..., C_{iln} \geq c_{iln}, ..., C_{iNn} \geq c_{iNn}\right)}{\partial c_{iln}},$$

hence from (A.1) we get

$$\Pr\left(C_{i1n} \geq c_{i1n}, ..., C_{iln} = c_{iln}, ..., C_{iNn} \geq c_{iNn}\right) = \theta\left(\sum_{k=1}^N \left[T_{ik}\left(\frac{\xi_{ikn}}{c_{ikn}}\right)^{-\theta}\right]^{\frac{1}{1-\rho}}\right)^{-\rho}\left(T_{il}\xi_{iln}^{-\theta}\right)^{\frac{1}{1-\rho}} c_{iln}^{\theta/(1-\rho)-1}. \tag{A.2}$$

Notice also that if $c < \xi_{ikn}\widetilde{T}_i^{-1/\theta}$ for all k, and using the definition of ψ_{iln},

$$\begin{aligned}\Pr\left(\arg\min_k C_{ikn} = l \ \cap \min_k C_{ikn} = c\right) &= \Pr\left(C_{i1n} \geq c, ..., C_{iln} = c, ..., C_{iNn} \geq c\right) \\ &= \theta\Psi_{in}^{-\frac{\rho}{1-\rho}}\left(T_{il}\xi_{iln}^{-\theta}\right)^{\frac{1}{1-\rho}} c^{\theta-1} = \psi_{iln}\Psi_{in}\theta c^{\theta-1} .\end{aligned}$$

Given Assumption 1 we know that $c_{in}^* < \xi_{ikn}\widetilde{T}_i^{-1/\theta}$ so that we can integrate the previous expression over c from 0 to c_n^* to show that the probability that firms from i serving market n will choose location l for production is

$$\Pr\left(\arg\min_k C_{ikn} = l \ \cap \min_k C_{ikn} \leq c_n^*\right) = \psi_{iln}\Psi_{in}\left(c_n^*\right)^\theta , \tag{A.3}$$

while

$$\Pr\left(\min_k C_{ikn} \leq c_n^*\right) = \sum_k \psi_{ikn}\Psi_{in}\left(c_n^*\right)^\theta = \Psi_{in}\left(c_n^*\right)^\theta .$$

Hence,

$$\Pr\left(\arg\min_k C_{ikn} = l \ \mid \min_k C_{ikn} \leq c_n^*\right) = \psi_{iln}. \ \textbf{QED}.$$

C Derivations of Equations 7 and 9

Multiplying ($A.3$) by the measure of firms in i, M_i, and using (3), we get the measure of firms from i that serve market n from location l,

$$M_{iln} = M_i\psi_{iln}\Psi_{in}\left(\frac{\sigma w_n^p F_n}{X_n}\right)^{-\theta/(\sigma-1)}\frac{P_n^\theta}{\widetilde{\sigma}^\theta}. \tag{A.4}$$

Since the sales of a firm with cost c in a market n are $\widetilde{\sigma}^{1-\sigma}X_n P_n^{\sigma-1}c^{1-\sigma}$, equation (5) implies that total sales from n to l by firms from i, X_{iln}, are

$$X_{iln} = M_i\psi_{iln}\Psi_{in}\widetilde{\sigma}^{1-\sigma}X_n P_n^{\sigma-1}\int_0^{c_n^*}\theta c^{\theta-\sigma}dc.$$

Solving for the integral, using (3) and simplifying yields

$$X_{iln} = \frac{\widetilde{\sigma}^{-\theta}\theta}{\theta-\sigma+1}M_i\psi_{iln}\Psi_{in}\left(\sigma w_n^p F_n\right)^{(\theta-\sigma+1)/(1-\sigma)}X_n^{\theta/(\sigma-1)}P_n^\theta. \tag{A.5}$$

Combining (A.5) and (A.4) yields (9). In turn, the formula for the price index in (1) together with the pricing rule in (2), the density in (5), and the cut-off in (3) imply that

$$P_n^{-\theta} = \zeta^\theta\left(\frac{w_n^p F_n}{X_n}\right)^{1-\frac{\theta}{\sigma-1}}\sum_k M_k\Psi_{kn}, \tag{A.6}$$

where $\zeta \equiv \left(\frac{\widetilde{\sigma}^{1-\sigma}\theta}{\theta-\sigma+1}\right)^{1/\theta}\left(\frac{\sigma}{\widetilde{\sigma}^{1-\sigma}}\right)^{\frac{\sigma-1-\theta}{\theta(\sigma-1)}}$. Plugging this result into (A.5), we obtain (7) by noting that λ_{in}^E is given by expression (8).

B Data

The production data for the *restricted sample* (X_{iln}, where i = U.S.) were assembled from several sources that depend on the location of production l. For the case of $l \neq U.S.$ (U.S. MP abroad), our data are from the confidential 1999 survey of the BEA of U.S. direct investment abroad. This legally mandatory survey identifies all U.S. firms that own productive facilities abroad. The survey requires firms to report for their majority-owned, manufacturing affiliates the location of the affiliates l, the sales of these affiliates to customers in their host country ($l = n$) and their sales to customers in the United States, Canada, Japan, the United Kingdom, and an aggregation of a subset of countries in the European Union ($l \neq U.S., n$).[35] For the case of $l = U.S.$, the data was constructed using a mixture of publicly available data and a confidential survey conducted by the BEA on the activities of the U.S. affiliates of foreign firms. Aggregate bilateral trade volumes in manufactures and aggregate domestic manufacturing sales were collected from Feenstra et al. (2002) and the Census of Manufacturing respectively. From these aggregates we subtracted the total contribution of foreign firms to these sales using the BEA data set.

The data for the *unrestricted sample* ($\sum_i X_{iln}$) were also constructed using data from several sources. The bilateral trade data ($l \neq n$) came from Feenstra et al. (2002) for the year 1999. The domestic production data ($l = n$) was collected from the OECD for most developed countries, from the INSTAT database maintained by UNIDO for many of the developing countries, and for a few additional countries the domestic absorption data was obtained from the estimates found in Simonovska & Waugh (2013). In the estimation we use only those bilateral pair observations for which both X_{iln} and X_{ln} are both nonzero and non-missing, yielding a sample of 316 observations.

The data for trade frictions was drawn from several sources. The raw tariff data was obtained from either the WTO or from WITS maintained by the World Bank. Tariffs applied by a given country n can differ from their MFN levels across exporting countries l either because no tariff is applied, as when $n = l$ or n and l are both in a free trade agreement or customs union, or because country n extends GSP tariffs to a developing country l. Data for distance (d_{ln}) and for the standard gravity controls (H_{ln}) are from the *Centre d'Etudes Prospectives et Informations Internationales* (CEPII). To allow for non-linearities in the effect of distance on trade cost, we constructed six categorical variables ($D1$ through $D6$) defined by the size of the distance.[36] Finally, a dummy variable was included that takes a value of one for the case in which $l = n$ and a value of zero for the case $l \neq n$.

[35] These countries are Austria, Belgium, Denmark, France, Finland, Germany, Greece, Luxembourg, Ireland, Italy, Netherlands, Portugal, Spain, and Sweden. The BEA data for affiliate exports contains information on the destination for only these four countries and for seven regions in total. Of these regions, only the European countries share a common tariff.

[36] The categories are less than 1,000km, between 1,000 and 3,000km, between 3000 and 6000km, between 6000 and 9000km, between 9,000 and 12,000km, and greater than 12,000 km.

C Calibration Procedure

The algorithm for calibration is divided in three steps explained below.

Step 1. Given a value for θ and ρ, the data on absorption, trade flows, and MP flows, we use our model to obtain an implied set of trilateral flows X_{iln}. Having those trilateral flows, we can then apply a generalized Head-Ries procedure to obtain estimates of (symmetric) trade and MP costs. Define $t_{il} \equiv T_l^p (w_l \tau_{ln})^{-\theta}$ and $g_{il} \equiv M_i T_i^e \gamma_{il}^{-\theta}$. Using (7), combined with (8) and the definitions of ψ_{iln} and Ψ_{in}, the set of trilateral flows X_{iln} can be written as:

$$X_{iln} = \left(\frac{g_{il} t_{ln}}{\left[\sum_k \left(g_{ik} t_{kn} \right)^{\frac{1}{1-\rho}} \right]^{1-\rho}} \right)^{\frac{1}{1-\rho}} \frac{\left[\sum_k \left(g_{ik} t_{kn} \right)^{\frac{1}{1-\rho}} \right]^{1-\rho}}{\sum_r \left[\sum_j \left(g_{rj} t_{jn} \right)^{\frac{1}{1-\rho}} \right]^{1-\rho}} X_n. \tag{C.1}$$

Using (10) and (11), λ_{ln}^T and λ_{il}^M, respectively, can also be written as a function of these variables:

$$\lambda_{ln}^T = \sum_i \left(\frac{g_{il} t_{ln}}{\left[\sum_k \left(g_{ik} t_{kn} \right)^{\frac{1}{1-\rho}} \right]^{1-\rho}} \right)^{\frac{1}{1-\rho}} \frac{\left[\sum_k \left(g_{ik} t_{kn} \right)^{\frac{1}{1-\rho}} \right]^{1-\rho}}{\sum_r \left[\sum_j \left(g_{rj} g_{jn} \right)^{\frac{1}{1-\rho}} \right]^{1-\rho}} \tag{C.2}$$

and

$$\lambda_{il}^M = \frac{1}{Y_l} \sum_n \left(\frac{g_{il} t_{ln}}{\left[\sum_k \left(g_{ik} t_{kn} \right)^{\frac{1}{1-\rho}} \right]^{1-\rho}} \right)^{\frac{1}{1-\rho}} \frac{\left[\sum_k \left(g_{ik} t_{kn} \right)^{\frac{1}{1-\rho}} \right]^{1-\rho}}{\sum_r \left[\sum_j \left(g_{rj} t_{jn} \right)^{\frac{1}{1-\rho}} \right]^{1-\rho}} X_n, \tag{C.3}$$

where gross manufacturing output for country l in the data is simply calculated using data on trade flows and absorption as $Y_l = \sum_n \lambda_{ln}^T X_n$. Using data on bilateral MP and trade shares, as well as absorption and gross manufacturing output, we can back up the set of g_{il} and t_{ln} from (C.2) and (C.3) and then use them to solve for X_{iln} in (C.1).

Using the expression for X_{iln} in (A.5) and assuming symmetry (i.e. $\tau_{ln} = \tau_{nl}$ and $\gamma_{il} = \gamma_{li}$), we calculate

$$\hat{\tau}_{ln}^{hr} = \left(\sqrt{\frac{X_{inn} X_{ill}}{X_{iln} X_{inl}}} \right)^{\frac{1-\rho}{\theta}}, \hat{\gamma}_{il}^{hr} = \left(\sqrt{\frac{X_{iin} X_{lln}}{X_{iln} X_{lin}}} \right)^{\frac{1-\rho}{\theta}}.$$

Step 2. We set the parameters T_i^e and T_i^p to match r_i, with $T_{USA}^p = T_{USA}^e = 1$, and Y_i, with $Y_{USA} = 1$, respectively. We calculate the innovation share r_i using the data on bilateral MP shares, absorption, and gross production calculated as explained above, as well as the equilibrium conditions of the model, labor market clearing and free entry conditions. The labor market equilibrium in production is given by

$$L_i^p w_i^p = \frac{1}{\tilde{\sigma}} Y_i + \frac{1 + \theta - \sigma}{\sigma \theta} X_i,$$

while the market clearing condition for innovation workers can be written as

$$L_i^e w_i^e = \eta \sum_l \lambda_{il}^M Y_l.$$

Combining the two, we get the total labor income for country i,

$$L_i^p w_i^p + L_i^e w_i^e = \frac{1}{\tilde{\tilde{\sigma}}} Y_i + \frac{1+\theta-\sigma}{\sigma\theta} X_i + \eta \sum_l \lambda_{il}^M Y_l,$$

where output is directly calculated from the data using absorption and bilateral trade shares for country l, $Y_l = \sum_n \lambda_{ln}^T X_n$. The innovation share r is simply given by

$$r_i = 1 - \frac{L_i^p w_i^p}{L_i^p w_i^p + L_i^e w_i^e}.$$

Notice that the innovation share r_i is adjusted by the current account imbalance as implied by the data: We do not equate total (labor) income (i.e. $L_i^p w_i^p + L_i^e w_i^e$) to total expenditure (i.e. X_i), in a country. The Online Appendix shows innovation shares, r_i, expenditure, X_i, output, Y_i, and the implied aggregate trade and MP imbalances, $\Delta_i = X_i - (L_i^p w_i^p + L_i^e w_i^e)$, for each country in our sample.

Step 3. We iterate on the value of the parameter θ such that we match the unrestricted-gravity trade elasticity in the data, by estimating by OLS

$$\log \lambda_{ln}^T = \beta_u \log \tau_{ln} + D_n + S_l + u_{ln},$$

where λ_{ln}^T are the trade shares coming from the model's simulations and τ_{ln} are the calibrated trade costs.

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