Scale Effects and Productivity Across Countries: The Role of Openness and Domestic Frictions*

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Abstract

Models in which growth is driven by innovation naturally lead to scale effects. These scale effects have the counterfactual implication that larger countries should be much richer than smaller ones. To reconcile theory with data, we explore and quantify two candidate mechanisms to weaken scale effects: Countries are not fully isolated from each other, and countries are not fully integrated domestically. We build and calibrate a model of trade with frictions to move goods across and within countries, and show that the resulting model 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 real per-capita income implied by the standard semi-endogenous growth model (34 percent). We conclude that domestic frictions play a key role in bringing the model closer to matching the data.

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

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1 Introduction

Models in which growth is driven by innovation naturally lead to scale effects. In Jones's (2005) words, "scale effects are so inextricably tied to idea-based growth models that rejecting one is largely equivalent to rejecting the other." As explained by Romer (1990), Kortum (1997), and Jones (2005), scale effects follow directly from the common assumption that ideas are non-rival. An immediate implication of this assumption is that larger countries should be richer than smaller ones.[1] It is widely known, however, that small countries are not poor compared to larger ones; Belgium is not poorer than France and Hong-Kong is not poorer than China.[2]

It has long been recognized that this counterfactual prediction is largely a result of the crude way in which geography has been treated in these idea-based models. First, any idea in a given country is instantly available to all residents of that country; countries are completely integrated domestically. And second, countries are assumed to be fully isolated units; interactions between countries are shut down.

In this paper we present a general equilibrium multi-country model that incorporates a rich geographic structure within each country and across countries. To capture the idea that countries are not fully isolated, the model allows for international trade, and to capture the idea that countries are not fully integrated units, each country is modeled as a collection of regions facing trade frictions. The basic insight is that a higher stock of ideas only makes large countries richer if countries are sufficiently integrated domestically. If moving goods between regions within a county is sufficiently costly, small and rich countries will not systematically differ in income per capita. Section 2 presents the baseline model.

We are interested in quantifying the role of openness and domestic frictions in reconciling the standard model with the data on income per capita. We calibrate the model to data on trade flows across countries, within-country trade flows (available for the United States and Canada), and a measure of a country's size. Our calibrated model suggests that openness and domestic frictions

[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 effect, such as Lucas and Moll (2011), and Alvarez, Buera, and Lucas (2011), depart from the standard assumption that ideas are non-rival.

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

are indeed important to explain the discrepancy between the standard model and the data. 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 real per-capita income implied by the standard semi-endogenous growth model (34 percent). We find that, of the two channels proposed in our theory, domestic frictions are quantitatively much more important than trade openness: If we augmented the standard semi-endogenous growth model by only domestic frictions, Denmark's real income per capita would be 71 percent of the U.S. level, while if we augmented the model by only trade openness, Denmark's income would be 41 percent of the U.S. level. We also provide additional evidence on domestic frictions that is consistent with other model. The quantitative analysis is concentrated in Section 3.

Our model builds on the seminal model of geography and trade of Eaton and Kortum (2002), but we could have equally built it on Melitz (2003) under a Pareto distribution for firm-level productivity.[3] Besides their convenience for quantitative work, these are idea-based models in the same way as standard semi-endogenous growth models are. Not only do they feature (weak) scale effects by virtue of which a larger population is linked to a higher stock of non-rival ideas, and hence, to higher income, but also these economies of scale are the same ones generating the gains from trade. Conveniently, the gains from trade in this class of models can be easily written as a function of trade flows, as shown in Arkolakis, Costinot, and Rodríguez-Clare (2012). Thanks to this feature of our model, the calibration procedure becomes straightforward.

A close relative of our paper is Redding (2012). He computes the gains from international trade in a setting where countries are composed of multiple asymmetric regions and labor is mobile across them. Our work differs from his in that we use the theory to quantify the role of domestic frictions in explaining the observed real income per capita across countries.

Additionally, 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

[3]The Eaton and Kortum (2002) model has been subsequently used by Alvarez and Lucas (2007), Waugh (2010), Fieler (2011), Arkolakis et al. (2012), Ahlfedlt, Redding , Sturm and Wolf (2012), Ramondo and Rodríguez-Clare (2013), and Donaldson (2013), among others.

trade openness (instrumented by geography) lead to higher income levels.

In Sections 4 we extend the baseline model to capture an additional channel for the gains from openness beyond international trade: We allow for multinational production as in Ramondo and Rodríguez-Clare (2013). Our main conclusion from Section 3 continues to hold: Domestic frictions are key to reconcile the model with the data.

In Section 5, we discuss other possible channels to reconcile the model with the data, like institutions and diffusion of ideas. Section 6 concludes.

2 Baseline Model

The baseline model is a simple version of the Ricardian trade model developed by Eaton and Kortum (2002)—henceforth EK. There is a set of economies 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 economy m, and immobile across economies. 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 $\widetilde{d}_{mm} = 1$. (The reason for the use of tildas on some variables will become clear below.)

Let $\widetilde{X}_{mk}$ be imports by economy m from economy k, $\widetilde{X}_m \equiv \sum_k \widetilde{X}_{mk}$ be total expenditure by economy m, and $\widetilde{\lambda}_{mm} \equiv \widetilde{X}_{mm}/\widetilde{X}_m$ be the domestic trade share of economy m. A well-known result from EK is that real wages can be written as a function of $\widetilde{T}_m$ and $\widetilde{\lambda}_{mm}$,

$$\frac{\widetilde{w}_m}{\widetilde{P}_m} = \gamma \widetilde{T}_m^{1/\theta} \widetilde{\lambda}_{mm}^{-1/\theta}, \tag{1}$$

where γ is a positive constant.[4]

We depart from the standard practice of modeling countries as single economies, and instead think of countries as collections of economies, which we henceforth refer to as "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.

[4] $\gamma \equiv (\Gamma(\frac{1-\sigma}{\theta} + 1))^{1/(\sigma-1)}$.

To be able to connect our model to country-level data, we make the following symmetry assumption: $\widetilde{L}_m = \widetilde{L}_{m'}$ 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 $k, k' \in \Omega_i$. A country can now be described by the the number of regions, M_n, the size and technology level of each of its regions, $\bar{L}_n$ and $\bar{T}_n$, and trade costs d_{ni}, with these country-level variables defined from the region-level variables introduced above as follows: $\bar{L}_n \equiv \widetilde{L}_m$ and $\bar{T}_n \equiv \widetilde{T}_m$ for $m \in \Omega_n$, and $d_{ni} \equiv \widetilde{d}_{mk}$ for $m \in \Omega_n$ and $k \in \Omega_i$. We assume that $d_{nn} > 1$, so that domestic trade across regions is costly, while we assume that trade within regions is costless.

Country-level bilateral trade flows are $X_{ni} \equiv \sum_{m \in \Omega_n} \sum_{k \in \Omega_i} \widetilde{X}_{mk}$, and obey a standard gravity-like equation—see the Appendix for details.

Our symmetry assumptions imply that, if $m \in \Omega_n$, then $X_{nn} = M_n \sum_{k \in \Omega_n} \widetilde{X}_{mk}$ and $X_n = M_n \widetilde{X}_m$. For all $m \in \Omega_n$, we then have

$$\widetilde{\lambda}_{mm} \equiv \frac{\widetilde{X}_{mm}}{\widetilde{X}_m} = \frac{\hat{X}_{nn}}{X_{nn}} \lambda_{nn}, \tag{2}$$

where $\hat{X}_{nn} \equiv \sum_{m \in \Omega_n} \widetilde{X}_{mm}$ are total trade flows in country n that take place within regions and $\lambda_{nn} \equiv X_{nn}/X_n$ is the country-level domestic trade share. Plugging (2) into (1) and noting that, by symmetry, $w_n = \widetilde{w}_m$ and $P_n = \widetilde{P}_m$ for $m \in \Omega_n$, then

$$\frac{w_n}{P_n} = \gamma \bar{T}_n^{1/\theta} \lambda_{nn}^{-1/\theta} \left(\frac{\hat{X}_{nn}}{X_{nn}} \right)^{-1/\theta}. \tag{3}$$

The term $\hat{X}_{nn}/X_{nn}$ is the share of total domestic trade flows in country n that take place within regions. If there were no domestic frictions, $d_{nn} = 1$, this share would be $1/M_n$, and (3) would collapse to EK's formula for country-level real wages,

$$\frac{w_n}{P_n} = \gamma T_n^{1/\theta} \lambda_{nn}^{-1/\theta}, \tag{4}$$

where $T_n \equiv M_n \bar{T}_n$. In the presence of domestic frictions, $\hat{X}_{nn}/X_{nn}$ is higher than $1/M_n$, and hence, real wages in (3) are lower than those given by (4). In the extreme, if $d_{nn} \to \infty$, then all trade within country n is also trade within regions, hence $\hat{X}_{nn}/X_{nn} = 1$ and $w_n/P_n = \gamma \bar{T}_n^{1/\theta} \lambda_{nn}^{-1/\theta}$.

Let D_n be a measure of domestic frictions in country n defined as

$$D_n \equiv \left(\frac{1}{M_n} + \frac{M_n - 1}{M_n} d_{nn}^{-\theta} \right)^{-1}. \tag{5}$$

Note that $D_n^{1/\theta}$ is a weighted power mean of the trade cost within each region, which is one, and the trade cost across regions within a country, which is d_{nn}, with power $-\theta$ and weights $1/M_n$ and $(M_n - 1)/M_n$. Thus, if $d_{nn} > 1$, then D_n is higher than one and increasing with d_{nn} and M_n. We show in the Appendix that the share of domestic expenditure that takes place within regions is determined by this measure of domestic frictions and the number of regions,

$$\frac{\hat{X}_{nn}}{X_{nn}} = \frac{D_n}{M_n}. \tag{6}$$

Plugging (6) into (3) yields our key expression for real wages,

$$\frac{w_n}{P_n} = \gamma \left(M_n \bar{T}_n \right)^{1/\theta} D_n^{-1/\theta} \lambda_{nn}^{-1/\theta}. \tag{7}$$

An immediate implication of this equation is that, even in the presence of domestic frictions, the gains from international trade (i.e., the change in the equilibrium real wage from a situation where a country is isolated to a situation with international trade) are the same as the ones in EK,

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

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 assume that $\bar{T}_n = \phi_n \bar{L}_n$, with ϕ_n possibly varying with n to reflect differences in innovation intensity across countries.[5] Our main equation (7) can now be rewritten as

$$\frac{w_n}{P_n} = \gamma \left(\phi_n L_n \right)^{1/\theta} D_n^{-1/\theta} G T_n, \tag{9}$$

[5] To establish some foundations for this assumption, think of a "technology" as a productivity ξ drawn from a Fréchet distribution with parameters θ and 1, and let $\bar{T}_n$ be the number of technologies per good in a region of country n. It is easy to show that the best technology for a good in a region, $z \equiv \max \xi$, is distributed Fréchet with parameters θ and $\bar{T}_n$. The critical assumption is that the number of technologies is proportional to population, so that $\bar{T}_n = \phi_n \bar{L}_n$.

where $L_n \equiv M_n \bar{L}_n$ is total population in country n.[6]

If there were no domestic frictions, then $D_n = 1$ and larger countries would exhibit higher real income levels with an elasticity given by $1/\theta$. 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 (see Ramondo and Rodríguez-Clare, 2010). However, in the presence of domestic trade costs, economies of scale depend on whether L_n increases via M_n or $\bar{L}_n$. We henceforth assume that $\bar{L}_n = \bar{L}$ for all n, so that all variation in country size comes from variation in the number of regions. Larger economies have higher L_n but also higher D_n, weakening the strength of economies of scale. The effect comes exclusively from assuming that countries are represented by many not fully integrated regions, rather than a single unit as in the standard trade and growth model.

3 Quantitative Analysis

We consider the same set of nineteen OECD countries as Eaton and Kortum (2002).[7] 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 compute real wages in the data as real GDP (PPP-adjusted) from the Penn World Tables (6.3) divided by L_n, which we measure as equipped labor to account for differences in physical and human capital per worker, as calculated by Klenow and Rodríguez-Clare (2005). 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.

[6] Equation (9) is not exclusive of EK Ricardian-type models. Similarly to the results in Arkolakis et al. (2012), this expression will also come out of a Melitz-Chaney-type model (with θ replaced by the Pareto-scale parameter), and a Krugman model (with θ replaced by $\sigma - 1$), with both international trade and domestic geography.

[7] 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.

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 do so, 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 gross manufacturing production to calculate the gains from trade for each country n.[8] 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.

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, as indicated by (9).

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 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

$$g = g_L/\theta. \tag{10}$$

Equation (10) 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 (10), these growth rates imply that $\theta = 4.8$.[9]

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.[10]

[8] We use data on manufacturing trade flows from country i to n from STAN to calculate domestic trade flows, normalized by total absorption in manufacturing (calculated as gross production minus total exports plus total imports), an average over 1996-2001. The online Appendix presents the detailed data on domestic trade shares.

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

[10] Bernard, Jensen, Eaton, and Kortum (2004) estimate $\theta = 4$; Simonovska and Waugh (2011) estimate θ between 2.5

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.[11] This elasticity can be interpreted in the context of (9). If geography is captured by D_n, 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 elasticity of the real wage with respect to size—i.e., $\partial \ln(w_n/P_n)/\partial \ln L_n$—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.

Calibration of Domestic Frictions. Our calibration of domestic frictions, d_{nn}, is based on (6). Given a measure of the share of domestic trade that takes place within regions, $\hat{X}_{nn}/X_{nn}$, (6) can be used together with M_n to infer D_n which can then be combined with (5) 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.[12] 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 manu-

and 5 with a preferred estimate of 4; Arkolakis et al. (2013) estimate θ between 4.5 and 5.5.

[11] 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.

[12] These data has been used before to quantify domestic trade costs—see Anderson and van Wincoop (2003), and Hillberry and Hummels (2008).

facturing 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 7 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 (5) imply $d_{US,US}$ of 2.43. The corresponding numbers for the year 2007 are $\hat{X}_{nn}/X_{nn} = 0.45$ and $d_{US,US} = 2.52$.[13] 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.[14] 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 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.[15] Of course, we are allowing for differences in D_n 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 five percent the ones for the United States. Conversely, a large country like Japan, with $M_{JPN} = 26$, has D_n calibrated to be 72 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

[13] As we explain in more detail in Section 3.3, using the Head and Ries methodology to estimate domestic trade costs delivers slightly higher results.

[14] 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).

[15] 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.

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.[16] In Section 3.3, 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.[17]

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 with the share of R&D employment observed in the data.[18] We use data on R&D employment from the World Development Indicators averaged over the nineties. 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.

3.1 The Role of Trade Openness and Domestic Frictions

We now quantify the role of trade openness and domestic frictions in reconciling the standard semi-endogenous growth model with the data on TFP across countries. Using (7), the real wage

[16] Using the same data we use, but setting $\theta = 8$ (rather than our $\theta = 4$), Tombe and Winter (2012) estimate a value of $d_{nn} < 2$ for Canada than our estimate of $d_{nn} \approx 2.5$.

[17] 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.

[18] 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.

for country n relative to the U.S. can be written as

$$\frac{w_n/P_n}{w_{US}/P_{US}} = \underbrace{\left(\frac{\phi_n L_n}{\phi_{US} L_{US}}\right)^{1/\theta}}_{\text{country size}} \times \underbrace{\left(\frac{GT_n}{GT_{US}}\right)}_{\text{gains from trade}} \times \underbrace{\left(\frac{D_n}{D_{US}}\right)^{-1/\theta}}_{\text{domestic frictions}}. \tag{11}$$

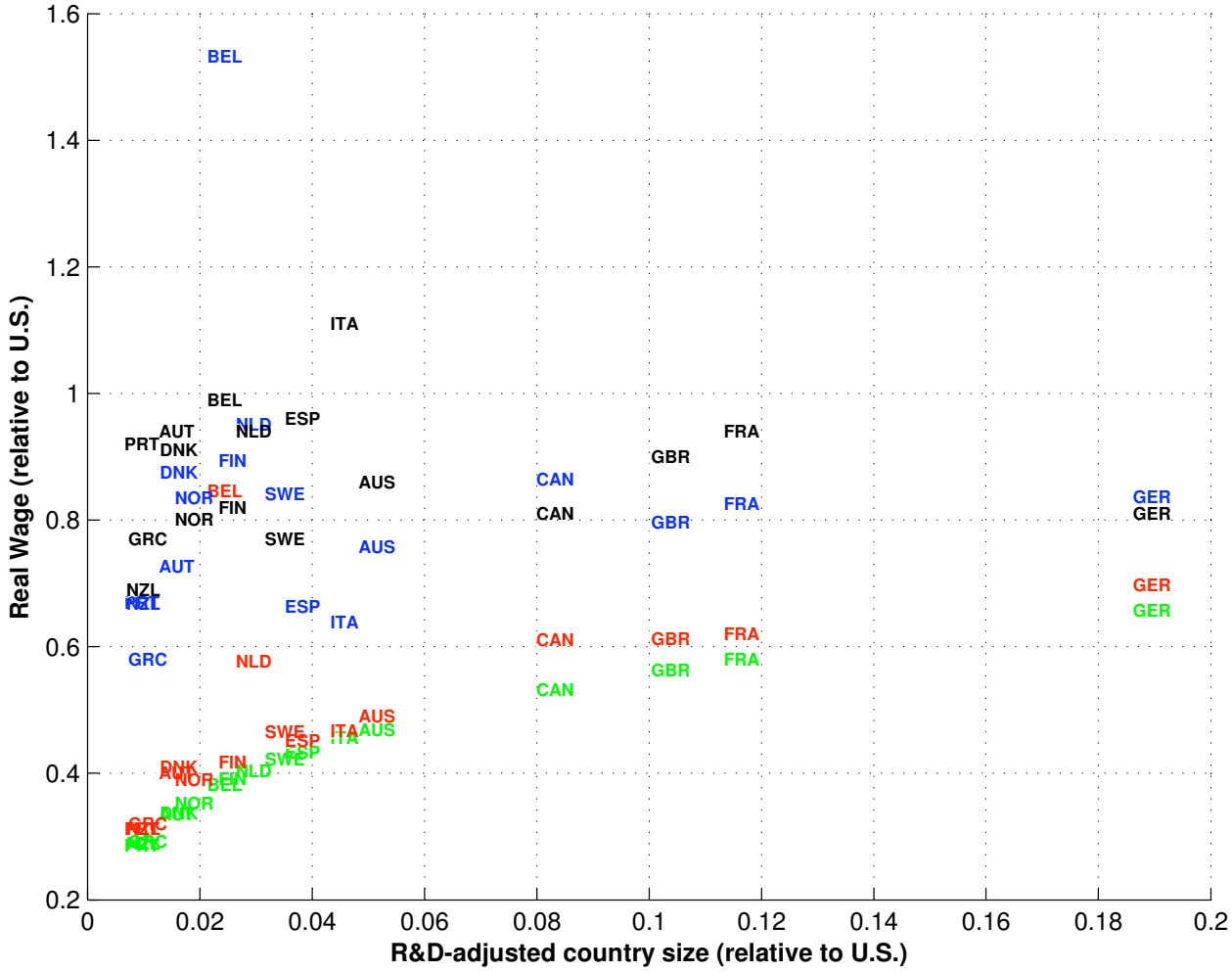
The role of scale effects is captured by the first term on the right-hand side of this expression, the role of openness to trade is captured by the second term, and the role of domestic frictions is captured by the third term.

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 (weak) 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). 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 Figure1—calculated using only the first and second terms on the right-hand side of (11), 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

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.

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]

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.[20]

Domestic frictions are the channel that helps to bring the calibrated model's implied 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 (11)—(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.[21] 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

$$\Delta \equiv \sum_{n} \left[(w_n/P_n)^{model} - (w_n/P_n)^{data} \right]^2, \tag{12}$$

as a measure of the fit of the model with the data. For our calibrated model (blue dots), $\Delta = 0.85$,

[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).

[20] Contrary to the set up in Redding (2012), we assume that regions within countries are symmetric. Besides the fact that we can focus on more countries, for which data on internal trade flows are not available, the assumption is quantitatively innocuous for the gains from trade: While assuming symmetric or asymmetric regions delivers very different gains from trade at the *region* level, as Redding (2012) shows, at the *national* level, the gains from trade are virtually identically in the two set-ups.

[21] 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.

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 Figure1). 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.

3.2 Gravity and Domestic Frictions

We now provide some independent evidence on the presence of domestic frictions. We start by deriving the gravity equation implied by our model of trade augmented with domestic frictions. Trade flows from country l to n are given by

$$X_{nl} = d_{nl}^{-\theta} \left(\frac{w_l}{\gamma P_n} \right)^{-\theta} \phi_l L_l X_n, \tag{13}$$

while trade flows within country n are

$$X_{nn} = D_n^{-1} \left(\frac{w_n}{\gamma P_n} \right)^{-\theta} \phi_n L_n X_n. \tag{14}$$

Equations (13) and (14) are derived in the Appendix.

Combining (14) with (13) implies

$$\frac{X_{nl}}{X_{ll}} = D_l \times \left(d_{nl} \frac{P_l}{P_n} \right)^{-\theta} \left(\frac{X_n}{X_l} \right). \tag{15}$$

The term D_l is a country specific effect greater than one. When $d_{ll} = 1$, $D_l = 1$ and (15) collapses to the expression in Eaton and Kortum (2002) and Waugh (2010).

Following Waugh (2010), international trade costs can be parameterized as

$$\log d_{nl} = dist_k + b_{nl} + ex_l + \varepsilon_{nl}, \tag{16}$$

where $dist_k$ with $k = 1, 2, ..., 6$ indicates the effect of distance between country l and n lying in the

kth distance intervals, b_{nl} captures the effect of a shared border ($b_{nl} = 1$ if country l and n share a border, and zero otherwise), ex_l is an exporter fixed effect, and ε_{nl} reflects barriers to trade arising from all other country-pair specific factors that are orthogonal to the regressors.[22] The expression in (15) can be written as

$$\log \frac{X_{nl}}{X_{ll}} = S_l - H_n - \theta dist_k - \theta b_{nl} - \theta \varepsilon_{nl}, \tag{17}$$

where

$$S_l \equiv \log D_l - \theta ex_l - \theta \log P_l^g + \log w_l L_l, \tag{18}$$

and

$$H_n \equiv \log w_n L_n - \theta \log P_n^g. \tag{19}$$

These two terms gather source and destination country characteristics, respectively. Subtracting (24) from (18) for country l yields

$$S_l - H_l = \log D_l - \theta ex_l. \tag{20}$$

If domestic frictions were present, the fixed effect ex_l could not be identified from (20). Moreover, the effect of domestic frictions on trade flows would be interpreted as part of the exporter fixed effect and Waugh (2010)'s estimates would truly be

$$\widetilde{ex}_l \equiv -\frac{1}{\theta}(S_l - H_l) = ex_l - \frac{1}{\theta} \log D_l. \tag{21}$$

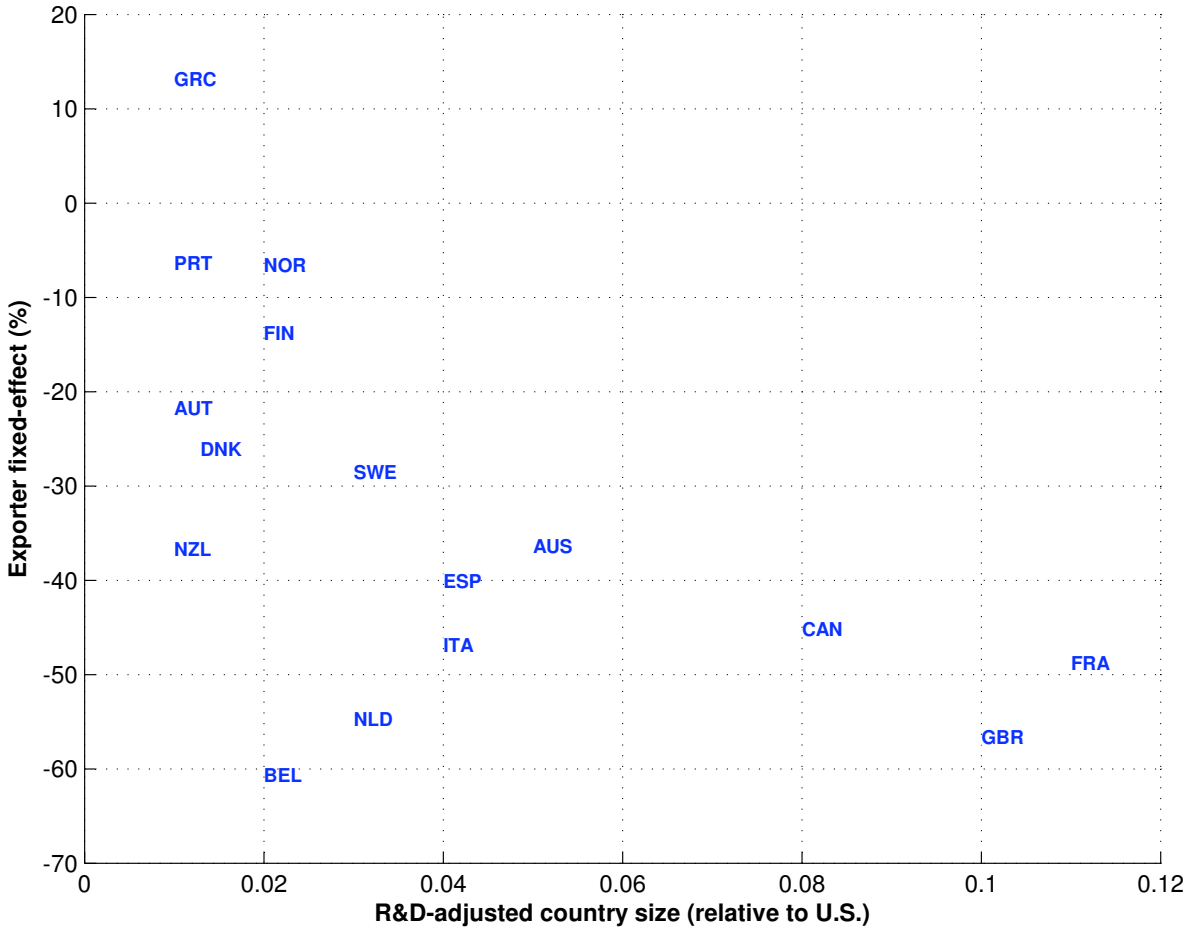
Clearly, the estimates coming from the model without domestic frictions would be biased. In particular, as shown by (5), the term D_l is larger, the larger the country. Hence, the estimated fixed effect, $\widetilde{ex}_l$, is lower than the "true" exporter fixed effect, ex_l, the larger the country is. In other words, Waugh (2010)'s estimates would be downward biased and would present a systematic variation with country size.[23] More specifically, the correlation between country size and the

[22] The key difference between Waugh (2010) and Eaton and Kortum (2002) is to include an exporter, rather than an importer, fixed effect, as part of the trade costs. Furthermore, Waugh (2010) shows how a model with trade costs parameterized as in (16) captures much better several features of the data.

[23] 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 D_l come exclusively from the number of regions M_l within a country.

exporter fixed effect estimated by Waugh (2010) should be negative.[24] Figure 2 gives support to the idea that countries are not perfectly integrated units and that larger countries have larger domestic frictions.

Figure 2: Exporter fixed effects and country size.



The exporter fixed effect is expressed in terms of the percentage effect on cost, $e^{-\theta ex_l} - 1$, 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. Japan = (0.57,-54.6) and USA = (1,-62.5)—not shown.

Larger countries have systematically lower estimated costs of exporting: The correlation between R&D-adjusted size ($\phi_n L_n$) and the exporter fixed effects as estimated by Waugh (2010) is

[24]The exporter fixed effect is expressed in terms of the percentage effect on cost, $e^{-\theta ex_l} - 1$, with the mean across countries normalized to zero. For the United States, Waugh estimates 62.5 percent, indicating that the U.S. cost of exporting is 62.5 percentage points lower than the cost in the average country.

-0.46.[25] This result is robust to other measures of country size and a larger sample of countries.[26] 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 -0.51, while the same correlation using the sample of 77 countries that Waugh considers is -0.23.[27]

The systematic pattern between the estimated exporter fixed effects and country size supports the idea that, not only domestic frictions to trade flows exist, but also they are larger for large countries.

3.3 Robustness

3.3.1 The Role of θ

To explore the effect of the value of θ on our results, let $O_n \equiv \lambda_{nn}^{-1}$ and rewrite (11) as

$$\frac{w_n/P_n}{w_{US}/P_{US}} = \left[\left(\frac{\phi_n L_n}{\phi_{US} L_{US}}\right)\left(\frac{D_n}{D_{US}}\right)^{-1}\left(\frac{O_n}{O_{US}}\right)\right]^{1/\theta}. \tag{22}$$

All the terms inside the bracket come, directly or indirectly, from the data and do not depend on the value of θ. Hence, this expression tells us how the relative real wage implied by the calibrated model changes with θ (in the exponent).[28] For countries with a lower real wage than the U.S., 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.

[25] The R-squared of a regression of the exporter fixed effects on (log of) R&D-adjusted size, with robust standard errors and a constant, is 0.45, and the size coefficient is -0.11 (s.e. 0.025).

[26] Our measure of R&D-adjusted size, presented above, is available only for relatively rich countries.

[27] 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.

[28] Notice that the variable $d_{nn}^{-\theta}$ is pinned down by $\widehat{X}_{nn}/X_{nn}$ and M_n, both coming from the data for the United States, and using (6). D_n is computed using the implied $d_{nn}^{-\theta}$, so that although changes in θ lead to changes in the calibrated d_{nn}, there is no change in $d_{nn}^{-\theta}$, implying no change in D_n.

3.3.2 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.[29] 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 (6) and (5) to calibrate d_{nn}. For $\theta = 4$ and year 2007, 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 (6) and (5), 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.[30] 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

[29] 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.

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

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 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 (2009), to domestic trade flows. In particular,

$$d_{mk}^{HR} \equiv \left(\frac{\widetilde{X}_{mk}}{\widetilde{X}_{kk}} \frac{\widetilde{X}_{km}}{\widetilde{X}_{mm}} \right)^{-\frac{1}{2\theta}},$$

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.[31]

[31] Figure 3 in the online Appendix shows the distribution of costs for the United States and Canada, respectively.

4 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 assume that a technology in region m of country n can be used for production in other regions of country n as well as outside of country n. Whenever a technology is used outside of the region where it originated, 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 in country i but 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 $h_{li} \geq 1$. Finally, the total MP cost associated with using a technology from country i in country $l \neq i$ outside of the technology's home region in country l is $h_{li}h_{ll}$.[32]

In sum, each technology is then 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 $(i, \boldsymbol{z}, \boldsymbol{m})$ used in the technology's home region in country $l \neq i$ is z_l/h_{li}, while if it is used in country $l \neq i$, but outside of the technology's home region, then the effective productivity is $z_l/h_{li}h_{ll}$.

Finally, 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

[32]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.

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, $1 \leq d_{nn} = h_{nn}$, so that in equilibrium we have: "domestic MP" in final but not in intermediate goods (i.e., technologies to produce intermediate goods are always used in their home region); domestic trade only in intermediate goods; and international trade and MP in both final and intermediate goods.[33]

Our object of interest is, as in the baseline model, the equilibrium real wage in each country n to be compared with the data.[34] In the model with trade, MP, and domestic frictions, this endogenous variable can be written as a function of trade and MP flows,

$$\frac{w_n}{P_n^f} = \gamma^M \underbrace{(\phi_n L_n)^{(1+\eta)/\theta}}_{\text{size}} \times \underbrace{(H_n)^{-1/\theta} (D_n)^{-\eta/\theta}}_{\text{domestic frictions}} \times \underbrace{\left(\frac{X_{nn}}{\eta w_n L_n}\right)^{-\eta/\theta}}_{\text{gains from trade}} \times \underbrace{\left(\frac{Y_{nn}^f}{w_n L_n}\right)^{-1/\theta} \left(\frac{Y_{nn}^g}{\eta w_n L_n}\right)^{-\eta/\theta}}_{\text{gains from MP}} \tag{23}$$

where γ^M is a positive constant (defined in the Appendix), P_n^f is the price index for final goods, and

$$H_n \equiv \left[\frac{1}{M_n} + \frac{M_n - 1}{M_n}(h_{nn})^{-\theta}\right]^{-1}. \tag{24}$$

The variable H_n serves an analogous role for domestic MP flows as D_n does for domestic trade flows. The variables Y_{nn}^g and Y_{nn}^f refer to total production in n done with domestic technologies, in the tradable and non-tradable sectors, respectively. The last two terms on the right-hand side of (23) are the gains from MP (i.e., the change in the real wage from a situation with no MP to the observed equilibrium), for final and intermediate goods, respectively. The gains from openness are just the product of the gains from trade and the gains from MP.

[33] For intermediate goods, we assume a break even condition such that if $h_{nn} = d_{nn}$ then we have trade but no MP.

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

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. 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 $d_{nn} = 1.81$. The variables Y_{nn}^f and Y_{nn}^g are from the data, as explained in detail in the Appendix.

Column 7 of Table 5 shows the relative real wage for the model with trade, MP, and domestic frictions. Columns 2, 3, 4, and 5 of Table 5 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 $H_n = D_n$, and hence, $\left(\frac{H_n}{H_{US}}\right)^{-1/\theta}\left(\frac{D_n}{D_{US}}\right)^{-\eta/\theta} = \left(\frac{D_n}{D_{US}}\right)^{-(1+\eta)/\theta}$. Since $(1+\eta)/\theta = 1/4$, 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 5, 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 (12) 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.[35] 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

[35]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.

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.

5 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 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 8 in the online Appendix lists all these variables, as well as patents per capita, 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.[36] 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.[37]

The presence of diffusion within and across countries may also be an additional explanation for the high domestic costs that we estimate. But if some ideas (i.e., technologies) from one region can be used to produce in other regions of the world at no cost (or at a lower cost than trade), then high trade costs may lead to the use of foreign ideas through diffusion rather than trade. If diffusion is a feature of reality, ignoring it in the model will deliver an estimate of trade costs that is biased upwards; this would be a problem common to most of the trade literature. The big challenge, however, would be to discipline diffusion as it is not directly observable in the data. This issue is left to be explored in future research.

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

[36] 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.

[37] 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.

R&D-adjusted size is zero.[38] Again, this evidence suggests that smallness do not confer some productivity advantage through immigration.

6 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. We argue that this prediction is largely a result of the crude way in which geography has been treated in these models. In particular, these models assume that any innovation produced in a given country is instantly available to all residents of that country. We build a general equilibrium multi-country model that features a rich geographic structure within each country, and builds on the seminal model of geography and trade of Eaton and Kortum (2002), combined with a treatment of innovation à la Kortum (1997). Using data on trade flows across countries, within-country trade flows (available for the United States and Canada), and the country's R&D-adjusted equipped labor, we calibrate the model and evaluate the role of domestic frictions, vis-à-vis trade openness, in reconciling the data and the theory. Our calibrated model suggests that internal barriers are much more important than trade openness to explain the discrepancy between standard models and the data. 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 real per-capita income implied by the standard semi-endogenous growth model (34 percent), and the model with only international trade (41 percent).

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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 (22). 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 (11). 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 M_n and d_{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 (11) 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: 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 (23). 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 Derivation of equation 6

From basic EK algebra, for $m \in \Omega_n$, we have

$$\widetilde{X}_{mm} = \left(\frac{w_n}{\gamma P_n}\right)^{-\theta} \bar{T}_n \widetilde{X}_m, \tag{25}$$

and, for $m, k \in \Omega_n$ with $m \neq k$, we have

$$\widetilde{X}_{mk} = d_{nn}^{-\theta} \left(\frac{w_n}{\gamma P_n}\right)^{-\theta} \bar{T}_n \widetilde{X}_m. \tag{26}$$

Combining (25), (26), and $X_{nn} = M_n \sum_{k \in \Omega_n} \widetilde{X}_{mk}$ yields

$$X_{nn} = M_n \left(\frac{w_n}{\gamma P_n}\right)^{-\theta} \bar{T}_n \widetilde{X}_m \left[1 + (M_n - 1)\, d_{nn}^{-\theta}\right]. \tag{27}$$

Combining (25) with (27), we obtain

$$\frac{\widehat{X}_{nn}}{X_{nn}} = \left[1 + (M_n - 1)\, d_{nn}^{-\theta}\right]^{-1},$$

where $\widehat{X}_{nn} \equiv \sum_{m \in \Omega_n} \widetilde{X}_{mm} = \widetilde{X}_{mm} M_n$. The result follows immediately from the definition of D_n in (5).

B Derivation of equations (13) and (14)

The gravity equation at the country level is derived by replacing

$$\widetilde{X}_{mk} = \frac{\widetilde{T}_k w_k^{-\theta} \widetilde{d}_{mk}^{-\theta}}{\sum_l \widetilde{T}_l w_l^{-\theta} \widetilde{d}_{ml}^{-\theta}} \widetilde{X}_m$$

in $X_{ni} \equiv \sum_{m \in \Omega_n} \sum_{k \in \Omega_i} \widetilde{X}_{mk}$, to get

$$X_{nl} = \sum_{m \in \Omega_n} \sum_{k \in \Omega_l} \frac{\widetilde{T}_k w_k^{-\theta} \widetilde{d}_{mk}^{-\theta}}{\sum_l \widetilde{T}_l w_l^{-\theta} \widetilde{d}_{ml}^{-\theta}} \widetilde{X}_m.$$

For $n \neq l$,

$$\begin{aligned} X_{nl} &= \sum_{m\in\Omega_n} \frac{M_l \bar{T}_l w_l^{-\theta} d_{nl}^{-\theta}}{\sum_j \sum_{i\in\Omega_j} \widetilde{T}_i w_i^{-\theta} \widetilde{d}_{mi}^{-\theta}} \frac{X_n}{M_n} \\ &= \sum_{m\in\Omega_n} \frac{M_l \bar{T}_l w_l^{-\theta} d_{nl}^{-\theta}}{\sum_{j\neq n} M_j \bar{T}_j w_j^{-\theta} d_{nj}^{-\theta} + (M_n - 1)\bar{T}_n w_n^{-\theta} d_{nn}^{-\theta} + \bar{T}_n w_n^{-\theta}} \frac{X_n}{M_n} \\ &= \sum_{m\in\Omega_n} \frac{M_l \bar{T}_l w_l^{-\theta} d_{nl}^{-\theta}}{\sum_{j\neq n} M_j \bar{T}_j w_j^{-\theta} d_{nj}^{-\theta} + M_n \bar{T}_n w_n^{-\theta} \left[\frac{1}{M_n} + \frac{M_n - 1}{M_n} d_{nn}^{-\theta}\right]} \frac{X_n}{M_n} \\ &= \frac{T_l w_l^{-\theta} d_{nl}^{-\theta}}{\sum_{j\neq n} T_j w_j^{-\theta} d_{nj}^{-\theta} + T_n w_n^{-\theta} D_n^{-1}} M_n \frac{X_n}{M_n}. \end{aligned}$$

Since the price index is given by

$$(\gamma P_n)^{-\theta} = \sum_{j\neq n} T_j w_j^{-\theta} d_{nj}^{-\theta} + T_n w_n^{-\theta} D_n^{-1},$$

then

$$X_{nl} = \frac{T_l w_l^{-\theta} d_{nl}^{-\theta}}{(\gamma P_n)^{-\theta}} X_n,$$

which is (13).

For $n = l$,

$$\begin{aligned} X_{nn} &= \sum_{m\in\Omega_n} \sum_{k\in\Omega_n} \frac{\widetilde{T}_k w_k^{-\theta} \widetilde{d}_{mk}^{-\theta}}{\sum_l \widetilde{T}_l w_l^{-\theta} \widetilde{d}_{ml}^{-\theta}} \widetilde{X}_m \\ &= \sum_{m\in\Omega_n} \frac{(M_n - 1)\bar{T}_n w_n^{-\theta} d_{nn}^{-\theta} + \bar{T}_n w_n^{-\theta}}{\sum_{j\neq n} M_j \bar{T}_j w_j^{-\theta} d_{nj}^{-\theta} + (M_n - 1)\bar{T}_n w_n^{-\theta} d_{nn}^{-\theta} + \bar{T}_n w_n^{-\theta}} \frac{X_n}{M_n} \\ &= M_n \bar{T}_n w_n^{-\theta} \frac{\frac{1}{M_n} + \frac{M_n - 1}{M_n} d_{nn}^{-\theta}}{\sum_{j\neq n} M_j \bar{T}_j w_j^{-\theta} d_{nj}^{-\theta} + M_n \bar{T}_n w_n^{-\theta} D_n^{-1}} X_n \\ &= \frac{T_n w_n^{-\theta} D_n^{-1}}{\sum_{j\neq n} T_j w_j^{-\theta} d_{nj}^{-\theta} + T_n w_n^{-\theta} D_n^{-1}} X_n. \end{aligned}$$

Hence,

$$X_{nn} = \frac{T_n w_n^{-\theta} D_n^{-1}}{(\gamma P_n)^{-\theta}} X_n;$$

as in (14).

C The Model with Multinational Production and Non-Tradable Goods

C.1 Equilibrium Analysis

The characterization of the equilibrium follows closely the analysis in Eaton and Kortum (2002) and Alvarez and Lucas (2007).

Prices. Let c_n^f and c_n^g denote the unit costs of the input bundle for final and intermediate goods in country n, respectively, given by $c_n^f = A w_n^\alpha (P_n^g)^{1-\alpha}$ and $c_n^g = B w_n^\beta (P_n^g)^{1-\beta}$, where w_n and P_n^g are the wage and the price of the composite intermediate good, respectively, in country n, and A and B are constants that depend on α and β, respectively.

Let $z_{m,ni}^f(u)$ and $z_{m,ni}^g(v)$ be the highest productivity among the set of technologies for final good u and intermediate good v, respectively, originating in country i with home region m in country n. Let $z_{li}^g(v) = \max_m z_{m,li}^g(v)$.

Consider first the case of final goods. What are the different technologies available for region m, in country n, for consuming final good u? We have: (a) technologies from n with home region m at unit cost $c_n^f / z_{m,nn}^f(u)$; (b) technologies from $i \neq n$ with home region m at unit cost $h_{ni}^f c_n^f / z_{m,ni}^f(u)$; (c) technologies from n with home region different than m at unit cost $\min_{s \neq m} h_{nn}^f c_n^f / z_{s,nn}^f(u)$; (d) technologies from $i \neq n$ with home region different than m at unit cost $\min_{s \neq m} h_{nn}^f h_{ni}^f c_n^f / z_{s,ni}^f(u)$. This implies that

$$p_{m,n}^f(u) = \min \left(\frac{c_n^f}{z_{m,nn}^f(u)}, \frac{h_{ni}^f c_n^f}{z_{m,ni}^f(u)}, \min_{s \neq m} \frac{h_{nn}^f c_n^f}{z_{s,nn}^f(u)}, \min_{i \neq n} \min_{s \neq m} \frac{h_{nn}^f h_{ni}^f c_n^f}{z_{s,ni}^f(u)} \right).$$

What are the different technologies available for region m, in country n, for using intermediate good v? We have: (a) technologies from n with home region m at unit cost $c_n^g / z_{m,nn}^g(v)$; (b) technologies from $i \neq n$ with home region m at unit cost $h_{ni}^g c_n^g / z_{m,ni}^g(v)$; (c) technologies from n with home region different than m at unit cost

$$\min \left\{ \min_{s \neq m} \frac{h_{nn}^g c_n^g}{z_{s,nn}^g(v)}, \min_{s \neq m} \frac{d_{nn} c_n^g}{z_{s,nn}^g(v)} \right\};$$

(d) technologies from $i \neq n$ with home region different than m at unit cost

$$\min\left\{\min_{i\neq n}\min_{s\neq m}\frac{h^g_{nn}h^g_{ni}c^g_n}{z^g_{s,ni}(v)},\min_{i\neq n}\min_{s\neq m}\frac{d_{nn}h^g_{ni}c^g_n}{z^g_{s,ni}(v)}\right\};$$

(e) technologies from $i \neq n$ used in their home region in country i and imported to m at unit cost $\min_i d_{ni}c^g_i/z^g_{ii}(v)$; and (f) technologies from i used in their home region in $l \neq n$ and imported to m at unit cost $\min_{i,l} d_{nl}h^g_{li}c^g_l/z^g_{li}(v)$. Given $d_{nn} < h^g_{nn}$, this implies that

$$p^g_{m,n}(v) = \min\left(\frac{c^g_n}{z^g_{m,nn}(v)},\min_{i\neq n}\frac{h^g_{ni}c^g_n}{z^g_{m,ni}(v)},\min_{s\neq m}\frac{d_{nn}c^g_n}{z^g_{s,nn}(v)},\min_{i\neq n}\min_{s\neq m}\frac{d_{nn}h^g_{ni}c^g_n}{z^g_{s,ni}(v)},\min_{i\neq n}\frac{d_{ni}c^g_i}{z^g_{ii}(v)},\min_{i\neq n,l\neq n}\frac{d_{nl}h^g_{li}c^g_l}{z^g_{li}(v)}\right).$$

As in the case of a close economy, these results, together with the assumption that productivities are independently drawn from the Fréchet distribution, and D_n and H_n are defined by (5) and (24), respectively, imply that the price indices for final and intermediate goods are given, respectively, by

$$\left(\gamma P^f_n\right)^{-\theta} = M_n\bar{T}_n(c^f_n)^{-\theta}H_n^{-1} + \sum_{i\neq n}M_i\bar{T}_i(h^f_{ni}c^f_n)^{-\theta}H_n^{-1}, \tag{28}$$

and

$$\begin{aligned}(\gamma P^g_n)^{-\theta} &= M_n\bar{T}_n(c^g_n)^{-\theta}D_n^{-1} + \sum_{i\neq n,l=n}M_i\bar{T}_i(h^g_{ni}c^g_n)^{-\theta}D_n^{-1} \\ &+ \sum_{i\neq n,l=i}M_i\bar{T}_i(d_{ni}c^g_i)^{-\theta} + \sum_{l\neq n,l\neq i}M_i\bar{T}_i\left(d_{nl}h^g_{li}c^g_l\right)^{-\theta}.\end{aligned} \tag{29}$$

In the case of final goods, the first term on the right-hand side of (28) corresponds to technologies originating in country n, while the second term corresponds to technologies originating in country $i \neq n$. In the case of intermediate goods, the first term on the right-hand side of (29) corresponds to technologies originating in country n, the second term corresponds to technologies originating in country $i \neq n$, but used to produce domestically in country n, the third term corresponds to technologies originating in country $i \neq n$ used to produce in country i and export to country n, and the final term corresponds to technologies from any country used to produce outside of country n and outside of the country where the technology originates.

Trade flows. Examining the contribution of country l to the price index for intermediate goods

in $n \neq l$ reveals that the value of trade flows from country l to country n is

$$X_{nl} = \left(\frac{c_l^g}{\gamma P_n^g} d_{nl}\right)^{-\theta} \left[\sum_{i \neq l} M_i \bar{T}_i \left(h_{li}^g\right)^{-\theta} + M_l \bar{T}_l\right] \eta w_n L_n, \tag{30}$$

where $X_n^g = \eta w_n L_n$ is the expenditure on intermediate goods in country n. In turn, domestic trade flows are

$$X_{nn} = \left(\frac{c_n^g}{\gamma P_n^g}\right)^{-\theta} D_n^{-1} \left[\sum_{i \neq n} M_i \bar{T}_i \left(h_{ni}^g\right)^{-\theta} + M_n \bar{T}_n\right] \eta w_n L_n. \tag{31}$$

MP flows. Again, examining the price index for intermediate goods reveals that total MP in intermediate goods by country i in $l \neq i$ is

$$Y_{li}^g = M_i \bar{T}_i \left(\frac{c_l^g}{\gamma P_l^g} h_{li}^g\right)^{-\theta} \left[D_l^{-1} \eta w_l L_l + \sum_{n \neq l} d_{nl}^{-\theta} \eta w_n L_n \left(\frac{P_l^g}{P_n^g}\right)^{-\theta}\right], \tag{32}$$

while total production in country n with domestic technologies is

$$Y_{nn}^g = M_n \bar{T}_n \left(\frac{c_n^g}{\gamma P_n^g}\right)^{-\theta} \left[D_n^{-1} \eta w_n L_n + \sum_{j \neq n} d_{jn}^{-\theta} \eta w_j L_j \left(\frac{P_n^g}{P_j^g}\right)^{-\theta}\right]. \tag{33}$$

For final goods, total MP by country i in $n \neq i$ is

$$Y_{ni}^f = M_i \bar{T}_i \left(\frac{c_n^f}{\gamma P_n^f} h_{ni}^f\right)^{-\theta} H_n^{-1} w_n L_n, \tag{34}$$

while total production in n with domestic technologies is

$$Y_{nn}^f = M_n \bar{T}_n \left(\frac{c_n^f}{\gamma P_n^f}\right)^{-\theta} H_n^{-1} w_n L_n. \tag{35}$$

When $D_{nn} = H_{nn} = 1$, Y_{ni}^g and Y_{ni}^f collapse to the expressions in Ramondo and Rodríguez-Clare (2013), except that now MP flows in both sectors are multiplied by an extra L_i (from $M_i \bar{T}_i = \phi_i L_i$). This reflects the assumption that countries are a collection of not fully integrated regions.

The real wage and the gains from openness. We want to derive equation (23) in the paper.

First, (33) can be rewritten as

$$Y_{nn}^{g} = M_n \bar{T}_n \left(\frac{c_n^g}{\gamma P_n^g} \right)^{-\theta} \Psi'_n,$$

where

$$\Psi'_n = D_n^{-1} \eta w_n L_n + \sum_{j \neq n} \left(\frac{P_n^g}{P_j^g} d_{jn} \right)^{-\theta} \eta w_j L_j. \tag{36}$$

Using the expression above for Y_{nn}^g and (35), we can write the real wage as

$$\frac{w_n}{P_n^f} = \gamma^M (M_n \bar{T}_n)^{(1+\eta)/\theta} (H_n)^{-1/\theta} (Y_{nn}^g)^{-\eta/\theta} \left(\frac{Y_{nn}^f}{w_n L_n} \right)^{-1/\theta} (\Psi'_n)^{\eta/\theta}, \tag{37}$$

where $\gamma^M \equiv (\gamma^{-(1+\eta)} A B^{\eta})^{-1}$. We then rewrite (36) as

$$\Psi'_n = D_n^{-1} \eta w_n L_n + \eta w_n L_n \sum_{j \neq n} \left(\frac{P_n^g}{P_j^g} d_{jn} \right)^{-\theta} \frac{w_j L_j}{w_n L_n}.$$

Using (30) and the equivalent of (31) for X_{ll}, we obtain

$$\frac{X_{nl}/w_n L_n}{X_{ll}/w_l L_l} = D_l \left(d_{nl} \frac{P_l^g}{P_n^g} \right)^{-\theta}, \tag{38}$$

that, together with $\sum_{j=1}^{N} X_{jn} = \eta w_n L_n$, yields

$$\Psi'_n = D_n \eta w_n L_n \left(\frac{\eta w_n L_n}{X_{nn}} \right).$$

Replacing in (37), we obtain the real wage in (23).

The real wage in the closed economy is simply given by setting the last three terms in (37) to one,

$$\frac{w_n}{P_n^f} = \gamma^M \left(M_n \overline{T}_n \right)^{(1+\eta)/\theta} (H_n)^{-1/\theta} (D_n)^{-\eta/\theta}. \tag{39}$$

Thus, the gains from openness are easily calculated as the ratio of the real wage in (23) to the one in (39), yielding the last three terms in (23).

C.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.[39] 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 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 (23), 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.

C.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

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

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 (10) is replaced by $g = g_L(1+\eta)/\theta$, by differentiating (23) 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 (23), 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 (23), 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 $1/4$.

D Online Appendix

D.1 Data

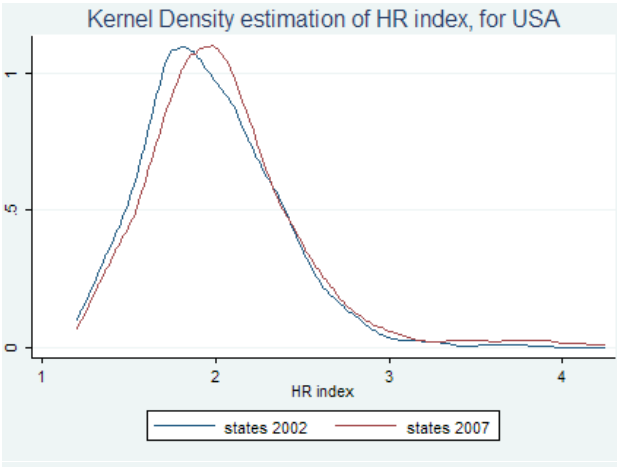
Table 6: Data: Summary.

	Domestic MP shares final (1)	intermediate (2)	Domestic Trade shares (3)	Real GDP per capita (4)	R&D employment (5)	Equipped labor (6)	Country's size (7)=(5)×(6)	Country's density (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 3: Domestic Trade Costs: Head and Ries Index.

(a) U.S. States



(b) Canadian Provinces

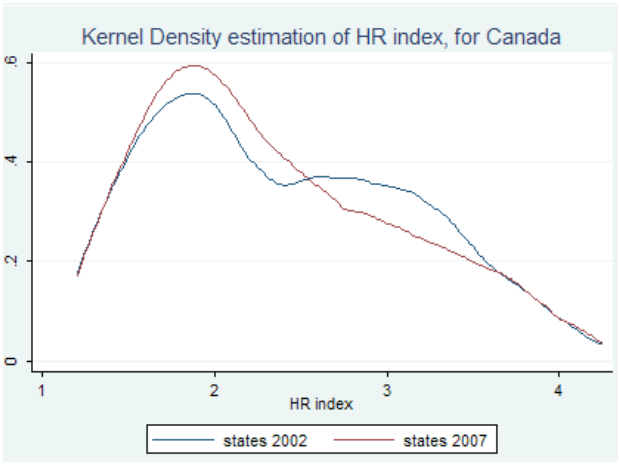


Table 7: Shipments within the United States, by state of destination.

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 8: 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.