Trade, Domestic Frictions, and Scale Effects*

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Abstract

Because of scale effects, idea-based growth models have the counterfactual implication that larger countries should be much richer than smaller ones. One might expect scale effects to be offset by the fact that small countries tend to gain more from trade than large ones. We show that although small countries do gain more from trade, such gains are not large enough to neutralize the underlying scale effects. We argue that another mechanism may be at work: frictions to domestic trade. We build an idea-based model featuring international trade, domestic frictions and scale effects that is largely consistent with the data. For example, for a small and rich country like Denmark, our calibrated model implies a real per-capita income of 88 percent (relative to the United States), much closer to the data (91 percent) than the trade model with no domestic frictions (41 percent). More generally, we show that, by offseting scale effects, domestic frictions help to reconcile the gravity model of trade with the cross-country patterns observed in the data for productivity, relative income levels, and trade shares.

JEL Codes: F1; F2; O4. Key Words: International trade; Openness; Domestic geography; Scale effects; Gravity; Multinational production; Semi-endogenous growth.

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1 Introduction

Scale effects are so central a feature of innovation-led growth theory that, in Jones's (2005) words, "rejecting one is largely equivalent to rejecting the other." Because of scale effects, idea-based growth models such as Jones (1995) and Kortum (1997) imply that larger countries should be richer than smaller ones.[1] It is widely known, however, that this is not borne out in the data; Belgium is not poorer than France and Hong-Kong is not poorer than China.[2]

New trade models such as Krugman (1980), Eaton and Kortum (2001) and Melitz (2003) are also idea-based models, and carry the same counterfactual implication that productivity strongly increases with country size. In such models, one might expect scale effects to be offset by the fact that small countries tend to gain more from trade than large ones. A first contribution of this paper is to show that although small countries do gain more from trade, such gains are not large enough to neutralize the underlying scale effects. We argue that another mechanism may be at work: frictions to domestic trade. The second and main contribution of our paper is to extend the trade model to allow for such domestic frictions and to use the resulting model to quantify their role in reconciling model and data.

The main building block of our whole exercise is an idea-based model featuring the convenient property that scale and trade increase productivity through a single mechanism, namely an expansion in the set of available non-rival ideas. Accordingly, productivity is proportional to $(L/\lambda)^{\varepsilon}$, where L is a measure of size, λ is the share of expenditure devoted to domestic goods, and ε is a positive parameter.[3] Since large countries trade proportionally less than small countries, trade adjusted size, L/λ, will vary less than size,

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[1] First-generation endogenous growth models such as Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992) feature "strong" scale effects, whereby scale increases growth, whereas second-generation semi-endogenous growth models such as Jones (1995), Kortum (1997), Aghion and Howitt (1998, Ch. 12), Dinopoulos and Thompson (1998), Peretto (1998), and Young (1998), feature "weak" scale effects, whereby scale increases income levels rather than growth (see Jones, 2005, for a detailed discussion). Models that do not display any scale effects, such as Lucas (2009), Alvarez, Buera, and Lucas (2013), and Lucas and Moll (2013), depart from the standard assumption that ideas are non-rival by assuming that (1) knowledge can only be used in production when it is embodied in individuals with limited time endowments, and that (2) individuals face search frictions in learning about better ideas.

[2] See Rose (2006) for a systematic exploration of scale effects in the data.

[3] In the Krugman model $\varepsilon = \sigma - 1$, where σ is the elasticity of substitution, while in the Eaton and Kortum (2002) model $\varepsilon = 1/\theta$, where θ is the shape parameter of the Fréchet distribution. For the Eaton and Kortum model, we assume that the scale parameter of the Fréchet distribution, T in their notation, is proportional to size, L, as in Eaton and Kortum (2001). In the case of the Melitz model with a Pareto distribution with shape parameter θ, productivity is proportional to $L^{1/(\sigma-1)}\lambda^{-1/\theta}f^{1/\theta-1/(\sigma-1)}$, where f is the fixed cost of domestic sales (see Arkolakis, Demidova, Klenow and Rodriguez-Clare, 2008). If $\sigma - 1 = \theta$, or if f scales up with size ($f = L$), then productivity is proportional to $(L/\lambda)^{1/\theta}$.

L, and the model could generate similar productivity levels across small and large countries. Indeed, in the extreme case of frictionless trade, λ is inversely proportional to L, so L/λ would not vary with L and scale effects would be exactly offset by trade. But the data show that trade is far from frictionless—in fact, the cross-country variation in λ is much lower than in L.

The key innovation in our model is that we think of countries as collections of symmetric regions that face positive costs to trade amongst themselves. By including domestic trading costs, we capture the fact that countries are not fully integrated economies, and by assuming symmetry across regions within countries we ensure that the resulting country-level trade flows still behave according to the standard gravity model. A critical feature of the model is that domestic trade costs are positive and increase with country size. Our calibrated model shows that such increasing trade costs work against the positive effect of size captured by $(L/\lambda)^{\varepsilon}$, and the result is that large countries are no longer implied to be much richer than small ones.

We calibrate our key parameter ε by appealing to the growth and trade literatures, as well as cross-country estimates of scale effects, and we calibrate domestic frictions so that the model is consistent with domestic trade data available for both the United States and Canada. The calibrated model reveals that domestic frictions are indeed important to explain the discrepancy between the standard trade model and the data. For a small and rich country like Denmark, our calibrated model implies a productivity level of 88 percent (relative to the United States), much closer to the data (91 percent) than the level implied by the trade model with no domestic frictions (41 percent).

By weakening scale effects, domestic frictions not only help the model better match the observed productivity levels across countries; they also make the model better match observed import shares and relative income levels. We make this point by estimating the model with and without domestic frictions to trade data and a set of variables such as geographic distance that are commonly used as determinants of trade costs. The results show that the model without domestic frictions generates relative income levels that increase too steeply and import shares that decrease too steeply with country size. In contrast, the model with domestic frictions generates variation of implied import shares and nominal income with size that is close to the one we see in the data.

Finally, we show that ignoring domestic trade costs leads to biases in the estimation of international trade costs. More specifically, large countries are found to have low inward trade costs in Eaton and Kortum (2002) and low outward trade costs in Waugh (2010) because, in the absence of domestic trade costs, gravity models imply low "multilateral trade resistance" terms in such countries, and hence low "bilateral trade resistance" terms are needed to match the observed trade flows.

We are not the first to point out the importance of country size for trade flows and relative income levels in gravity models. Anderson and van Wincoop (2003) theoretically show that "multilateral trade resistance" increases with country size, leading to lower import shares for larger countries, while Redding and Venables (2004) and Head and Mayer (2011) empirically show that relative income levels increase with a measure of "market potential," which is increasing in country size. Our contribution to this literature is twofold: first, we show that these size effects are too strong in models without domestic frictions, and second, we develop a model with domestic frictions that does a good job in matching the observed relationship between country size and either import shares or relative income levels.

Our paper is related to Alvarez and Lucas (2007) and Waugh (2010), who calibrate an Eaton and Kortum (2002) model to match observed trade flows and cross-country income levels. The calibration performed by Alvarez and Lucas (2007) as well as Waugh (2010) assumes that there are no domestic frictions but allows the technology levels to vary across countries. In fact, their calibration offsets strong scale effects by having technology levels decrease rapidly with country size. Since it is hard to defend such systematic variation in technology levels, we calibrate technology levels to observed R&D intensities, which do not vary systematically with size in our sample of developed countries, and instead allow for domestic frictions to vary with size as implied by our model.

In parallel work, Redding (2012) quantifies the gains from trade in a model with perfect labor mobility within countries composed of multiple asymmetric regions. However, we assume that regions are symmetric for three reasons: first, because Redding's analysis requires bilateral-trade data at the region level, which are available only for the United States and Canada; second, because under symmetry our model exhibits a standard gravity equation for country-level trade flows; and third, because at the national level the gains from trade do not seem to be affected substantially by this assumption.[4] This last point seems consistent with the results of Allen and Arkolakis (2013), who develop a model of trade and labor mobility for an economy with a continuum of regions arranged in a realistic geographic structure. In their calibration for the United States they deal with the fact that trade data are available only at the state level by assuming that the

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[4] We explore the quantitative implications of our symmetry assumption by studying a simplified version of Redding's model with two countries, one with a single region and the other with two asymmetric regions. We compute the gains from trade ignoring the asymmetries between the two regions in the second country—this corresponds to using the formula in Arkolakis et al. (2012) at the country level, as it would be appropriate if countries were composed of symmetric regions. The results are reassuring: the difference between the gains from trade computed as in Redding (2012) and as in Arkolakis et al. (2012) is always tiny for the numerical examples we analyze—the details of this exercise are available upon request.

multilateral resistance terms are the same among the continuum of regions belonging to a state, just as would occur if those regions were symmetric. They use the model to show that inter-state trade flows are not significantly distorted by this symmetry assumption.

Finally, our paper is related to a literature exploring the theoretical and empirical relationship between country size, openness, and income. Ades and Glaeser (1999) and Alesina, Spolaore, and Wacziarg (2000) find a positive effect of country size and trade on income levels, with a negative interaction effect indicating that the positive scale effect is weakened by openness to trade. Frankel and Romer (1999) and Alcala and Ciccone (2004) also find that country size and trade openness (instrumented by geography) lead to higher income levels.

The rest of the paper is organized as follows. In Section 2 we present the baseline model and derive the expression for TFP in terms of size, trade and domestic trade costs that will be used to contrast the model to the data. Section 3 describes the calibration of the model, and Section 4 presents the quantitative results focusing on the model's implications for TFP across countries. In Section 5, we turn to the implications of the model for trade shares and relative income levels. In Section 6 we extend the baseline model to allow for multinational production (as in Ramondo and Rodríguez-Clare, 2013) as an additional channel for the gains from openness beyond international trade. Our main conclusion from Section 3 continues to hold: domestic frictions are key to reconcile the model with the data.

2 Baseline Model

We start with the simple version of the Ricardian trade model developed by Eaton and Kortum (2002 - EK) but here applied to subnational economies we call "regions" rather than countries. We then present our assumptions for how to aggregate regions into countries. Since most data is for countries rather than regions, the country-level model is the one we will use to think about the data.

There is a set of regions indexed by $m \in \{1, ..., M\}$ and a continuum of final goods indexed by $v \in [0, 1]$. Preferences are CES with elasticity of substitution σ. Labor is the only factor of production, available in quantity $\widetilde{L}_m$ in region m, and immobile across regions.[5] Technologies are linear with productivities $z_m(v)$ drawn from a Fréchet distribution with parameters θ and $\widetilde{T}_m$. There is perfect competition and iceberg trade costs $\widetilde{d}_{mk} \geq 1$ to trade from k to m, with $\widetilde{d}_{mm} = 1$. Bilateral trade flows between regions, $\widetilde{X}_{mk}$, statisfy the

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[5] As it is explained below, this assumption will not matter at all for our analysis.

standard expression in the EK model,

$$\widetilde{X}_{mk} = \frac{\widetilde{T}_k \widetilde{w}_k^{-\theta} \widetilde{d}_{mk}^{-\theta}}{\sum_{k'} \widetilde{T}_{k'} \widetilde{w}_{k'}^{-\theta} \widetilde{d}_{mk'}^{-\theta}} \widetilde{X}_m, \tag{1}$$

where $\widetilde{w}_m$ is the wage in region m and $\widetilde{X}_m \equiv \sum_k \widetilde{X}_{mk}$ is total expenditure in region m. In turn, price indices are

$$\widetilde{P}_m = \mu^{-1} \left(\sum_k \widetilde{T}_k \widetilde{w}_k^{-\theta} \widetilde{d}_{mk}^{-\theta} \right)^{-1/\theta} \tag{2}$$

where μ is a positive constant, given by $\mu \equiv \Gamma(\frac{1-\sigma}{\theta} + 1)^{1/(\sigma-1)}$.

We depart from the standard practice of modeling countries as single economies, and instead think of countries as collections of regions. We index countries by $n \in \{1, ..., N\}$ and let Ω_n be the set of regions belonging to country n and M_n be the number of regions in that set. To be able to connect our model to country-level data, we make the following symmetry assumption:

A1. [Symmetry] *$\widetilde{L}_m = \widetilde{L}_{m'}$ and $\widetilde{T}_m = \widetilde{T}_{m'}$ for all $m, m' \in \Omega_n$, and $\widetilde{d}_{mk} = \widetilde{d}_{m'k'}$ for all $m, m' \in \Omega_n$ and $k, k' \in \Omega_i$.*

As we now explain, this assumption implies that, at the country-level, our model is isomorphic to the EK model with the only exception that the trade cost of a country with itself is a function of its size, M_n, and the trade cost among regions belonging to that country, $d_{nn} \equiv \widetilde{d}_{mm'}$ for $m \neq m'$ with $m, m' \in \Omega_n$. To proceed, we introduce notation to keep track of country-level variables. Let $L_n \equiv \sum_{m \in \Omega_n} \widetilde{L}_m$ and $T_n \equiv \sum_{m \in \Omega_n} \widetilde{T}_m$ denote the country-level labor endowment and technology parameters, respectively, and let $X_{ni} \equiv \sum_{m \in \Omega_n} \sum_{k \in \Omega_i} \widetilde{X}_{mk}$, $X_n \equiv \sum_i X_{ni}$ and $w_n = \widetilde{w}_m$ for $m \in \Omega_n$ denote country-level bilateral trade flows, total expenditure levels, and wage levels, respectively. For future reference, note that, thanks to A1, $\widetilde{L}_m = L_n/M_n \equiv \bar{L}_n$ and $\widetilde{T}_m = T_n/M_n \equiv \bar{T}_n$ for all $m \in \Omega_n$.

The following Proposition shows how to go from the standard region-level EK model to the country-level model that we can relate to bilateral trade data (all proofs are in the Appendix):

Proposition 1. Country-level trade flows are

$$X_{ni} = \frac{T_i w_i^{-\theta} \tau_{ni}^{-\theta}}{\sum_j T_j w_j^{-\theta} \tau_{nj}^{-\theta}} X_i \tag{3}$$

and price indices at the country-level are

$$P_n = \mu^{-1} \left(\sum_j T_j w_j^{-\theta} \tau_{nj}^{-\theta} \right)^{-1/\theta} \tag{4}$$

where

$$\tau_{ni} \equiv d_{mk} \text{ for } m \in \Omega_n \text{ and } k \in \Omega_i \text{ for } n \neq i, \tag{5}$$

and

$$\tau_{nn} \equiv \left(\frac{1}{M_n} + \frac{M_n - 1}{M_n} d_{nn}^{-\theta} \right)^{-1/\theta}. \tag{6}$$

If there were no domestic trade costs, i.e., $d_{nn} = 1$, then $\tau_{nn} = 1$ and the country-level model collapses to the standard EK model with trade costs given by the (symmetric) trade cost between all regions of country i and all regions of country n, as in (5). The key departure from this standard case, then, is caused by the presence of trade costs between regions belonging to the same country, $d_{nn} > 1$, which in our model leads to positive domestic trade costs given by τ_{nn}. According to Proposition 1, these domestic trade costs are a weighted power mean with exponent $-\theta$ of the cost of intra-regional trade (which we assume is one) and the cost of trade between regions belonging to the same country (d_{nn}), with weights given by $1/M_n$ and $1 - 1/M_n$.

Equations (3) and (4) imply that trade shares are given by

$$\lambda_{ni} \equiv \frac{X_{ni}}{X_n} = \frac{T_i w_i^{-\theta} \tau_{ni}^{-\theta}}{(\mu P_n)^{-\theta}}.$$

Applied to the case $n = i$, this leads to the following result for real wages in terms of technology levels, T_n, average domestic trade costs, τ_{nn}, and equilibrium domestic trade shares, λ_{nn},

$$\frac{w_n}{P_n} = \mu T_n^{1/\theta} \tau_{nn}^{-1} \lambda_{nn}^{-1/\theta}. \tag{7}$$

An immediate implication of this expression for real wages is that, even in the presence of domestic frictions, the gains from international trade (i.e., the change in the equilibrium real wage from autarky to the trade equilibrium) are the same as the ones in EK, namely

$$GT_n = \lambda_{nn}^{-1/\theta}. \tag{8}$$

Aggregate economies of scale arise in this model as soon as we acknowledge that the technology parameter T_n is naturally increasing with population (see Eaton and Kortum, 2001). Formally, we make the following assumption:

A2. [Technology Scales with Population] $T_n = \phi_n L_n$ for all n.

We allow ϕ_n to vary with n to reflect differences in "innovation intensity" across countries, but the important part of this assumption is that, conditional on ϕ_n, technology levels are proportional to population. This comes out naturally if we think of a "technology" as a productivity drawn from a Fréchet distribution and if we assume that the number of technologies is proportional to population.[6] An equivalent proportionality result arises in the Krugman and the Melitz models because of the free entry assumption, which implies that the number of varieties scales up with population.

Under A2, Equation (7) can now be rewritten as

$$\frac{w_n}{P_n} = \mu \left(\phi_n L_n\right)^{1/\theta} \tau_{nn}^{-1} \lambda_{nn}^{-1/\theta}. \tag{9}$$

If there were no domestic frictions, then $\tau_{nn} = 1$ and larger countries would exhibit higher real income levels with an elasticity given by $1/\theta$.[7] This is because a larger population is linked to a higher stock of non-rival ideas (i.e., technologies), and more ideas imply a superior technology frontier. The strength of this effect is linked to the Fréchet parameter θ: The lower is θ, the higher is the dispersion of productivity draws from this distribution, and the more an increase in the stock of ideas improves the technology frontier. These are the aggregate economies of scale that play a critical role in semi-endogenous growth models and that underpin the gains from openness in EK-style models.

In the presence of domestic trade costs, economies of scale depend on how τ_{nn} is affected by size, L_n. To derive sharp results, we assume that all variation in country size comes from variation in the number of regions, M_n, with all regions being the same size, $\bar{L}_n = \bar{L}$ for all n. We state this more directly as follows:

A3. [Size Scales with the Number of Regions] $L_n = M_n \bar{L}$ for all n.

We now arrive at our basic result for real wages:

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[6] Formally, consider a region in country n, and let a "technology" be a productivity ξ drawn from a Fréchet distribution with parameters θ and ϕ_n, and assume that the number of technologies per good is equal to population, $\bar{L}_n$. It is then easy to show that the best technology for a good, $z \equiv \max \xi$, is distributed Fréchet with parameters θ and $\bar{T}_n = \phi_n \bar{L}_n$.

[7] In the quantitative analysis of Sections 4 and 5, we will think of L as equipped labor and hence w/P in the model will correspond to TFP in the data.

Proposition 2. Under A1, A2 and A3, equilibrium real wages are given by

$$\frac{w_n}{P_n} = \mu \bar{L}^{1/\theta} \cdot \underbrace{\phi_n^{1/\theta}}_{\text{R\&D Intensity}} \cdot \underbrace{L_n^{1/\theta}}_{\text{Pure Scale Effect}} \cdot \underbrace{\left(\frac{1}{L_n} + \frac{L_n/\bar{L} - 1}{L_n} d_{nn}^{-\theta}\right)^{1/\theta}}_{\text{Domestic Frictions}} \cdot \underbrace{\lambda_{nn}^{-1/\theta}}_{\text{Gains from Trade}} . \tag{10}$$

There are four distinct terms that determine the real wages across countries: $\phi_n^{1/\theta}$ captures innovation intensity, $L_n^{1/\theta}$ reflects pure scale effects, $\left(\frac{1}{L_n} + \frac{L_n/\bar{L}-1}{L_n} d_{nn}^{-\theta}\right)^{1/\theta}$ captures the effect of domestic frictions on real wages, and $\lambda_{nn}^{-1/\theta}$ are the gains from trade. Since $\left(\frac{1}{L_n} + \frac{L_n/\bar{L}-1}{L_n} d_{nn}^{-\theta}\right)^{1/\theta}$ is decreasing in size when $d_{nn} > 1$, the presence of domestic frictions weakens economies of scale.[8] To see this more clearly, note that the strength of economies of scale adjusted by the fact that larger countries suffer more from domestic frictions is given by

$$\kappa \equiv \frac{d \ln \left[L_n^{1/\theta} \left(\frac{1}{L_n} + \frac{L_n/\bar{L}-1}{L_n} d_{nn}^{-\theta}\right)^{1/\theta} \right]}{d \ln L_n} = \frac{1}{\theta} \left(\frac{d_{nn}}{\tau_{nn}}\right)^{-\theta} .$$

If $d_{nn} = 1$ then $\tau_{nn} = 1$ and this is just $\kappa = 1/\theta$, as in the model. Otherwise, the term d_{nn}/τ_{nn} will be lower than one and weaken economies of scale, $\kappa < 1/\theta$.

3 Model's Calibration

We consider the same set of nineteen OECD countries as Eaton and Kortum (2002).[9] We restrict the sample to this set of richer countries to ensure that the main differences across countries are dominated by size, geography, and R&D, rather than other variables outside the model that directly affect TFP.

We need to calibrate the parameters θ and $\bar{L}$ as well as the vectors d_{nn}, M_n and ϕ_n, for all n.

Calibration of θ. The value of θ is critical for our exercise. We consider three approaches for the calibration of this parameter. First, we calibrate θ to match the growth rate of income per unit of equipped labor (or TFP) observed in the data. If $\bar{L}$ grows at a

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[8] It is worth noting that when both international and domestic trade costs are the same, $d_{mk} = d$ for all $m.k$, under A3, scale effects disappear.

[9] These countries are Australia, Austria, Belgium, Canada, Denmark, Spain, Finland, France, Great Britain, Germany, Greece, Italy, Japan, Netherlands, Norway, New Zealand, Portugal, Sweden and United States.

constant rate $g_L > 0$ in all countries and $\bar{T}_n = \phi_n \bar{L}$, then $g_T = g_L$ and the model leads to a long-run income growth rate, common across countries, of

$$g = g_L/\theta. \tag{11}$$

Equation (11) simply follows from differentiating (9) with respect to time (with a constant M_n). Following Jones (2002), we set $g_L = 0.048$, the growth rate of research employment, and $g = 0.01$, the growth rate of TFP, among a group of rich OECD countries. Together with (11), these growth rates imply that $\theta = 4.8$.[10]

Our second approach is to calibrate the parameter θ by noting that our model is fully consistent with the Eaton and Kortum (2002) model of trade. Eaton and Kortum (2002) estimate θ in the range of 3 to 12, with a preferred estimate of $\theta = 8$. More recent estimates using different procedures range from 2.5 to 5.5.[11]

Finally, a third approach is to use the results in Alcala and Ciccone (2004), who show that controlling for a country's geography (land area), institutions, and trade openness, larger countries in terms of population have a higher real GDP per capita with an elasticity of 0.3.[12] This elasticity can be interpreted in the context of (9). If geography is captured by τ_{nn}, institutions by ϕ_n, and trade openness is represented by the last term on the right-hand side of (9), the coefficient on L_n, $1/\theta$, can be equated to 0.3, the value of the (partial) income-size elasticity in Alcala and Ciccone (2004). The implied θ equals 3.3.

Given these estimates, we choose $\theta = 4$ as our baseline value, and we show our results for $\theta = 2.5$ and $\theta = 5.5$ in the robustness section. The implied (conditional) elasticity of the real wage with respect to size is then $1/\theta = 1/4$, in-between the one in Jones (2002) of $1/5$, and the one in Alcala and Ciccone (2004) of $1/3$. This elasticity may seem high relative to estimates of the scale elasticity in the urban economics literature. For example, Combes, Duranton, Gobillon, Puga, and Roux (2012) find an elasticity of productivity with respect to density at the city level of between 0.04 to 0.1. One should keep in mind, however, that these are reduced form elasticities, whereas our $1/4$ is a structural elasticity. Thus, the same reasons (i.e., internal frictions and trade openness) that make small countries richer than implied by the strong scale effects associated with an elasticity of $1/4$ should also lead to a lower observed effect of city-size on productivity in the cross-sectional data.

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[10] Jones and Romer (2010) follow a similar procedure and conclude that the data supports $g/g_L = 1/4$, which implies $\theta = 4$.

[11] Bernard, Jensen, Eaton, and Kortum (2004) estimate $\theta = 4$; Simonovska and Waugh (2011) estimate θ between 2.5 and 5 with a preferred estimate of 4; Arkolakis et al. (2013) estimate θ between 4.5 and 5.5.

[12] This finding does not contradict Rose (2006)'s finding that small countries are not poor. While his result is unconditional, the one in Alcala and Ciccone (2004) is conditional on quality of institutions, geography, and trade.

Calibration of domestic frictions. Our calibration of domestic frictions, d_{nn}, is based on the expression in (12) below. Let $\hat{X}_{nn} \equiv \sum_{m\in\Omega_n} \widetilde{X}_{mm}$ be total intra-regional trade in country n. From (1),

$$\hat{X}_{nn} = \frac{(T_n/M_n)\, w_n^{-\theta}}{(\mu P_n)^{-\theta}} X_n$$

while from (3),

$$X_{nn} = \frac{T_n w_n^{-\theta} \tau_{nn}^{-\theta}}{(\mu P_n)^{-\theta}} X_n.$$

Hence

$$\frac{\hat{X}_{nn}}{X_{nn}} = \frac{\tau_{nn}^{-\theta}}{M_n}. \tag{12}$$

Given a measure of the share of domestic trade that takes place within regions, $\hat{X}_{nn}/X_{nn}$, (12) can be used together with M_n to infer τ_{nn} which can then be combined with (6) to get an estimate of d_{nn}.

We use data for domestic manufacturing trade flows for the United States from the Commodity Flow Survey (CFS), for the years 2002 and 2007, respectively. To use these data, we think of regions in the model as states in the data and hence set $M_{US} = 51$ (fifty states plus the District of Columbia). This immediately implies that $\bar{L} = L_{US}/51$. We measure $\hat{X}_{nn}$ as the sum across all states of the intra-state manufacturing shipments, and we measure X_{nn} as total domestic manufacturing trade flows, both according to the CFS. This yields $\hat{X}_{nn}/X_{nn} = 0.41$, for 2002, implying that 41 percent of domestic U.S. trade flows are actually intra-state trade flows (see Table 8 in the online Appendix for trade flows by state). Together with $M_{US} = 51$ and $\theta = 4$, $\hat{X}_{nn}/X_{nn} = 0.41$ and (6) imply $d_{US,US}$ of 2.43. The corresponding numbers for the year 2007 are $\hat{X}_{nn}/X_{nn} = 0.45$ and $d_{US,US} = 2.52$. Notice that the high estimate for the domestic trade cost d_{nn} is a direct consequence of the high domestic trade share $\hat{X}_{nn}/X_{nn}$ (and, obviously, θ); in a frictionless world ($d_{nn} = 1$), this share would be much lower, $\hat{X}_{nn}/X_{nn} = 1/51 = 0.02$.

The only other country for which we have the required data to perform this exercise is Canada, for which we have data on manufacturing domestic trade flows across and within the thirteen provinces for years 2002 and 2007.[13] The ratio $\hat{X}_{nn}/X_{nn}$ computed with these data, for $n = CAN$, is 0.77 and 0.79 for years 2002 and 2007, respectively. The higher percentage of domestic trade that takes place within regions in Canada compared to the United States is a natural consequence of Canada being smaller, $M_{CAN} = 13 < M_{US} = 51$. In fact, this basically explains all the difference in $\hat{X}_{nn}/X_{nn}$ across the two countries. The

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[13] The source is British Columbia Statistics, at $http : //www.bcstats.gov.bc.ca/data/bus_stat/trade.asp$. Other papers that used these data are McCallum (1995), Anderson and van Wincoop (2003), and more recently, Tombe and Winter (2012).

implied d_{nn} for $n = CAN$ is 2.53 for 2002 (and 2.52 for 2007), almost the same to the number estimated for the United States.

Since we do not have the required data to calibrate d_{nn} separately for each country, we impose $d_{nn} = 2.43$ for all n.[14] Of course, we are allowing for differences in τ_{nn} across countries that come from differences in country size through M_n; this is precisely what will weaken the economies of scale in the model with domestic frictions. For instance, a small country like Denmark with an implied M_{DNK} of 1, has domestic frictions that are less than fifty percent the ones for the United States. Conversely, a large country like Japan, with $M_{JPN} = 26$, has τ_{nn} calibrated to be 70 percent the one of the United States.

In the robustness section, we consider various alternative calibrations of domestic frictions as well as of the size of the regions, $\bar{L}$.

Discussion. Readers may be surprised by our high estimates for domestic frictions d_{nn}. In fact, high trade costs are a standard feature of quantitative trade models, although they are quite sensitive to the value of the trade elasticity (see Anderson and Van Wincoop, 2004, for a related discussion). With $\theta = 4$, as we are assuming here, we need high trade costs to explain the little domestic trade we observe in the data. A higher trade elasticity would lead to lower estimates for d_{nn}. For instance, setting $\theta = 8$, which is the upper range of the estimates in the literature, would lead to a much lower value of $d_{nn} = 1.56$ for the United States. In Section 4.1, we explore the sensitivity of our results to different values of this trade elasticity.

Other estimates in the literature point to high domestic frictions within the United States. For instance, using the CFS at the most disaggregated level, Hillberry and Hummels (2008) find that shipments between establishments in the same zip code are three times larger than between establishments in different zip codes.[15]

One explanation for the high estimates of d_{nn} is the existence of non-tradable goods even within the manufacturing sector. As recently emphasized by Holmes and Stevens (2010), there are many manufactured goods that are specialty local goods (e.g., custom-made goods that need face-to-face contact between buyers and sellers), and hence non-traded. If we assumed in our model that a share of manufactures were non-tradable, the required d_{nn} would be lower, but the consequences for our exercise would be the same.

Calibration of technology and size. We calibrate ϕ_n assuming that it varies directly

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[14] We choose $d_{nn} = 2.43$ computed for $n = US$ for the year 2002 rather than the other higher estimates reported above to be conservative about the importance of domestic frictions.

[15] They propose as explanations one in which upstream-downstream producers sort in space to avoid spatial frictions, and another one in which consumers simply substitute away from distant goods simply because they are more expensive due to the spatial frictions.

with the share of R&D employment observed in the data.[16] We use data on R&D employment from the World Development Indicators averaged over the nineties. We measure L_n as equipped labor to account for differences in physical and human capital per worker, as calculated by Klenow and Rodríguez-Clare (2005), an average over the nineties as well. Note that the term $\phi_n L_n$ in (9) is a measure of R&D-adjusted equipped labor, or what we henceforth refer to simply as country size.

4 Scale Effects and Real Wages

In this section, our goal is to compute real wages implied by (9) and compare them with real wages (or TFP) in the data, and evaluate the role of openness and domestic frictions in reconciling the model and data.

To such end, we first compute real wages in the data as real GDP (PPP-adjusted) from the Penn World Tables (7.1) divided by L_n. The real wage calculated in this way is simply TFP; we henceforth refer indistinctly to real wage or TFP of country n. We consider averages over the period 1996-2001.

Next, we need to quantify the gains from trade for each country n, GT_n, the last term in (9). Similar to the procedure proposed by Arkolakis et al. (2012), we have expressed these gains as a function of observable variables in the data. Hence, we can use directly the data on trade flows and absorption (calculated as gross production minus total exports plus total imports) in manufacturing, from STAN (an average over 1996-2001), to calculate the gains from trade for each country n. [The online Appendix presents the detailed data on domestic trade shares.] The convenience of this procedure comes from the fact that it does not require to calibrate the entire matrix of international trade costs by targeting the observed bilateral trade shares; imposing the observed trade shares in the expression for the gains from trade assures that the calibrated model exactly matches the data.[17]

Using (7), the real wage for country n relative to the U.S. can be written as

$$\frac{w_n/P_n}{w_{US}/P_{US}} = \underbrace{\left(\frac{\phi_n L_n}{\phi_{US} L_{US}}\right)^{1/\theta}}_{\text{country size}} \times \underbrace{\left(\frac{GT_n}{GT_{US}}\right)}_{\text{gains from trade}} \times \underbrace{\left(\frac{\tau_{nn}}{\tau_{US,US}}\right)^{-1}}_{\text{domestic frictions}}. \tag{13}$$

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[16] If we calibrate ϕ_n to the number of patents per equipped labor registered by country n's residents, at home and abroad, results are unchanged (not shown). Similarly to R&D employment share, small countries do not have a higher number of patents per capita.

[17] This is not longer true when, as in the next section, the focus is on, for example, the terms of trade of a country. In such case, one has to estimate the entire matrix of international trade costs in order to being able to calculate the model's (equilibrium) variable of interest.

The role of scale effects is captured by the first term on the right-hand side of this expression, the role of openness to trade is captured by the second term, and the role of domestic frictions is captured by the third term.

Figure 1 shows the real wage implied by our model with scale effects, international trade, and domestic frictions (blue dots) as well as the real wage implied by the model with only scale effects (green dots) and with both scale effects and international trade but no domestic frictions (red dots). The real wages observed in the data are represented by the black dots. Real wages are plotted against our measure of country size, $\phi_n L_n$. Table 1 presents the numbers behind Figure 1.

It is very clear from the figure that the standard semi-endogenous growth model severely underestimates the real wage observed in the data (green versus black dots). According to that model, the real wage for a small country country like Denmark would be only 34 percent of the one in the U.S., reflecting very strong scale effects. In contrast, the observed relative real wage of Denmark is 91 percent. Adding domestic frictions and trade openness helps reconcile the real wage in the model and the data. In fact, our calibrated model captures very well the pattern of real wages in the data (blue versus black dots).[18] Continuing with the case of Denmark, the calibrated model implies a relative real wage of 88 percent, much closer to the data (91 percent) than the real wage implied by the standard semi-endogenous growth model (34 percent). Similar results obtain for the other small countries in our sample. In fact, the are some countries, like Belgium, for which the our calibrated model actually over-predicts the observed relative real wage.

What is the role of domestic frictions and trade openness, separately, in closing the gap between the standard model with only scale effects and the calibrated model? As the red dots indicate in Figure 1—calculated using only the first and second terms on the right-hand side of (13), trade openness does not help much in bringing the model closer to the data. Focusing again on Denmark, if countries were fully integrated domestically (i.e., no domestic frictions) and open to trade, the relative real wage for Denmark would be only 41 percent as high as in the U.S., a small improvement with respect to the standard semi-endogenous growth model. In general, small countries would be much poorer in the model than in the data without domestic frictions (with Belgium being the exception).[19]

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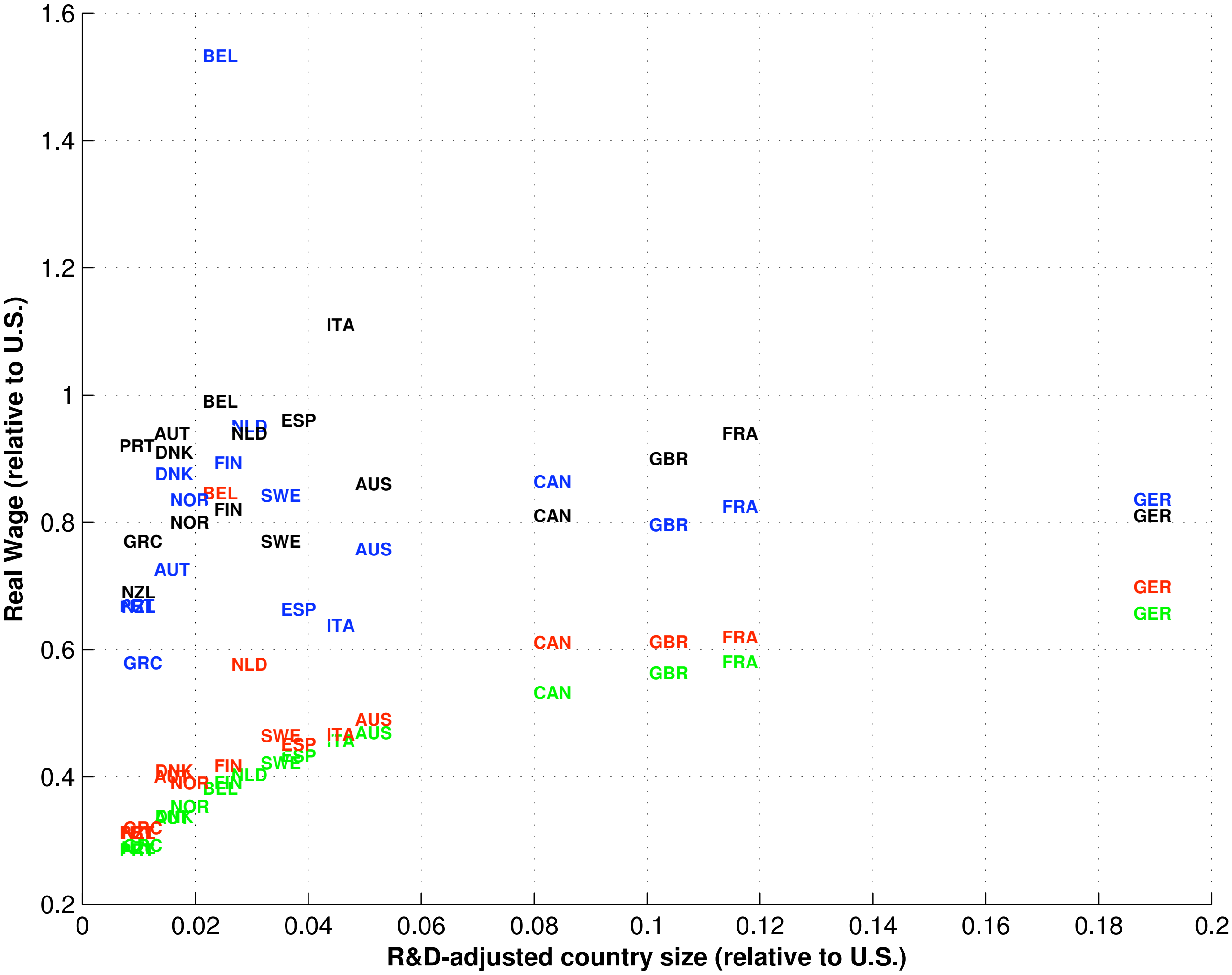
[18] An OLS regression (with robust standard errors and no constant) delivers a TFP elasticity of 0.038 (s.e. 0.0076) and R-squared of 0.51, with respect to R&D-adjusted country size, in the data, while the regression using our model delivers an elasticity of 0.061 (s.e. 0.014) and R-squared of 0.55.

[19] This counterfactual implication is avoided in calibrated trade-only models, such as Waugh (2010), by calibrating the Fréchet parameter T_n to exactly match the real wages in the data. This leads to ratios of T_n/L_n that are much higher for small countries (this is also a consequence of Eaton and Kortum (2002) calibration strategy).

Figure 1: Scale Effects, Trade Openness, and Domestic Frictions.



Blue = model with international trade and domestic frictions (baseline calibration). Red = Model with international trade and no domestic frictions. Green = model with no international trade and no domestic frictions. Black = data. Japan not shown. R&D-adjusted country size refers to $\phi_n L_n$, where ϕ_n is the share of R&D employment observed in the data and L_n is a measure of equipped labor. All variables are relative to the United States.

It is important to clarify that, as expected, small countries do gain much more than large countries. It is just that this is not large enough to have a substantial role in closing the gap between the model and the data. For example, Denmark has much larger gains from trade than the U.S. (29.5 versus 6.7 percent), but this only increases the implied relative real wage of Denmark from 34 to 41 percent. Column 2 in Table 1 shows the results for the gains from trade (relative to the U.S.), by country.

Domestic frictions are the channel that helps to bring the calibrated model's relative real wage closer to the one observed in the data. If countries were closed to international trade but not fully integrated domestically—first and third term on the right-hand side of (13)—(not shown in the figure), the (relative) real wage for Denmark would be 0.71, much closer to the real wage implied by the full model (0.88). A simple decomposition reveals that domestic frictions close more than two thirds of the gap between the real wage in the data and in the model with only scale effects, while openness to trade only accounts for around thirteen percent.[20] This is very similar for all small countries in our sample. In particular, for the six smallest countries in our sample, on average, domestic frictions account for almost 65 percent of the gap, while trade openness accounts for less than ten percent.

More formally, we use

$$\Delta \equiv \sum_{n} \left[(w_n/P_n)^{model} - (w_n/P_n)^{data} \right]^2 , \tag{14}$$

as a measure of the fit of the model with the data. For our calibrated model (blue dots), $\Delta = 0.85$, while for the standard semi-endogenous growth model (green dots) Δ is three times higher (3.88). We also compute the Δ for the models with scale effects, but one with trade openness and no domestic frictions (red dots) and one with domestic frictions but no trade openness (not shown in Figure 1). While for the first model, $\Delta = 2.9$, for the second model, we get $\Delta = 0.95$. The fact that in the latter case Δ is very similar to the one for the full model shows that most of the work of reconciling the model with the data is actually done by domestic frictions rather than trade openness.

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[20] We calculate the difference between the real wage implied by only scale effects and the data, and compare it with the difference between the real wage implied by the model augmented with only domestic frictions and only trade openness, respectively, and the real wage implied by scale effects.

4.1 Robustness

4.1.1 The Role of θ

To explore the effect of the value of θ on our results, let $O_n \equiv \lambda_{nn}^{-1}$, $D_n \equiv \tau_{nn}^{\theta}$ and rewrite (13) as

$$\frac{w_n/P_n}{w_{US}/P_{US}} = \left[\left(\frac{\phi_n L_n}{\phi_{US} L_{US}} \right) \left(\frac{D_n}{D_{US}} \right)^{-1} \left(\frac{O_n}{O_{US}} \right) \right]^{1/\theta} . \tag{15}$$

All the terms inside the bracket come directly or indirectly, from the data and do not depend on the value of θ.[21] Hence, this expression tells us how the relative real wage implied by the calibrated model changes with θ (in the exponent). For countries with a lower real wage than the United States, a higher θ increases the relative real wage towards one.

Table 2 shows how the gap between the calibrated and observed real wage varies with different values of θ. For $\theta = 5.5$, Denmark's calibrated real wage, relative to U.S., is exactly as observed in the data, 0.91. In contrast, for $\theta = 2.5$, the calibrated model delivers a relative real wage for Denmark of 0.81. Notice that, under isolation and no domestic frictions, for $\theta = 2.5$, the relative real wage implied by the model for Denmark would be of only 0.18, while for $\theta = 5.5$, it would reach 0.45.

4.1.2 Alternative Calibrations for Domestic Frictions

We consider alternative calibrations for domestic trade costs, d_{nn}, and the size of regions, $\bar{L}$, and show that they entail similar results regarding the relative real wage as for the baseline calibration.

Following the same procedure as for the fifty one states of the United States, we consider shipments between 100 geographical units, among which we have Consolidated Statistical Areas (CSA), Metropolitan Statistical Areas (MSA), and the remaining portions of (some of) the states, for 2007, from the Commodity Flow Survey.[22] The ratio $\widehat{X}_{nn}/X_{nn}$ calculated using the 100 U.S. geographical units is 0.35, against 0.41 when using U.S. states. We set $M_{US} = 100$ and use (12) and (6) to calibrate d_{nn}. For $\theta = 4$ and year 2007,

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[21] Notice that D_n does not depend on θ because $d_{nn}^{-\theta}$ is pinned down, through (12), by $\widehat{X}_{nn}/X_{nn}$ and M_n, both coming from the data for the United States.

[22] We compute internal trade for 99 geographical units: 48 are Consolidated Statistical Areas (CSA), 18 are Metropolitan Statistical Areas (MSA), and 33 represent remaining portions of (some of) the states. For each of the 99 geographical units, we compute the total purchases from the United States and subtract trade with the 99 geographical units to get trade with the rest of the United States, which is considered the 100th geographical unit in our exercise.

we get $d_{nn} = 2.69$, against $d_{nn} = 2.52$ using U.S. states.

As mentioned above, we alternately use data on trade flows between ten provinces and three territories of Canada, for 2002 and 2007, respectively. Using (12) and (6), together with $M_{CAN} = 13$ and $\theta = 4$, we get $d_{nn} = 2.53$ and $d_{nn} = 2.52$, for 2002 and 2007, respectively.

Each of the calibrations on internal frictions discussed above entail a different M_n for the remaining countries in the sample. Specifically, as in the baseline calibration, we set $\overline{L} = 100/L_{US}$ when calibrating to the 100 U.S. geographical units and $\bar{L} = 13/L_{CAN}$ when calibrating to the 13 Canadian geographical units. We then set M_n for the rest of the countries in our sample using $M_n = L_n/\overline{L}$. Columns 2 and 3 in Table 3 present the implied number of regions in each case, for all countries in the sample.

Our third robustness exercise incorporates data on population density for each country in our sample into our measure of M_n.[23] The idea is that more dense countries should be allowed to have larger regions, hence a higher $\bar{L}_n$. We assume that $\overline{L}_n$ is proportional to population density defined as habitants per unit of land, $v_n \equiv L_n/A_n$, where A_n is area of country n. Rather than fixing the size of all regions to the size of a U.S. region in terms of equipped labor, we fix the *area* of all regions to the average *area* of U.S. regions, $\bar{A}_{US} = A_{US}/M_{US}$, with $M_{US} = 51$ as in our baseline case. Then, $\bar{L}_n = \bar{A}_{US}v_n$ and again $M_n = L_n/\bar{L}_n$. Column 4 in Table 3 presents the implied number of regions by country. With this alternative calibration, low-density countries are have more regions because a low density implies that more regions are needed to fit a given population.

Finally, we consider the case in which M_n is calibrated directly to the number of towns with more than 250,000 habitants observed in the data, for each country. This calibration naturally implies that $\bar{L}_n$ is different for each country n. Column 5 in Table 3 shows these data.

In the calibrations that use the country's density and the number of towns observed in the data to calibrate M_n, we keep d_{nn} as in our baseline estimate.

The results do not change in any significant way as we consider these alternative calibrations. Columns 6 to 10 in Table 3 present the implied relative real wage for the five different calibrations described above. The gap between data and model for Denmark remains very similar across all calibrations. In fact, for the calibration that uses the observed number of towns of more than 250K habitants, the gap between data and model is virtually closed. One exception among the small countries is Netherlands for which the

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[23] Density is defined as population per square kilometer of land space. The data are from the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2007).

calibration that assumes regions of fixed land areas delivers a much higher relative real wage than the one observed in the data. Overall, the R-squared for the model calibrated to U.S. regions—our baseline calibration—is the highest.

Our final robustness exercise involves an alternative calibration of d_{nn}. The procedure applies the index of trade costs developed by Head and Ries (2001), and Head, Mayer, and Ries (2010), to domestic trade flows. In particular,

$$d_{mk}^{HR} \equiv \left(\frac{\widetilde{X}_{mk}}{\widetilde{X}_{kk}} \frac{\widetilde{X}_{km}}{\widetilde{X}_{mm}} \right)^{-\frac{0.5}{\theta}},$$

where the assumption is that $d_{mk}^{HR} = d_{km}^{HR}$, and m and k are geographical units belonging to the same country. We estimate d_{mk}^{HR} using *all* the bilateral matrix of internal trade flows among the fifty one U.S. states, among the 100 U.S. smaller geographical units (CSA-MSA), and among the thirteen Canadian provinces, respectively. In all cases, the average trade cost index is higher than the value used in our baseline calibration. Table 4 summarizes the results.[24]

4.2 Other Channels

Our results show that trade openness and domestic frictions account for a large share of the difference in the real wage for small countries between the calibrated model and the data. Both channels together explain more than 85 percent of the gap between model and data for Denmark's real wage relative to the United States. The numbers for other small countries are similar. We restricted our attention to income differences across countries only coming from differences in R&D-adjusted size, gains from trade, gains from MP, diffusion, and domestic frictions. Here we discuss some forces left out of the model that can be potentially important to further reconcile the model and the data.

One obvious possibility is that small countries benefit from "better institutions," which in the model would be reflected in higher technology levels ($\overline{T}_n$) than those implied by the share of labor devoted to R&D. Good institutions might be precisely what allowed these countries to remain small and independent in the first place. To explore this possibility, we used patents per R&D-adjusted equipped labor, rather than R&D employment shares, as a proxy for $\overline{T}_n$ in our quantitative exercise. Our baseline results do not change. In fact, small countries do not exhibit higher patenting productivity than larger ones; on the contrary, the correlation between patents per unit of R&D-adjusted equipped labor

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[24] Figure 4 in the online Appendix shows the distribution of costs for the United States and Canada, respectively.

and country's R&D-adjusted size is positive and around 0.7, when the United States and Japan are included, decreasing to 0.35 when those two countries are excluded.

Furthermore, small countries are not systematically better in terms of schooling levels, corruption in government, bureaucratic quality, and rule of law. The correlations between these variables and R&D-adjusted size are 0.30, -0.17, 0.12, 0.22, respectively; the data do not support the idea that smallness confers some productivity advantage through better institutions. Table 9 in the online Appendix lists all these variables, as well as patents per unit of equipped labor, by country.

Another possibility is that the gains from openness materialize in ways other than trade and MP. An obvious example is international technology diffusion which allows local firms to use foreign technologies. Unfortunately, except for the small part that happens through licensing, technology diffusion does not leave a paper trail that can be used to *directly* measure the value of production done in a country by domestic firms using foreign technologies.[25] Some indirect evidence points to the importance of international diffusion for growth. Eaton and Kortum (1996, 1999) develop a quantitative model that allows them to use international patent data to indirectly infer diffusion flows. They estimate that most of the productivity growth in OECD countries, except for the United States, is due to foreign research: between 84 percent and 89 percent in Germany, France, and the United Kingdom, around 65 percent for Japan, and about 40 percent for the United States.[26]

Finally, a potential source of gains from openness is international migration. A recent paper by Ortega and Peri (2012) points out to the importance of the diversity of immigrant pool, rather than trade, as a key variable in explaining income differences across countries, using a sample of more than 120 countries. For our sample of rich OECD countries, the correlation between the degree of diversity of immigrants and income per capita is positive, of almost 0.5, but the correlation with R&D-adjusted size is zero.[27] Again, this evidence suggests that smallness do not confer some productivity advantage through immigration.

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[25] According to the data published by the Bureau of Economic Analysis, royalties and licenses paid to U.S. parents and foreign affiliates by unaffiliated parties for the use of intangibles represented only one percent of total affiliates sales, in 1999.

[26] Keller (2004) also finds that, for nine countries that are smaller than the United Kingdom, the contribution of domestic sources to productivity growth is about ten percent.

[27] The degree of diversity of immigrants is measured by the number of source countries of immigrants, as in Ortega and Peri (2011), for 2000.

5 Beyond Real Wages: Gravity, Terms of Trade, and Domestic Frictions

What are the implications of adding domestic frictions for standard results in the trade literature? We first focus on gravity estimates of international trade costs, and study the consequence of not including domestic frictions on the estimates of the "exporter fixed effect," as proposed by Waugh (2010). We then show that allowing for domestic frictions as implied by our model and calibrated in Section 3 lead to better performance of the model in terms of matching the data on import shares and relative income levels across countries.

5.1 Exporter Fixed Effects and Domestic Frictions

Combining the expression for trade flows in (3), for $l \neq n$ and $l = n$ yields

$$\frac{X_{nl}}{X_{nn}} = \left(\frac{\tau_{nl}}{\tau_{nn}}\frac{w_l}{w_n}\right)^{-\theta}\left(\frac{\phi_l L_l}{\phi_n L_n}\right). \tag{16}$$

The term τ_{nn} is a country-specific effect greater than one. When $d_{nn} = 1$, $\tau_{nn} = 1$ and (16) collapses to the expression in Eaton and Kortum (2002) and Waugh (2010).

We follow Waugh (2010) and assume that international trade costs include an exporter fixed effect, ex_l,

$$\log \tau_{nl} = \delta_d \log dist_{nl} + b_{nl} + l_{nl} + ex_l + \varepsilon_{nl}. \tag{17}$$

The variable $dist_{nl}$ is distance between n and l in kilometers, b_{nl} (l_{nl}) is equal to one if n and l share a border (language), and zero otherwise, and ε_{nl} reflects barriers to trade arising from all other country-pair specific factors that are orthogonal to the regressors. The expression in (16) can then be written as

$$\log \frac{X_{nl}}{X_{nn}} = S_l - H_n - \theta\delta_d \log dist_{nl} - \theta b_{nl} - \theta l_{nl} - \theta\varepsilon_{nl}, \tag{18}$$

where

$$S_l \equiv -\theta ex_l - \theta \log w_l + \log \phi_l L_l, \tag{19}$$

and

$$H_n \equiv -\theta \log \tau_{nn} + \theta \log w_n + \log \phi_n L_n. \tag{20}$$

These expressions for S_l and H_n gather source and destination country characteristics, respectively. Subtracting (20) from (19) for country l yields

$$S_l - H_l = \theta(\log \tau_{ll} - ex_l). \tag{21}$$

Clearly, if domestic frictions were present, the fixed effect ex_l could not be identified from (21). Moreover, the effect of domestic frictions on trade flows would be interpreted as part of the exporter fixed effect whose estimate would be

$$\hat{ex}_l \equiv -\frac{1}{\theta}(\hat{S}_l - \hat{H}_l) = ex_l - \log \tau_{ll}. \tag{22}$$

This result implies that estimates coming from the model without domestic frictions will be biased. More importantly, as shown in (6), τ_{ll} is larger for larger countries, so that the bias $\hat{ex}_l - ex_l$ will be systematically lower for larger countries.[28] If the true fixed effect ex_l does not vary systematically with country size, we should find that the correlation between country size and the estimated fixed effect, $\hat{ex}_l$, should be negative. Figure 2 plots the exporter fixed effects, derived from estimating (18) by ordinary least squares (OLS), against our measure of R&D-adjusted size, $\phi_n L_n$.[29,30]

Larger countries have systematically lower estimated costs of exporting: the correlation between $\phi_n L_n$ and $\hat{ex}_l$ is -0.67.[31] This result is robust to other measures of country size and a larger sample of countries.[32] If we use absorption in manufacturing for 1996, as in Waugh (2010), rather than R&D-adjusted size, the correlation between that measure of country size and the exporter fixed effect goes to -0.71. The same correlation using the sample of 77 countries considered by Waugh (2010) as well as his own estimates of $\hat{ex}_l$ is -0.23.[33]

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[28] This is under the assumption that d_{ll} does not systematically vary with country size. We assume that $d_{ll} = d$ for all l, in our quantitative analysis, so that variations in τ_{ll} come exclusively from the number of regions M_l within a country.

[29] The exporter fixed effect is expressed in terms of the percentage effect on cost, $e^{-\theta \hat{ex}_l} - 1$, with the mean across countries normalized to zero. For the United States, we find $e^{-\theta \hat{ex}_l} - 1 = -0.94$, indicating that the U.S. cost of exporting is 94 percentage points lower than the cost in the average country in our sample.

[30] With 342 observations, and robust standard errors, the OLS estimates of (18) are:

$$\log \frac{X_{nl}}{X_{nn}} = \widehat{S}_l - \widehat{H}_n - 0.92^{***} \log dist_{nl} + 0.035 b_{nl} + 0.51^{***} l_{nl},$$

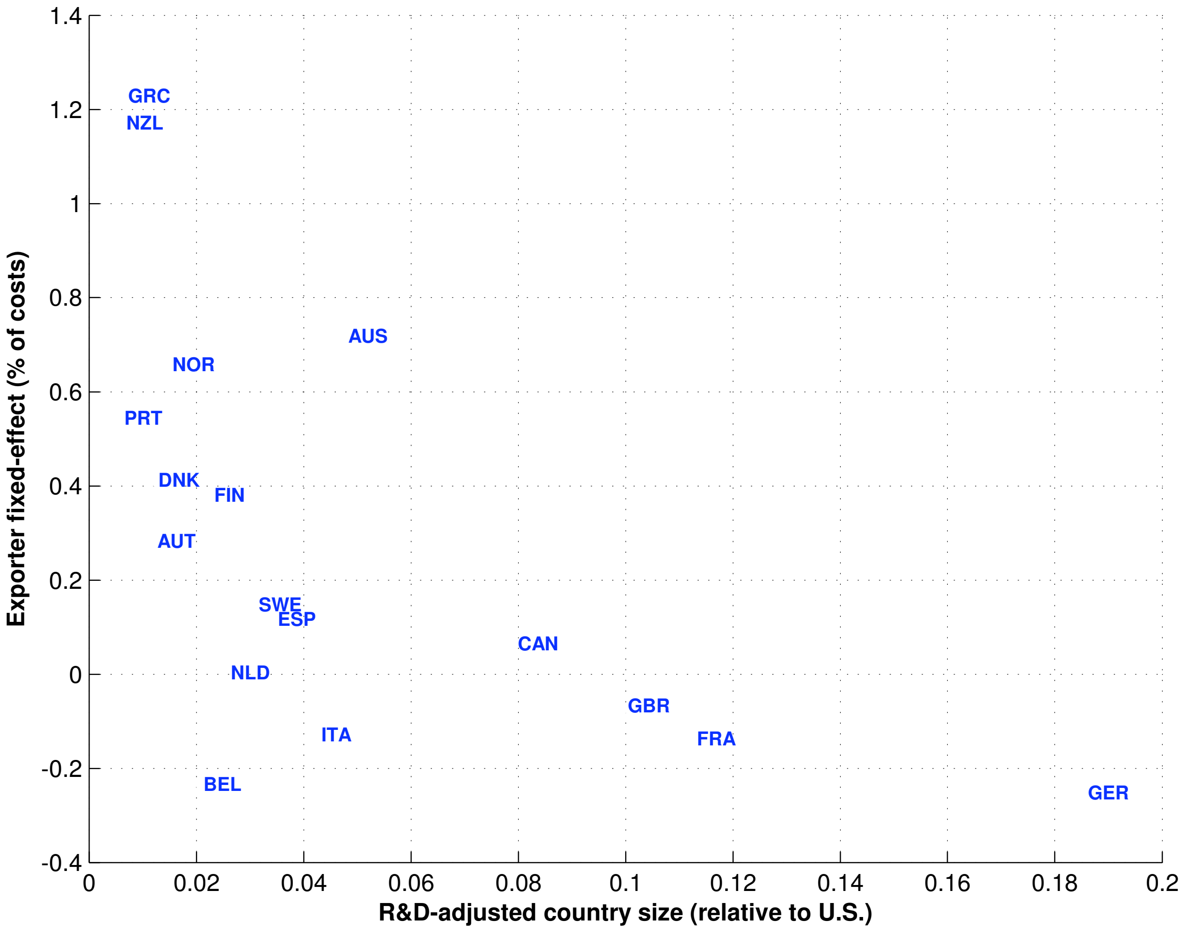
where *** denotes a level of significance of $p < 0.01$.

[31] The R-squared of a regression of the exporter fixed effects, expressed as costs, on (log of) R&D-adjusted size, with robust standard errors and a constant, is 0.68, and the size coefficient is -0.31 (s.e. 0.046).

[32] Additionally, taking the estimated exporter fixed effects directly from Waugh (2010), for our sample of countries, delivers a correlation with R&D-adjusted size of -0.46.

[33] The R-squared for a regression of the exporter fixed effects on (log of) absorption, with robust standard errors and a constant, is 0.56 and the size coefficient is -0.18 (s.e. 0.019), for the sample of 77 countries.

Figure 2: Exporter fixed effects and country size.



The exporter fixed effect is expressed in terms of the percentage effect on cost, $e^{-\theta \hat{ex}_l} - 1$, with the mean across countries normalized to zero. R&D-adjusted country size refers to $\phi_n L_n$, where ϕ_n is the share of R&D employment observed in the data and L_n is a measure of equipped labor. Not shown: Japan = (0.57,-40) and USA = (1,-94).

We draw two conclusions from this exercise. First, there is a positive correlation between estimated exporter fixed effects and country size, and this supports the idea that domestic frictions are important and increase with country size. Second, ignoring domestic frictions leads to a bias in the estimation of international trade costs, with exporting costs having an upward bias for small countries and an upward bias for large countries.

5.2 Terms of Trade, Import Shares, and Domestic Frictions

We now assess the performance of the trade model with domestic frictions, vis-$\grave{a}$-vis the trade model without domestic frictions, in terms of a import shares and terms of trade, defined as the wage in country n relative to the U.S. We also show, again, the predictions of both models regarding the real wage, for reasons that will be clear below.

In order to calculate both the import share and the relative wage for country n, it is necessary to have the matrix of international trade costs τ_{nl}, for $n \neq l$. This is true for the model with and without domestic frictions. To estimate such frictions, we recur to the structural iterated least squared (SILS) method proposed by Head and Mayer (2013) to estimate a gravity model of trade. First, we assume that trade costs have the form

$$\log \tau_{nl} = \delta_1 + \delta_2 \log dist_{nl}, \tag{23}$$

for $n \neq l$. For $n = l$, trade costs take the values from our baseline calibration in the model with domestic frictions, and the value of one for the model with no frictions. By assuming that international trade costs depend only on geographic bilateral variables, we make sure that these costs are not capturing country size. SILS proceeds as follows:

1. Guess a value for δ's and compute (23), for $n \neq l$;
2. Given the parameters calibrated in Section 3, compute the equilibrium (following the algorithm in Alvarez and Lucas, 2007) to get wages and price indices, and then compute E_l and I_n defined as

$$\log X_{nl}/X_n = \underbrace{\log T_l - \theta \log w_l}_{E_l} + \underbrace{\theta \log(\mu P_n)}_{I_n} - \theta \log \tau_{nl}; \tag{24}$$

3. Estimate new δ's through OLS on

$$\log \frac{X_{ni}^{data}}{X_n^{data}} - E_l - I_n = -\theta\delta_1 - \theta\delta_2 \log dist_{nl}; \tag{25}$$

4. Iterate on δ's until convergence.

The procedure is run twice: for τ_{nn} as defined in (6), for the values of d_{nn} and M_n calibrated in Section 3, and for $\tau_{nn} = 1$, alternately. The R-squared for (25), at the estimated δ's. for the model with $\tau_{nn} > 1$ is 0.75, while the R-squared for the model with $\tau_{nn} = 1$ is 0.70.

The question we ask is: using these estimates for international trade costs, what are the implications of a model with and without domestic frictions, respectively, regarding the import share ($\sum_{l \neq n} X_{nl}/X_n$), the terms of trade ($w_l$), and the real wage ($w_l/P_l$), for country l? To proceed, we simulate both models using the estimates of international trade costs coming from the SILS procedure for both models.[34] Figure 3 summarizes the results.

It is clear that the model with no domestic frictions fails to capture the pattern of import shares, terms of trade, and real wages, across countries of different size, observed in the data.[35] Relative to the United States, import shares are, as shown in the figure, on average, 3.3 in the data, 3.98 in our model, and 11.5 in the model with no domestic frictions. Evidently, the trade model without domestic frictions delivers import shares that decrease too rapidly with respect to country size. The presence of domestic frictions, by offsetting scale effects, reconciles much better the model with the data. A similar story is found for the terms of trade: when domestic frictions are ignored, small countries have relative wages that are too low with respect to the ones observed in the data. This results is driven by the fact that in the standard model of trade, small countries have a disadvantage due, precisely, to their small size. Again, by offsetting scale effects, domestic frictions bring the model much closer to the data. Finally, the real wage, as found in the previous section, is severely underestimated for small countries when there are no domestic frictions. Table 5 summarizes the statistics behind Figure 3.

Our results for the model without domestic frictions stand in contrast to those of Alvarez and Lucas (2007), whose calibrated trade model matches well the relationship between size and import shares across countries. As we do in A2, Alvarez and Lucas (2007) allow technology levels to scale up with size, but rather than using equipped labor as a measure of size, they calibrate L_n so that $w_n L_n$ in the model equals nominal GDP in the

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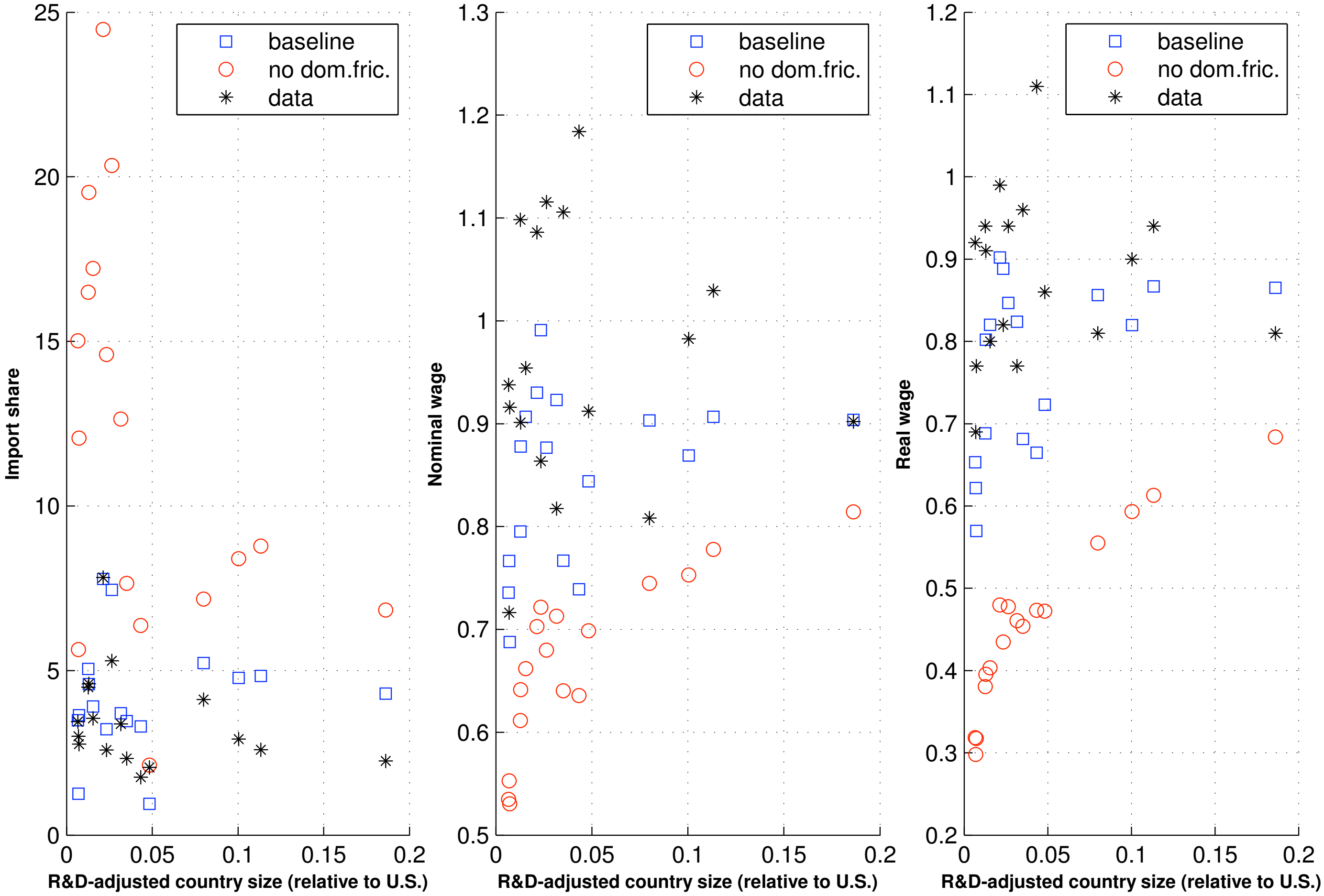
[34] Notice that the implications for the real wage shown in previous sections, for a model with and without frictions, respectively, were drawn for a calibrated model that exactly matched the import shares observed in the data. Here, the models are calibrated using gravity and, consequently, the implied real wages are different.

[35] The import share for country n in the data is calculated as the sum of trade flows in manufacturing into n from all the remaining countries in our sample, as a share of absorption in manufacturing for country n. The nominal wage in the data is calculated as GDP at current prices (PPP-adjusted) from the Penn World Tables (7.1) divided by our measure of equipped labor.

Figure 3: Import shares, terms of trade, and real wages.



The import share for country l is given by $\sum_{l \neq n} X_{nl}/X_n$; the terms of trade for country l are w_l; and the real wage is w_l/P_l^f. All variables are relative to the U.S. R&D-adjusted country size refers to $\phi_n L_n$, where ϕ_n is the share of R&D employment observed in the data and L_n is a measure of equipped labor. Japan not shown.

data. Letting e_n be efficiency per unit of equipped labor in country n, their procedure is equivalent to calibrating e_n such that $e_n \left(L_n/\lambda_n\right)^{1/\theta}$ matches observed TFP levels. For our sample of countries, their calibrated size ($e_n L_n$) has much less variation than the observed measure of equipped labor (S.D. of 0.06 versus 0.24, respectively), implying that small countries have a much higher efficiency per unit of equipped labor than large ones, as reflected in the negative and significant OLS coefficient of -0.90 coming from estimating (log of) e_n on (log of) L_n (with a constant and robust standard errors).

Waugh (2010) goes back to using equipped labor (from Caselli, 2005) as the empirical counterpart of size (L) in the model, but then estimates T so that the model without domestic frictions matches the trade data. His estimated T/L ratios (with T_{USA}/L_{USA}=1) are much higher for small than large countries: the OLS coefficient for (log of) T_n/L_n on (log of) L_n (with a constant and robust standard errors) is significantly negative (-0.67).

Summing up, the exercises in this section point out to domestic trade frictions as an important channel not only for reconciling the standard model of trade with the data on real wages, but also for reconciling the standard model with the data on import shares and terms of trade.

6 Multinational Production and Non-Tradable Goods

In the model of Section 2, international trade was the only channel through which countries could gain from openness. But, arguably, the activity of multinational firms could be even more important. We now incorporate multinational production as an extra channel for the gains from openness. To do so, we extend the model of Section 2 by allowing technologies to be used outside of the region where they originate. Whenever this happens we say that there is multinational production (MP).

We follow Ramondo and Rodríguez-Clare (2013) in assuming that a technology has a productivity z_n in each country $n = 1, ..., N$. Moreover, to introduce frictions to the "movement of ideas" within countries, in parallel to the way we introduced domestic frictions for trade, we assume that each technology has a "home region" in each country. Using a technology originated in country i for production outside of the technology's home region in country i entails an iceberg-type efficiency loss, or "MP cost," of $h_{ii} \geq 1$. Moreover, using a technology originated in country i in the technology's home region in country $l \neq i$ entails an MP cost of $\gamma_{li} \geq 1$. Finally, the total MP cost associated with using a technology from country i outside of the technology's home region in country $l \neq i$ is

$\gamma_{li} h_{ll}$.[36]

In sum, each technology is characterized by three elements: first, the country i from which it originates; second, a vector that specifies the technology's productivity parameter in each country, $\boldsymbol{z} = (z_1, ..., z_N)$; and third, a vector that specifies the technology's home region in each country, $\boldsymbol{m} = (m_1, ..., m_N)$. The effective productivity of a technology $(i, \boldsymbol{z}, \boldsymbol{m})$ is z_i if used in region m_i, z_i/h_{ii} if used in region $m \in \Omega_i$ with $m \neq m_i$, z_l/γ_{li} if used in region m_l for $l \neq i$, and $z_l/\gamma_{li} h_{ll}$ if used in region $m \in \Omega_l$ for $l \neq i$ and $m \neq m_l$.

We assume that productivity levels z_n for technologies originating in country i are independently drawn from the Fréchet distribution with parameters $\bar{T}_i$ and θ, and we assume that m_n is uniformly and independently drawn from the set Ω_n.

In the model with MP, we introduce both tradable and non-tradable goods, since around half of MP flows in the data occur in non-tradable goods. We follow Alvarez and Lucas (2007) and assume that tradable goods are intermediate goods while non-tradable goods are final goods. There is a continuum of final goods and a continuum of intermediate goods, both in the interval $[0, 1]$. Preferences over final goods are CES with elasticity of substitution $\sigma > 0$. Intermediate goods are used to produce a composite intermediate good also with a CES aggregator with elasticity $\sigma > 0$. The composite intermediate together with labor are used via a Cobb-Douglas production function to produce final and intermediate goods with labor shares α and β, respectively.

We assume that MP is possible in both the final and intermediate goods, and that the MP costs are the same in both cases. Further, we assume that $1 \leq d_{nn} = h_{nn}$. Consider a particular intermediate good whose home region is m_n. The price of this good in other regions of country n ($m \in \Omega_n$, $m \neq m_n$) is determined by z/d_{nn} if traded and z/h_{nn} if produced locally via MP. Our assumption that $d_{nn} = h_{nn}$ implies that there is indifference between these two options. We assume that the indifference is broken in favor of trade, which implies that there is no MP across regions within countries for intermediates.

Our main object of interest in this Section is the equilibrium real wage in each country n, which we will compare with the real wage (or TFP) in the data.[37] In the model with trade, MP, and domestic frictions, this endogenous variable can be written as a function

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[36] The assumption that technologies have a home region in each country is made to keep the treatment of domestic and foreign technologies consistent. We assume that technologies originated in country i are "born" in a particular region and then face an MP cost h_{ii} to be used in another region of country i. The analogous assumption for the use of technologies from i in country $n \neq i$ is that they also have a region in country n where they are "reincarnated" (their home region), and then face an MP cost h_{nn} to be used in another region of country n.

[37] A detailed derivation of the model's equilibrium with trade, MP, and domestic frictions in both goods and ideas is relegated to the Appendix.

of trade and MP flows,

$$\frac{w_n}{P_n} = \mu^M \underbrace{\phi_n^{\frac{1+\eta}{\theta}}}_{\text{R\&D Intensity}} \cdot \underbrace{L_n^{\frac{1+\eta}{\theta}}}_{\text{Pure Scale Effect}} \cdot \underbrace{\gamma_{nn}^{-1}\tau_{nn}^{-\eta}}_{\text{Dom. Frictions}} \cdot \underbrace{\lambda_{nn}^{-\frac{\eta}{\theta}}}_{\text{Gains Trade}} \cdot \underbrace{\pi_{nn}^{-\frac{1+\eta}{\theta}}}_{\text{Gains MP}}, \tag{26}$$

where μ^M is a positive constant (defined in the Appendix), $\eta \equiv \frac{1-\alpha}{\beta}$,

$$\gamma_{nn} \equiv \left[\frac{1}{M_n} + \frac{M_n - 1}{M_n} h_{nn}^{-\theta}\right]^{-1/\theta}, \tag{27}$$

and π_{nn} is the domestic MP share.[38] There are several points to note about the result in Equation (26). First, the pure scale effect now has elasticity $(1+\eta)/\theta$ rather than $1/\theta$. The reason is that there are scale effects operating in both the final and intermediate goods sectors. The scale effect elasticity in the final goods sector is $1/\theta$, just as before, but this elasticity is η/θ in the intermediate goods sector. The term η captures the amplification of gains by factor $1/\beta$ in the intermediate goods sector because of the input-output loop and the weakening of the overall effect because intermediates are only used with share $1-\alpha$ in the production of final goods. Second, the real wage is now affected by frictions to domestic trade and to domestic MP. The impact of domestic trade frictions is now $\tau_{nn}^{-\eta}$, while the impact of domestic MP frictions is γ_{nn}^{-1}. Third, the gains from trade are now captured $\lambda_{nn}^{-\eta/\theta}$ rather than $\lambda_{nn}^{-1/\theta}$. Finally, the term $\pi_{nn}^{-(1+\eta)/\theta}$ captures the gains from MP (i.e., the change in the real wage from a situation with no MP to the observed equilibrium), for both final and intermediate goods. The *gains from openness* are just the product of the gains from trade and the gains from MP, $\lambda_{nn}^{-\eta/\theta}\pi_{nn}^{-(1+\eta)/\theta}$.

Conveniently, as for the gains from trade, the gains from MP are expressed as a function of observed flows. Data on the gross value of production for multinational affiliates from i in n, from UNCTAD, is used as the empirical counterpart of bilateral MP flows in the model, which in turn is used to compute the MP shares, π_{nn}. GDP in current dollars (from World Development Indicators) is the empirical counterpart of $w_n L_n$ in the model. We also need to calibrate the labor shares α and β, and recalibrate the parameter θ accordingly. We set $\alpha = 0.75$, $\beta = 0.50$, and $\theta = 6$. The Appendix presents the description of the MP data and more details on the calibration of these three parameters. Here we just note that $(1+\eta)/\theta = 1/4$ so that the strength of scale effects is the same as for the baseline calibration. Our calibration of domestic frictions for trade in goods and number of regions in each country is equivalent to the procedure described for the baseline model. For $\theta = 6$, we get $d_{nn} = 1.81$.

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[38] Formally, $\pi_{li} \equiv Y_{li}/Y_l$, where Y_{li} is value of production in country l with technologies originated in country i, with $Y_l \equiv \sum_i Y_{li}$.

Column 7 of Table 6 shows the relative real wage for the model with trade, MP, and domestic frictions. Columns 2, 3, 4, and 5 of Table 6 show the gains from trade, MP, and openness, and the term capturing domestic frictions, respectively, all relative to the United States. Given our assumption that $h_{nn} = d_{nn}$ then $\gamma_{nn} = \tau_{nn}$. Together with $(1 + \eta)/\theta = 1/4$ and the recalibration of d_{nn} to maintain (12), this implies that there is no difference in the role of domestic frictions here with respect to the model of Section 2. But the gains from trade are now $\lambda_{nn}^{-\eta/\theta}$, with $\eta/\theta = 1/12$, rather than $\lambda_{nn}^{-1/\theta}$, with $1/\theta = 1/4$ in Section 2. Consequently, the gains from trade have a smaller role now, as shown in column 6 of Table 6, although the gains from openness now also include the gains from MP. But as column 3 indicates, MP does not help much to increase real wages relative to the United States for small countries because the United States has large gains from MP. While only Japan has lower gains from trade than the United States (column 2), several countries have lower gains from MP than the United States.

Overall, our measure of fit in (14) for the model with both trade and MP presents an improvement with respect to the model with only trade, from 0.85 to 0.65.[39] The improvement in fit is even larger if only the six smallest countries in the sample are considered (from 0.15 to 0.03). Nevertheless, the result from Section 3 still holds: the existence of domestic frictions, rather than openness, remains the dominant channel to bring the calibrated model closer to the data. For instance, for Denmark, adding MP does not help much quantitatively to bring the relative real wage in the calibrated model closer to the one observed in the data: the implied relative real wage is 0.80, against 0.91 in the data and 0.88 in the baseline model. More generally, looking at the average for the six smallest countries in the sample, trade and MP openness together help to close around 17 percent of the gap between the standard model with only scale effects and the data on relative real wages, while domestic frictions close 60 percent of the gap.

7 Conclusion

Models in which growth is driven by innovation naturally lead to scale effects. This feature results in the counterfactual implication that larger countries should be much richer than smaller ones. These scale effects are also present in the standard gravity model of trade. In those models, trade and scale lead to TFP gains through exactly the same mechanism as innovation-led growth models, namely an expansion in the set of available non-rival ideas. These trade models, as semi-endogenous growth models do, assume that

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[39] The fit of the baseline model in Section 3 is driven by Belgium; once this country is removed, Δ goes down from 0.85 to 0.55.

any innovation produced in a given country is instantly available to all residents of that country. We depart from the standard assumption and build a trade model that incorporates costs to domestic trade. We calibrate the model and evaluate the role of domestic frictions in reconciling the data and the theory. Our calibrated model suggests that domestic frictions are key in reconciling the standard semi-endogenous growth model and the standard trade model with the data on real wages, relative wages, and import shares, across countries of different size. For a small and rich country like Denmark, for instance, our calibrated model implies a real per-capita income of 88 percent (relative to the United States), much closer to the data (91 percent) than the real per-capita income implied by the standard semi-endogenous growth model (34 percent), and the model with only international trade (41 percent).

As mentioned in Section 4.2, a possibility left out of the framework used in this paper is that countries interact in ways other than trade and multinational production (MP), for example through the free flow of ideas across countries. The gains from openness would then include trade, MP and international technology diffusion. The big challenge here would be to discipline the amount of diffusion occurring across countries as it is not directly observable in the data. This is an important topic for future research.

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Table 1: Baseline Calibration: Real Wage.

	Size	Gains from Trade	Domestic Frictions	Real Wage Model			Real Wage Data
	(1)	(2)	(3)	(1)x(2)	(1)x(3)	(1)x(2)x(3)	
Australia	0.47	1.05	1.54	0.49	0.72	0.76	0.86
Austria	0.34	1.19	1.81	0.40	0.61	0.73	0.94
Belgium	0.38	2.21	1.81	0.85	0.69	1.53	0.99
Canada	0.53	1.15	1.41	0.61	0.75	0.86	0.81
Denmark	0.34	1.21	2.14	0.41	0.72	0.88	0.91
Spain	0.43	1.04	1.47	0.45	0.64	0.66	0.96
Finland	0.39	1.07	2.14	0.42	0.84	0.89	0.82
France	0.58	1.07	1.33	0.62	0.77	0.82	0.94
Great Britain	0.56	1.09	1.30	0.61	0.73	0.80	0.90
Germany	0.66	1.06	1.20	0.70	0.79	0.84	0.81
Greece	0.29	1.09	1.81	0.32	0.53	0.58	0.77
Italy	0.46	1.02	1.37	0.47	0.62	0.64	1.11
Japan	0.87	0.97	1.08	0.84	0.94	0.92	0.70
Netherlands	0.40	1.43	1.65	0.58	0.66	0.95	0.94
Norway	0.35	1.11	2.14	0.39	0.76	0.84	0.80
New Zealand	0.29	1.08	2.14	0.31	0.62	0.67	0.69
Portugal	0.29	1.10	2.14	0.31	0.61	0.67	0.92
Sweden	0.42	1.10	1.81	0.46	0.76	0.84	0.77
United States	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Column 1 refers to the first term, column 2 to the second term, and column 3 to the third term on the right-hand side of (15). The real wage in the data is the real GDP (PPP-adjusted) per unit of equipped labor. All variables are calculated relative to the United States.

Table 2: Robustness: Different Values for θ.

	$\theta = 2.5$				$\theta = 4$				$\theta = 5.5$			
	size	GT	dom.fric.	real wage	size	GT	dom.fric.	real wage	size	GT	dom.fric.	real wage
Australia	0.30	1.08	2.00	0.64	0.47	1.05	1.54	0.76	0.58	1.03	1.37	0.82
Austria	0.17	1.33	2.59	0.60	0.34	1.19	1.81	0.73	0.45	1.14	1.54	0.79
Belgium	0.21	3.56	2.59	1.98	0.38	2.21	1.81	1.53	0.50	1.78	1.54	1.37
Canada	0.36	1.25	1.74	0.79	0.53	1.15	1.41	0.86	0.63	1.11	1.29	0.90
Denmark	0.18	1.36	3.38	0.81	0.34	1.21	2.14	0.88	0.45	1.15	1.74	0.91
Spain	0.26	1.07	1.85	0.52	0.43	1.04	1.47	0.66	0.54	1.03	1.32	0.74
Finland	0.22	1.11	3.38	0.83	0.39	1.07	2.14	0.89	0.51	1.05	1.74	0.92
France	0.42	1.11	1.58	0.74	0.58	1.07	1.33	0.82	0.67	1.05	1.23	0.87
Great Britain	0.40	1.14	1.52	0.69	0.56	1.09	1.30	0.80	0.66	1.06	1.21	0.85
Germany	0.51	1.10	1.33	0.75	0.66	1.06	1.20	0.84	0.74	1.05	1.14	0.88
Greece	0.14	1.15	2.59	0.42	0.29	1.09	1.81	0.58	0.41	1.07	1.54	0.67
Italy	0.28	1.04	1.65	0.49	0.46	1.02	1.37	0.64	0.57	1.02	1.26	0.72
Japan	0.80	0.95	1.14	0.87	0.87	0.97	1.08	0.92	0.90	0.98	1.06	0.94
Netherlands	0.23	1.77	2.23	0.92	0.40	1.43	1.65	0.95	0.52	1.30	1.44	0.96
Norway	0.19	1.17	3.38	0.75	0.35	1.11	2.14	0.84	0.47	1.08	1.74	0.88
New Zealand	0.14	1.13	3.38	0.52	0.29	1.08	2.14	0.67	0.41	1.06	1.74	0.75
Portugal	0.13	1.16	3.38	0.53	0.29	1.10	2.14	0.67	0.40	1.07	1.74	0.75
Sweden	0.25	1.17	2.59	0.76	0.42	1.10	1.81	0.84	0.53	1.07	1.54	0.88
United States	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

"Size," "GT," and "dom.fric." refer to the first, second, and third terms, respectively, on the right-hand side of (13). The real wage is the product of those three terms. All variables are calculated relative to the United States.

Table 3: Robustness: Alternative Calibrations for Domestic Frictions τ_{nn}.

	Number of Regions M_n					Real Wage					
	U.S. states (1)	U.S. CSA-SMA (2)	Canadian provinces (3)	Population density (4)	Towns with > 250K hab. (5)	U.S. states (6)	U.S. CSA-SMA (7)	Canadian provinces (8)	Population density (9)	Towns with > 250K hab. (10)	Data (11)
Australia	4	7	8	42	10	0.76	0.75	0.71	0.50	0.65	0.86
Austria	2	3	3	1	2	0.73	0.75	0.73	0.86	0.75	0.94
Belgium	2	3	4	1	1	1.53	1.57	1.43	1.81	1.87	0.99
Canada	6	11	13	54	14	0.86	0.85	0.81	0.61	0.76	0.81
Denmark	1	2	3	1	1	0.88	0.84	0.74	0.88	0.90	0.91
Spain	5	9	11	3	16	0.66	0.65	0.62	0.74	0.55	0.96
Finland	1	2	2	2	2	0.89	0.86	0.83	0.76	0.78	0.82
France	8	16	19	3	7	0.82	0.80	0.77	1.02	0.88	0.94
Great Britain	9	17	20	2	18	0.80	0.78	0.75	1.11	0.73	0.90
Germany	14	26	32	2	27	0.84	0.83	0.80	1.26	0.78	0.81
Greece	2	3	3	1	2	0.58	0.59	0.58	0.68	0.60	0.77
Italy	7	13	16	2	12	0.64	0.63	0.59	0.85	0.59	1.11
Japan	26	51	62	3	89	0.92	0.91	0.89	1.39	0.83	0.70
Netherlands	3	5	6	1	4	0.95	0.95	0.89	1.23	0.92	0.94
Norway	1	2	3	3	2	0.84	0.80	0.71	0.64	0.73	0.80
New Zealand	1	2	2	2	3	0.67	0.64	0.62	0.57	0.53	0.69
Portugal	1	2	3	1	1	0.67	0.64	0.57	0.67	0.69	0.92
Sweden	2	3	4	3	3	0.84	0.86	0.79	0.77	0.79	0.77
United States	51	100	121	51	74	1.00	1.00	1.00	1.00	1.00	1.00

Columns 1 to 3 refer to the calibrated number of regions calculated using $M_n = L_n/\overline{L}_R$ where $\overline{L}_R = L_R/M_R$, with R indicating data coming from U.S. states, sub-regional geographical units (CSA-MSA) in the United States, and Canadian provinces, respectively. Column 4 shows the number of regions calculated using population density in each country. Column 5 shows the number of towns with more than 250K habitants in the data. Columns 6 to 10 computes the real wage relative to U.S. in (13) using the different calibrations in columns 1 to 5, respectively. Calculations in columns 6 to 8 use d_{nn} coming from the calibrations for U.S. states, U.S. sub-regional geographical units, and Canadian provinces, respectively, while calculations in columns 9 to 10 use d_{nn} from the baseline calibration (U.S. states, 2002).

Table 4: Domestic Trade Costs Index: Descriptive statistics, by data source.

	2002		2007		
	$M_{USA} = 51$	$M_{CAN} = 13$	$M_{USA} = 51$	$M_{USA} = 100$	$M_{CAN} = 13$
Average	2.80	3.85	2.96	3.28	3.74
Standard Deviation	0.82	1.71	0.99	1.05	1.73
Maximum	7.30	7.59	8.70	11.04	8.70
Minimum	1.33	1.60	1.36	1.17	1.69
No. of Observations	911	69	1,002	3,000	66

Own calculations using data from the Commodity Flow Survey, and BCStats, for 2002 and 2007, for $\theta = 4$.

Table 5: Calibrated Models and Data.

	Average		Δ	
	full sample	6 smallest countries	full sample	6 smallest countries
Data				
import share	0.37	0.43	–	–
relative import share	3.30	3.64	–	–
terms of trade	0.95	0.92	–	–
real wage	0.88	0.84	–	–
Model with $\tau_{nn} > 1$				
import share	0.34	0.32	0.23	0.10
relative import share	3.98	3.66	28.3	4.25
terms of trade	0.86	0.79	0.73	0.19
real wage	0.79	0.69	0.58	0.19
Model with $\tau_{nn} = 1$				
import share	0.27	0.36	0.36	0.06
relative import share	11.5	14.3	1,662	780
terms of trade	0.70	0.59	1.85	0.73
real wage	0.51	0.35	3.30	1.46

The import share for country n is $\sum_{l \neq n} X_{nl}/X_n$. The relative import share is the import share of country n relative to U.S.The real wage for country n is w_n/P_n^f (relative to U.S.). The terms of trade for country n are w_n (relative to U.S.). $\Delta \equiv \sum_n \left(x_n^{model} - x_n^{data}\right)^2$, where x_n represents, alternately, the import share, terms of trade, and real wage, for country n. Six smallest countries (with respect to L_n) are: Austria, Denmark, Greece, Norway, New Zealand, and Portugal.

Table 6: The Model with Multinational Production: Real Wage.

	Size	GT	GMP	GO	Dom.Fric.	Real Wage Model				Real Wage Data
	(1)	(2)	(3)	(4)	(5)	(6) = (1)x(2)	(7) = (1)x(3)	(8)=(1)x(4)	(9)=(1)x(4)x(5)	(10)
Australia	0.47	1.02	1.12	1.14	1.55	0.48	0.52	0.53	0.82	0.86
Austria	0.34	1.06	1.07	1.13	1.81	0.36	0.36	0.38	0.69	0.94
Belgium	0.38	1.30	1.16	1.52	1.81	0.50	0.44	0.58	1.05	0.99
Canada	0.53	1.05	1.09	1.14	1.42	0.56	0.58	0.60	0.86	0.81
Denmark	0.34	1.07	1.03	1.10	2.14	0.36	0.35	0.37	0.80	0.91
Spain	0.43	1.01	0.97	0.98	1.47	0.44	0.42	0.42	0.63	0.96
Finland	0.39	1.02	0.93	0.95	2.14	0.40	0.37	0.37	0.80	0.82
France	0.58	1.02	0.99	1.01	1.33	0.59	0.58	0.59	0.78	0.94
Great Britain	0.56	1.03	1.16	1.19	1.30	0.58	0.65	0.67	0.87	0.90
Germany	0.66	1.02	0.98	1.00	1.20	0.67	0.64	0.66	0.79	0.81
Greece	0.29	1.03	1.03	1.07	1.81	0.30	0.30	0.31	0.56	0.77
Italy	0.46	1.01	0.93	0.94	1.37	0.46	0.42	0.43	0.59	1.11
Japan	0.87	0.99	0.93	0.92	1.09	0.86	0.81	0.80	0.87	0.70
Netherlands	0.40	1.13	1.22	1.37	1.65	0.45	0.49	0.55	0.91	0.94
Norway	0.35	1.03	1.03	1.07	2.14	0.37	0.36	0.38	0.81	0.80
New Zealand	0.29	1.03	1.34	1.37	2.14	0.30	0.39	0.40	0.85	0.69
Portugal	0.29	1.03	1.09	1.12	2.14	0.29	0.31	0.32	0.68	0.92
Sweden	0.42	1.03	1.01	1.04	1.81	0.44	0.43	0.44	0.80	0.77
United States	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Column 1 refers to the first term (size), column 2 to the third term (gains from trade), column 3 to the fourth term (gains from MP), and column 5 to the second term, respectively, on the right-hand side of (26). Column 4 are the gains from openness, $GO_n = GT_n \times GMP_n$. The real wage in the data is the real GDP (PPP-adjusted) per unit of equipped labor. All variables are calculated relative to the United States.

A Proof of Proposition 1

Replacing (1) into $X_{ni} \equiv \sum_{m\in\Omega_n}\sum_{k\in\Omega_i}\widetilde{X}_{mk}$, we get

$$X_{nl} = \sum_{m\in\Omega_n}\sum_{k\in\Omega_l}\frac{\widetilde{T}_k\widetilde{w}_k^{-\theta}\widetilde{d}_{mk}^{-\theta}}{\sum_{k'}\widetilde{T}_{k'}\widetilde{w}_{k'}^{-\theta}\widetilde{d}_{mk'}^{-\theta}}\widetilde{X}_m.$$

Using A1, for $n \neq l$, we have

$$\begin{aligned}
X_{nl} &= \sum_{m\in\Omega_n}\sum_{k\in\Omega_l}\frac{\widetilde{T}_k\widetilde{w}_k^{-\theta}\widetilde{d}_{mk}^{-\theta}}{\sum_j\sum_{k'\in\Omega_j}\widetilde{T}_{k'}\widetilde{w}_{k'}^{-\theta}\widetilde{d}_{mk'}^{-\theta}}\frac{X_n}{M_n}\\
&= \sum_{m\in\Omega_n}\frac{T_l w_l^{-\theta}\tau_{nl}^{-\theta}}{\sum_{j\neq n}T_j w_j^{-\theta}\tau_{nj}^{-\theta} + (M_n - 1)\bar{T}_n w_n^{-\theta}d_{nn}^{-\theta} + \bar{T}_n w_n^{-\theta}}\frac{X_n}{M_n}\\
&= \sum_{m\in\Omega_n}\frac{M_l\bar{T}_l w_l^{-\theta}\tau_{nl}^{-\theta}}{\sum_{j\neq n}T_j w_j^{-\theta}\tau_{nj}^{-\theta} + M_n\bar{T}_n w_n^{-\theta}\left[\frac{1}{M_n} + \frac{M_n-1}{M_n}d_{nn}^{-\theta}\right]}\frac{X_n}{M_n}\\
&= \frac{T_l w_l^{-\theta}\tau_{nl}^{-\theta}}{\sum_j T_j w_j^{-\theta}\tau_{nj}^{-\theta}}X_n.
\end{aligned}$$

Similarly, for $n = l$,

$$\begin{aligned}
X_{nl} &= \sum_{m\in\Omega_n}\sum_{k\in\Omega_l}\frac{\widetilde{T}_k\widetilde{w}_k^{-\theta}\widetilde{d}_{mk}^{-\theta}}{\sum_j\sum_{k'\in\Omega_j}\widetilde{T}_{k'}\widetilde{w}_{k'}^{-\theta}\widetilde{d}_{mk'}^{-\theta}}\frac{X_n}{M_n}\\
&= \sum_{m\in\Omega_n}\frac{(M_n - 1)\bar{T}_n w_n^{-\theta}d_{nn}^{-\theta} + \bar{T}_n w_n^{-\theta}}{\sum_{j\neq n}T_j w_j^{-\theta}\tau_{nj}^{-\theta} + (M_n - 1)\bar{T}_n w_n^{-\theta}d_{nn}^{-\theta} + \bar{T}_n w_n^{-\theta}}\frac{X_n}{M_n}\\
&= \frac{M_n\bar{T}_n w_n^{-\theta}\left[\frac{1}{M_n} + \frac{M_n-1}{M_n}d_{nn}^{-\theta}\right]}{\sum_{j\neq n}T_j w_j^{-\theta}\tau_{nj}^{-\theta} + M_n\bar{T}_n w_n^{-\theta}\left[\frac{1}{M_n} + \frac{M_n-1}{M_n}d_{nn}^{-\theta}\right]}X_n\\
&= \frac{T_n w_n^{-\theta}\tau_{nn}^{-\theta}}{\sum_j T_j w_j^{-\theta}\tau_{nj}^{-\theta}}X_n.
\end{aligned}$$

This establishes that

$$X_{nl} = \frac{T_l w_l^{-\theta}\tau_{nl}^{-\theta}}{\sum_j T_j w_j^{-\theta}\tau_{nj}^{-\theta}}X_n,$$

for all n, l, and τ_{nn} defined as in (6).

Turning to the price index, we know that for $m \in \Omega_n$, we have $P_n = \widetilde{P}_m$. Hence,

$$\begin{aligned} P_n &= \mu^{-1} \left(\sum_j \sum_{k \in \Omega_j} \widetilde{T}_k \widetilde{w}_k^{-\theta} \widetilde{d}_{mk}^{-\theta} \right)^{-1/\theta} \\ &= \mu^{-1} \left(\sum_{j \neq n} T_j w_j^{-\theta} \tau_{nj}^{-\theta} + (M_n - 1) \frac{T_n}{M_n} w_n^{-\theta} d_{nn}^{-\theta} + \frac{T_n}{M_n} w_n^{-\theta} \right)^{-1/\theta} \\ &= \mu^{-1} \left(\sum_j T_j w_j^{-\theta} \tau_{nj}^{-\theta} \right)^{-1/\theta} . \end{aligned}$$

B The Model with Multinational Production and Non-Tradable Goods

B.1 Equilibrium Analysis

The following Proposition characterizes trade and MP flows for the model of trade and MP with domestic frictions presented in Section 6. The results for trade flows are very similar to those of Proposition 1, except that now technology levels are augmented because of the possibility of using technologies from other countries, appropriately discounted by the efficiency costs: $\Gamma_l \equiv \sum_{i \neq l} T_i \gamma_{li}^{-\theta} + T_l$. Note that if MP costs go to infinity then $\Gamma_l \to T_l$, as in the model with no MP of Section 2.

We introduce the following notation: $c_l^f \equiv A w_l^{\alpha} \left(P_l^g\right)^{1-\alpha}$, $c_l^g \equiv A w_l^{\beta} \left(P_l^g\right)^{1-\beta}$ and $Y_l^s \equiv \sum_i Y_{li}^s$, where P_l^g is the price index of intermediate goods and where Y_{li}^f and Y_{li}^g denote the value of production of final and intermediate goods, respectively. It is easy to show that $Y_l^g = \eta w_l L_l$ while $Y_l^f = w_l L_l$.

Proposition 3. Country-level trade flows are

$$X_{nl} = \frac{\Gamma_l \left(\tau_{nl} c_l^g\right)^{-\theta}}{\sum_{l'} \Gamma_{l'} \left(\tau_{nl'} c_{l'}^g\right)^{-\theta}} X_n, \tag{28}$$

while country-level MP flows in intermediate and final goods are

$$Y_{li}^s = \frac{T_i \gamma_{li}^{-\theta}}{\Gamma_l} Y_l^s \text{ and } Y_{ll}^s = \frac{T_l}{\Gamma_l} Y_l^s \text{ for } s = g, f \tag{29}$$

and price indices at the country-level are

$$P_n^g = \mu^{-1}\left(\sum_l \Gamma_l \left(c_l^g\right)^{-\theta} \tau_{nl}^{-\theta}\right)^{-1/\theta}, \tag{30}$$

and

$$P_n^f = \mu^{-1} c_n^f \left(\gamma_{nn}^{-\theta}\Gamma_n\right)^{-1/\theta}, \tag{31}$$

where τ_{nl} is as in Proposition 1, and where

$$\gamma_{ll} \equiv \left(\frac{1}{M_l} + \frac{M_l - 1}{M_l} h_{ll}^{-\theta}\right)^{-1/\theta}. \tag{32}$$

Proof: The proof follows closely the proof of Proposition 1. First, note that no intermediate goods will be produced with technologies outside of their home region. This is because of our assumption that $h_{nn} = d_{nn}$, with the indifference broken in favor of trade rather than MP. Now, for $k \in \Omega_l$ we have an analogous result as (1) except that now instead of $\widetilde{T}_k$ we have $\sum_{i \neq l} \frac{M_i \bar{T}_i}{M_l} \gamma_{il}^{-\theta} + \widetilde{T}_k$. Country-level trade flows are then

$$X_{nl} = \frac{\left(\sum_{i \neq l} T_i \gamma_{ll}^{-\theta} + T_l\right) w_l^{-\theta} \tau_{nl}^{-\theta}}{\sum_j \left(\sum_{i \neq j} T_i \gamma_{ji}^{-\theta} + T_j\right) w_j^{-\theta} \tau_{nj}^{-\theta}} X_i = \frac{\Gamma_l w_l^{-\theta} \tau_{nl}^{-\theta}}{\sum_j \Gamma_j w_j^{-\theta} \tau_{nj}^{-\theta}} X_i$$

MP shares are simply given by the contribution of each source to Γ_l, hence

$$Y_{li}^s / Y_l^s = T_i \gamma_{li}^{-\theta} / \Gamma_l \text{ and } Y_{ll}^s / Y_l^s = T_l / \Gamma_l \text{ for } s = f, g$$

The price index for intermediate goods is simply $\gamma^{-1}\left(\sum_j \Gamma_j w_j^{-\theta} \tau_{nj}^{-\theta}\right)^{-1/\theta}$, while for final goods we have

$$\begin{aligned}
\left(\mu P_n^f\right)^{-\theta} &= \sum_{i \neq n} \frac{M_i \bar{T}_i}{M_n} \gamma_{ni}^{-\theta} \left(1 + \left(M_n - 1\right) h_{nn}^{-\theta}\right) + \left(M_n - 1\right) \bar{T}_n h_{nn}^{-\theta} + \bar{T}_n \\
&= \sum_{i \neq n} T_i \gamma_{ni}^{-\theta} \gamma_{nn}^{-\theta} + T_n \gamma_{nn}^{-\theta} = \gamma_{nn}^{-\theta} \Gamma_n.
\end{aligned}$$

□

We now derive an expression for real wages. First, from (28) and (30) we get

$$\frac{c_n^g}{P_n^g} = \mu \Gamma_n^{1/\theta} \tau_{nn}^{-1} \lambda_{nn}^{-1/\theta}.$$

Using (29) we then get

$$\frac{c_n^g}{P_n^g} = \mu T_n^{1/\theta} \tau_{nn}^{-1} \lambda_{nn}^{-1/\theta} \left(\frac{Y_{nn}^g}{Y_n^g}\right)^{-1/\theta}.$$

Using $c_n^g = B w_n^{\beta} \left(P_n^g\right)^{1-\beta}$ then

$$\frac{w_n}{P_n^g} = B^{-1/\beta} \mu^{1/\beta} T_n^{1/\beta\theta} \tau_{nn}^{-1/\beta} \lambda_{nn}^{-1/\beta\theta} \left(\frac{Y_{nn}^g}{Y_n^g}\right)^{-1/\beta\theta} \tag{33}$$

But from (31) and (29) we get

$$P_n^f = c_n^f \mu^{-1} \gamma_{nn} T_n^{-1/\theta} \left(\frac{Y_{nn}^f}{Y_n^f}\right)^{1/\theta}.$$

Using $c_n^f = A w_n^{\alpha} \left(P_n^g\right)^{1-\alpha}$ and (33) we then get

$$P_n^f = A B^{\eta} w_n \mu^{-(1+\eta)} T_n^{-\frac{1+\eta}{\theta}} \gamma_{nn} \tau_{nn}^{\eta} \lambda_{nn}^{\eta/\theta} \left(\frac{Y_{nn}^g}{Y_n^g}\right)^{\eta/\theta} \left(\frac{Y_{nn}^f}{Y_n^f}\right)^{1/\theta}.$$

Rearranging yields

$$\frac{w_n}{P_n^f} = A^{-1} B^{-\eta} \mu^{(1+\eta)} T_n^{\frac{1+\eta}{\theta}} \gamma_{nn}^{-1} \tau_{nn}^{-\eta} \lambda_{nn}^{-\eta/\theta} \left(\frac{Y_{nn}^g}{Y_n^g}\right)^{-\eta/\theta} \left(\frac{Y_{nn}^f}{Y_n^f}\right)^{-1/\theta}.$$

Using $\frac{Y_{nn}^g}{Y_n^g} = \frac{Y_{nn}^f}{Y_n^f} = \frac{T_l}{\Gamma_l} = \pi_{ll}$ and $T_n = \phi_n L_n$, and setting $\mu^M \equiv A^{-1} B^{-\eta} \mu^{(1+\eta)}$ yields (26).

B.2 Data on Multinational Production.

Data on the gross value of production for multinational affiliates from i in n is from UNCTAD, Investment and Enterprise Program, FDI Statistics, FDI Country Profiles, published and unpublished data.[40] We use this variable as the counterpart of bilateral MP flows in the model, $Y_{ni} \equiv Y_{ni}^f + Y_{ni}^g$.

The UNCTAD measure of MP includes both local sales in n and exports to any other country, including the home country i. Out of 342 possible country pairs, data are available for 219 country pairs. We impute missing values by running the following OLS regression

$$\log \frac{Y_{ni}}{w_n L_n} = \beta_d \log dist_{ni} + \beta_c b_{ni} + \beta_l l_{ni} + S_i + H_n + e_{ni},$$

where Y_{ni} is gross production of affiliates from i in n, $w_n L_n$ is GDP in country n, $dist_{ni}$ is

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[40] Unpublished data are available upon request at fdistat@unctad.org.

geographical distance between i and n, b_{ni} (l_{ni}) is a dummy equal to one if i and n share a border (language), and zero otherwise, and S_i and H_n are two sets of country fixed effects, for source and destination country, respectively. All variables are averages over the period 1996-2001. The variable GDP is in current dollars, from the World Development Indicators, and the variables for distance, common border, and common language are from the *Centre d'Etudes Prospectives et Informations Internationales* (CEPII).

To calculate the gains from MP—the last three terms in (26), we further need MP flows in manufacturing (Y_{ni}^{g}) and non-manufacturing (Y_{ni}^{f}), separately. The data refer to foreign affiliates in all non-financial sectors, except for the United States for which we have MP flows in manufacturing separately and represent approximately one half of the total MP flows. We then use one half of the total MP flows as the empirical counterpart for Y_{ni}^{g}, and similarly for Y_{ni}^{f}, for all countries.

B.3 Calibration with Multinational Production.

When non-tradable goods and MP are included into the model, we need to calibrate the labor shares in final and intermediate goods, α and β, respectively, as well as recalibrate the value of θ.

We set the labor share in the intermediate goods' sector, β, to 0.50, and the labor share in the final sector, α, to 0.75, as calibrated by Alvarez and Lucas (2007). This implies that $\eta \equiv (1-\alpha)/\beta = 0.5$.

We consider the same three different approaches for the calibration of the parameter θ as in the baseline model. When we calibrate θ to match the growth rate observed in the data, now (11) is replaced by $g = g_L(1+\eta)/\theta$, by differentiating (26) with respect to time. With $g_L = 0.048$, $g = 0.01$, and $\eta = 0.5$, $\theta = 7.2$. When we use the results in Alcala and Ciccone (2004), and using (26), the role of institutions is captured byϕ_n, geography is captured by both H_n and D_n, trade and MP openness are embedded in the last three terms of the right-hand side of (26), and the coefficient on L_n, $(1+\eta)/\theta$, can be equated to 0.3, the value of the income-size elasticity in Alcala and Ciccone (2004). With $\eta = 0.5$, θ equals 5.

To compromise between the different approaches, we choose $\theta = 6$ which implies an elasticity of the real wage with respect to size of $1/4$.

C Online Appendix

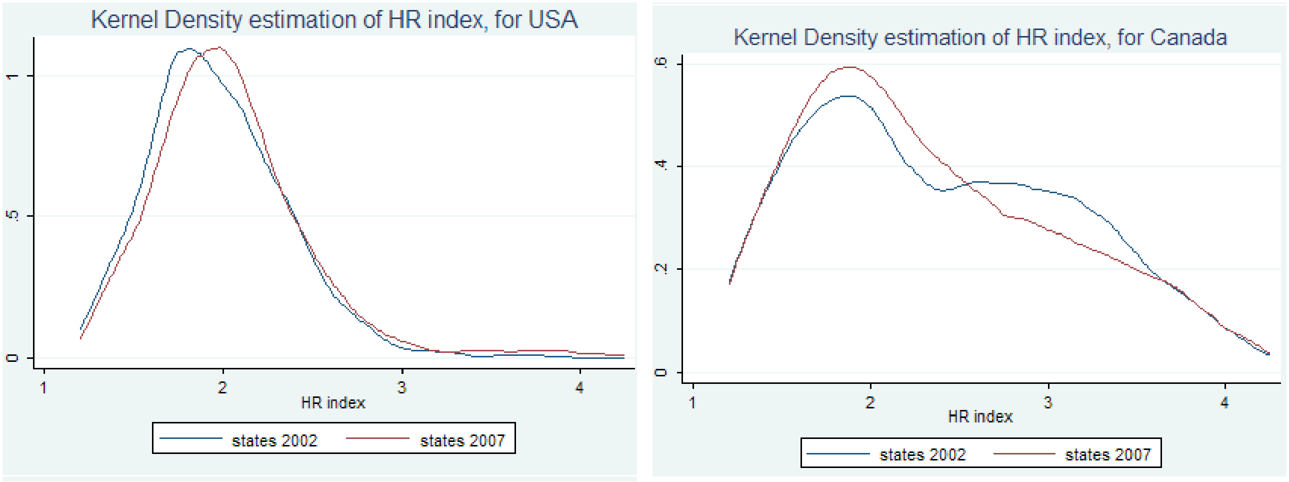
C.1 Data

Table 7: Data: Summary.

	Domestic MP shares		Domestic Trade shares	Real GDP per capita	R&D employment	Equipped labor	Country's size	Country's density
	final (1)	intermediate (2)	(3)	(4)	(5)	(6)	(7)=(5)×(6)	(8)
Australia	0.23	0.59	0.64	0.86	0.0068	791514.8	0.05	2
Austria	0.30	0.62	0.38	0.94	0.0048	292277.6	0.01	97
Belgium	0.24	0.34	0.03	0.99	0.0067	353165.2	0.02	335
Canada	0.29	0.53	0.44	0.81	0.0063	1398602	0.08	3
Denmark	0.32	0.79	0.36	0.91	0.0064	224880.2	0.01	124
Spain	0.48	0.77	0.65	0.96	0.0036	1076036	0.04	81
Finland	0.58	0.81	0.59	0.82	0.0126	205583.4	0.02	15
France	0.41	0.79	0.59	0.94	0.0062	2007570	0.11	108
Great Britain	0.21	0.46	0.55	0.90	0.0053	2083120	0.10	243
Germany	0.45	0.76	0.60	0.81	0.0061	3373349	0.19	230
Greece	0.31	0.84	0.54	0.77	0.0028	290140.6	0.01	83
Italy	0.57	0.87	0.70	1.11	0.0029	1672693	0.04	192
Japan	0.56	0.94	0.87	0.70	0.0095	6631071	0.57	336
Netherlands	0.18	0.34	0.18	0.94	0.0051	577125.4	0.03	383
Norway	0.31	0.85	0.52	0.80	0.0078	220680.8	0.02	12
New Zealand	0.12	0.25	0.57	0.69	0.0052	147859.2	0.01	14
Portugal	0.30	0.49	0.53	0.92	0.0030	247753.4	0.01	112
Sweden	0.40	0.66	0.52	0.77	0.0090	390107	0.03	20
United States	0.38	0.83	0.77	1.00	0.0085	13009948	1.00	30

Domestic MP in the final good sector in column 1 is calculated as share of GDP. Domestic MP in the intermediate good sector in column 2 is calculated as share of gross production in manufacturing. Domestic trade in manufacturing in column 3 is calculated as share of absorption in manufacturing. Real GDP per capita in column 4 is PPP- adjusted real GDP divided by equipped labor (in column 6). R&D employment in column 5 is calculated as share of total employment. Country's density in column 8 is the number of habitants per square kilometer. Equipped labor, real GDP per capita, and R&D employment are relative to the United States. Variables are averages over 1996-2001.

Figure 4: Domestic Trade Costs: Head and Ries Index.



(a) U.S. States

(b) Canadian Provinces

Table 8: Shipments within the United States, by state of destination.

Destination state	All states	Same state	All other states	Own to others
Alabama	124308	40388	83920	0.48
Arizona	118892	49047	69845	0.70
Arkansas	78105	22089	56016	0.39
California	894487	557566	336921	1.65
Colorado	104508	42796	61712	0.69
Connecticut	75329	20388	54941	0.37
Delaware	30719	4758	25961	0.18
District of Columbia	14154	588	13566	0.04
Florida	404644	194873	209771	0.93
Georgia	295406	98418	196988	0.50
Idaho	27887	9385	18502	0.51
Illinois	416154	164946	251208	0.66
Indiana	244031	82868	161163	0.51
Iowa	88753	29432	59321	0.49
Kansas	87391	25965	61426	0.42
Kentucky	159694	41730	117964	0.35
Louisiana	159495	76181	83314	0.91
Maine	29237	10411	18826	0.55
Maryland	151521	46222	105299	0.43
Massachusetts	159884	58214	101670	0.57
Michigan	406942	189489	217453	0.87
Minnesota	161310	69135	92175	0.75
Mississippi	77779	22058	55721	0.39
Missouri	177887	56661	121226	0.46
Montana	23295	7033	16262	0.43
Nebraska	52477	20741	31736	0.65
Nevada	69013	11957	57056	0.21
New Hampshire	32191	5263	26928	0.19
New Jersey	266867	77807	189060	0.41
New Mexico	34118	7277	26841	0.27
New York	372472	123744	248728	0.49
North Carolina	257179	115794	141385	0.82
North Dakota	24047	8384	15663	0.53
Ohio	413206	169127	244079	0.69
Oklahoma	82848	25450	57398	0.44
Oregon	94427	41290	53137	0.78
Pennsylvania	328278	117750	210528	0.56
Rhode Island	18147	3408	14739	0.23
South Carolina	128514	40927	87587	0.47
South Dakota	20137	7195	12942	0.56
Tennessee	200245	58344	141901	0.41
Texas	719284	365644	353640	1.03
Utah	62354	25803	36551	0.71
Vermont	17751	4188	13563	0.31
Virginia	198879	70575	128304	0.55
Washington	223300	122189	101111	1.21
West Virginia	36747	9446	27301	0.34
Wisconsin	182785	74401	108384	0.69
Wyoming	15548	4568	10980	0.42

Commodity Flow Survey. 2002. In millions of U$ dollars.

Table 9: Human Capital, Institutions, and Patents.

	Schooling (1)	Corruption in Gov. (2)	Rule of Law (3)	Bureaucracy Quality (4)	Patents per capita (5)
Australia	10.24	5	6.00	6.00	0.58
Austria	6.64	4.96	6.00	5.98	0.61
Belgium	9.15	4.68	5.87	5.97	0.62
Canada	10.37	6.00	6.00	6.00	0.83
Denmark	10.33	6.00	6.00	6.00	0.70
Spain	5.58	4.33	5.50	4.27	0.13
Finland	9.49	6.00	6.00	5.81	1.03
France	6.52	5.05	5.61	5.80	0.70
Great Britain	8.65	4.90	5.75	6.00	0.63
Germany	8.54	5.53	5.81	6.00	1.23
Greece	6.73	5.00	4.98	3.90	0.0004
Italy	6.28	3.60	5.31	4.85	0.67
Japan	8.46	4.96	5.68	5.85	1.17
Netherlands	8.57	6.00	6.00	6.00	1.28
Norway	10.38	5.81	6.00	5.42	0.21
New Zealand	12.04	5.81	5.96	6.00	0.25
Portugal	3.83	4.88	5.32	3.90	n/a
Sweden	9.45	6.00	6.00	6.00	0.93
United States	11.79	4.86	6.00	6.00	2.40

Column 1 refers to average years of schooling from Barro and Lee (2000). Corruption in government (column 2), rule of law (column 3), and bureaucratic quality (column 4), are indices ranging from zero (worst) to six (best), from Beck, Clarke, Groff, Keefer, and Walsh (2001). Column 5 refers to patents per unit of R&D-adjusted equipped labor from country i registered in all other countries in the sample (including itself), from the World Intellectual Property Organization (WIPO), average over 2000-2005.