Scale Effects and Productivity Across Countries: Does Country Size Matter?*

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Abstract

Models in which growth is driven by innovation naturally lead to scale effects. These scale effects result in the counterfactual prediction that larger countries should be much richer than smaller ones. We explore and quantify two candidates to solve the puzzle: First, countries are not fully isolated from each other; and second, countries are not fully integrated domestically. To such end, we build a quantitative model of trade and multinational production (MP) with frictions to move goods and ideas not only across, but also within countries. The calibrated model goes a long way to resolve the puzzle. The existence of domestic frictions, rather than openness to trade and MP, is what allows the extended model to come close to matching the data.

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

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1 Introduction

Models in which growth is driven by innovation naturally lead to scale effects. In Jones (2005)'s 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 nonrivalrous, and, in standard growth models, they imply that income levels should increase with country size.[1] A quick look at the data, however, immediately reveals that small countries are not poor compared to larger ones–think Belgium versus France, or Hong-Kong versus China.[2]

The goal of this paper is to explore this apparent inconsistency between idea-based growth models and the cross-country data. We start by studying the implications of Kortum (1997)'s model for country-level scale effects and noting that it implies that, *ceteris paribus*, small countries would be much poorer than larger ones. For example, according to our calibration, Denmark would have an income level of 34 percent of the U.S. level, much lower than the observed 91 percent.[3] We refer to this gap as the "Danish Puzzle," but it is a puzzle common to all small countries in our sample of OECD countries.[4]

Two candidate solutions to resolve this puzzle jump out immediately: First, countries are not fully isolated from each other; and second, countries are not fully integrated domestically. To capture the idea that countries are not isolated units, we extend Kortum (1997)'s model by allowing for trade–as in Eaton and Kortum (2002)– and multinational production (i.e., the use of ideas for production outside of their place of origin) –as in Ramondo and Rodríguez-Clare (2010). Thus, in our model, countries are integrated through trade and multinational production (henceforth, MP). To capture the idea that countries are not fully integrated units, we model each country as a group

[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.

[3] The same implication would arise if, alternately, we used the model developed by Jones (1995).

[4] One could argue that this puzzle arises because of selection, since our sample includes only rich (OECD) countries. But this would require small countries to exhibit much better institutions, higher R&D intensities, or patenting levels, things that we do not observe in the data. One reason to restrict the attention to a set of rich (OECD) countries is precisely that these countries are similar in those dimensions.

of regions, and allow for domestic frictions to trade and MP across regions, within countries.[5] Domestic frictions weaken country-level scale effects and put large countries at a disadvantage. In the extreme, if such frictions *within* countries were as strong as they are *across* countries, then country-level scale effects would disappear.[6]

Section 2 describes the model starting with the case of a closed economy composed of multiple identical regions. We use the closed-economy model to explain, in the simplest way, how we introduce domestic frictions to trade and to MP, and how these frictions weaken scale effects. We then extend the model to allow for international trade and MP (i.e., the use of ideas originated in any region of one country for production in any region of another country) and show that real wages are a function of domestic frictions and the gains from openness, which in turn depend on trade and MP flows.

Section 3 calibrates the model to the data on trade and MP flows, as well as to within-country trade flows (available for the United States and Canada), and then uses the calibrated model to explore the role that openness and domestic frictions play in the resolution of the Danish Puzzle. For the case of Denmark, our calibrated model implies a real per-capita income of 76 percent (relative to the U.S.), versus 91 percent in the data. Thus, our two channels together are able to explain more than 70 percent of the puzzle. We find that domestic frictions are quantitatively much more important than openness, as they explain more than two thirds of the Danish Puzzle, while trade and MP explain just five percent of the puzzle. We are left with one fourth of the gap unexplained, suggesting the presence of other forms of openness not associated with trade and MP, such as international diffusion of ideas taking place outside the firm. We offer a brief quantitative exploration of this conjecture in Section 4. Section 5 concludes.

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

[5]For lack of a better term, we also use the term MP to refer to the production done in one region using an idea from another region within the same country. Thus, for example, we would refer to the operation of Wal-Mart outside of Arkansas as MP even though it happens within the United States.

[6]The other extreme, namely no frictions within countries and infinite frictions across countries, is the case considered in standard growth models.

by geography) lead to higher income levels. Controlling for trade, quality of institutions, and geography, Alcala and Ciccone (2004) find an elasticity of income to size of 0.30, very similar to the one implied by the calibration of the structural parameters in our model. As in this literature, we find that small countries gain relatively more from trade, but our calibrated model suggests that the effect is small: Openness to trade cannot explain much of the Danish Puzzle.

One admittedly strong assumption in our analysis is that regions within a country are identical. In our set-up, a country's internal geography is entirely characterized by domestic trade and MP costs as well as its number of regions.[7] In a recent paper, Redding (2012) has shown how to compute the gains from trade in a setting with perfect labor mobility within countries composed of multiple asymmetric regions. In principle, we could extend this model to incorporate MP and then compute the gains from trade and MP while allowing for asymmetric regions within each country. Unfortunately, this extension would require data on trade and MP flows between every pair of regions in the world (e.g., trade and MP flows between every state in the United States and every province in Canada), and such data are simply non-existent.[8]

2 The Model

We extend Ramondo and Rodríguez-Clare (2010)'s model of trade and MP to incorporate domestic trade and MP costs. The model is Ricardian with a continuum of tradable intermediate and non-tradable final goods, produced under constant returns to scale. We adopt the probabilistic representation of technologies as first introduced by Eaton and Kortum (2002). We embed the model into a general equilibrium framework similar to the one in Alvarez and Lucas (2007).

[7] The number of regions we attribute to a country is determined by the country's total size or population, as explained below.

[8] The symmetry assumption in our set-up is not as strong quantitatively as one may first think. We computed the gains from trade using a simplified version of Redding (2012)'s model with two countries, one with a single region and the other with two asymmetric regions. We then applied our methodology to compute the gains from trade ignoring the asymmetries between the two regions in the second country. The results are reassuring: The difference between the gains from trade computed in these two ways is never larger than one percent for different parameters' values. The online appendix presents the results.

2.1 The Closed Economy

Consider a closed economy formed by a set of identical regions, $m = 1, ..., M$, each with population $\bar{L}$. The total population is then $L = \bar{L}M$. We use subscript m to denote variables associated with region m and superscripts f and g to denote variables associated to final and intermediate goods, respectively. A representative agent in region m consumes a continuum of final goods indexed by $u \in [0,1]$ in quantities $q_m^f(u)$. Preferences over final goods are CES with elasticity $\sigma^f > 0$.

Final goods are produced with labor and a continuum of intermediate goods indexed by $v \in [0,1]$. Intermediate goods used in quantities $q_m^g(v)$ are aggregated into a *composite intermediate good* via a CES production function with elasticity $\sigma^g > 0$. We henceforth assume that $\sigma^g = \sigma^f = \sigma$. Denoting the total quantity produced of the composite intermediate good in region m as Q_m, we have

$$Q_m = \left(\int_0^1 q_m^g(v)^{(\sigma-1)/\sigma} dv \right)^{\sigma/(\sigma-1)}.$$

The composite intermediate good and labor are used to produce final goods via Cobb-Douglas technologies with varying productivities across goods and regions,

$$\widetilde{q}_m^f(u) = z_m^f(u) L_m^f(u)^{\alpha} Q_m^f(u)^{1-\alpha}. \tag{1}$$

The variable $\widetilde{q}_m^f(u)$ denotes the quantity produced of final good u in region m – we use a "tilda" over q to differentiate production, $\widetilde{q}_m^f(u)$, from consumption, $q_m^f(u)$. The variables $L_m^f(u)$ and $Q_m^f(u)$ denote the quantity of labor and the composite intermediate good, respectively, used in the production of final good u in region m, and $z_m^f(u)$ is a productivity parameter for good u in region m. Similarly, intermediate goods in region m are produced according to

$$\widetilde{q}_m^g(v) = z_m^g(v) L_m^g(v)^{\beta} Q_m^g(v)^{1-\beta}. \tag{2}$$

Resource constraints (at the region level) are

$$\begin{aligned}\int_0^1 L_m^f(u)du + \int_0^1 L_m^g(v)dv &= \bar{L},\\ \int_0^1 Q_m^f(u)du + \int_0^1 Q_m^g(v)dv &= Q_m.\end{aligned}$$

We have assumed that labor is immobile and the composite intermediate good is non-tradable across regions, but these assumptions are innocuous since regions are identical.

Final goods are non-tradable (even across regions within a country), but intermediate goods can be traded across regions with iceberg-type trade costs $d \geq 1$ (and there is no trade cost if the good is sold in the same region where it is produced). The assumption that final goods are non-tradable implies that $\widetilde{q}_m^f(u) = q_m^f(u)$, while the possibility of trade in intermediate goods implies that we can have $\widetilde{q}_m^g(v) \neq q_m^g(v)$.

There are L technologies for each good (i.e., one technology per person), and each of these technologies is freely available to perfectly competitive producers. Each technology is characterized by a productivity parameter z and a "home" region m. If technology (z, m) is used to produce outside of its home region (i.e., in region $s \neq m$), there is an iceberg-type efficiency loss $h^f \geq 1$ for final goods and $h^g \geq 1$ for intermediate goods, and the effective productivity is z/h^f and z/h^g. If the technology is used to produce in its home region (i.e., in region m), the effective productivity is z. With a slight abuse of terminology, we will say that if a technology is used for production outside of its home region, there is "multinational production," or MP. We assume that the cost of MP for intermediate goods is higher than the cost of trade, i.e., $h^g > d$.

For each good, the L technologies are uniformly assigned to the M regions as home regions; that is, for each good, the number of technologies for which a particular region is the home region (i.e., $\bar{L} = L/M$) is the same as the number of technologies for which any other region is the home region.[9] We assume that z is drawn from a Fréchet distribution with parameters $\bar{T}$ and $\theta > \max\{1, \sigma - 1\}$, $F(z) = \exp\left(-\bar{T}z^{-\theta}\right)$, for $z > 0$.

[9] Technically, the number of ideas should be a nonnegative integer. This would require that $\bar{L}$ be an integer. To simplify the analysis, we henceforth ignore this integer constraint.

2.1.1 Equilibrium Analysis

To describe the competitive equilibrium for this economy, it is convenient to introduce the notion of an *input bundle for the production of final goods* and an *input bundle for the production of intermediate goods*. Both input bundles are produced via Cobb-Douglas production functions with labor and the composite intermediate good, and used to produce final and intermediate goods, as specified in (1) and (2), respectively. The unit cost of the input bundle for final goods is $c^f = Aw^{\alpha}(P^g)^{1-\alpha}$, and the unit cost of the input bundle for intermediate goods is $c^g = Bw^{\beta}(P^g)^{1-\beta}$, where w and P^g are the wage and the price of the composite intermediate good, respectively, and A and B are constants that depend on α and β, respectively. Letting $p^g_m(v)$ denote the price of intermediate good v, the price index for the composite intermediate good is $P^g = \left(\int_0^1 p^g_m(v)^{1-\sigma}dv\right)^{1/(1-\sigma)}$. Since regions are identical, there is no need to differentiate aggregate variables (e.g., wages, price indices, unit costs) across regions.

The characterization of the equilibrium follows closely the analysis in Eaton and Kortum (2002) and Alvarez and Lucas (2007). Let $z^f_m(u)$ be the highest productivity among the set of technologies for final good u with home region m, and let $z^g_m(v)$ be the highest productivity among the set of technologies for intermediate good v with home region m. Since each region is the home region for $\bar{L}$ technologies with scale parameter $\bar{T}$, by the properties of the Fréchet distribution, $z^f_m(u)$ and $z^g_m(v)$ are both distributed Fréchet with parameters $T \equiv \bar{L}\bar{T}$ and θ.

The unit cost of a final good u in region m produced with a technology with home region s is $h^f c^f/z^f_s(u)$ if $s \neq m$, and $c^f/z^f_m(u)$ if $s = m$. In a competitive equilibrium, the price of the final good u in region m is simply the minimum unit cost at which this good can be obtained,

$$p^f_m(u) = \min(c^f/z^f_m(u), \min_{s\neq m}(h^f c^f/z^f_s(u))).$$

The unit cost of an intermediate good v in region m produced in region k with a technology with home region s is $dh^g c^g/z^g_s(v)$ if $m \neq k \neq s$, $dc^g/z^g_s(v)$ if $m \neq k = s$, $h^g c^g/z^g_s(v)$ if $m = k \neq s$, and $c^g/z^g_s(v)$ if $m = k = s$. Our assumption that $d < h^g$ implies that an intermediate good used in region m is either produced with the local technology, which entails unit cost $c^g/z^g_m(v)$, or it

is imported from some other region s, which entails unit cost $dc^g/z_s^g(v)$.[10] Thus, the price of an intermediate good v in region m is

$$p_m^g(v) = \min\left(c^g/z_m^g(v), \min_{s\neq m}(dc^g/z_s^g(v))\right).$$

Note that, since final goods are non-tradable and $d < h^g$, there is MP but no trade in final goods and trade but no MP in intermediate goods.

Combining these results with the assumption that productivities are independently drawn from the Fréchet distribution, and following standard procedures as in Eaton and Kortum (2002) and Alvarez and Lucas (2007), we can easily show that the price indices for the final and intermediate goods are given, respectively, by

$$P^f = \gamma c^f \left(T + (M-1)T\left(h^f\right)^{-\theta}\right)^{-1/\theta}, \tag{3}$$

and

$$P^g = \gamma c^g \left(T + (M-1)Td^{-\theta}\right)^{-1/\theta}, \tag{4}$$

where γ is a positive constant. Intuitively, the term $T + (M-1)T\left(h^f\right)^{-\theta}$ can be understood as the number of technologies available for each final good in region m', where the $(M-1)T$ technologies with home regions $m \neq m'$ are "discounted" by $\left(h^f\right)^{-\theta}$. Similarly, the term $T + (M-1)Td^{-\theta}$ is the number of technologies available for each intermediate good in region m', where the $(M-1)T$ technologies with home regions $m \neq m'$ are "discounted" by $d^{-\theta}$.

Using $c^f = Aw^\alpha(P^g)^{1-\alpha}$ and $c^g = Bw^\beta(P^g)^{1-\beta}$, and letting $\eta \equiv (1-\alpha)/\beta$,

$$H \equiv \left[\frac{1}{M} + \frac{M-1}{M}\left(h^f\right)^{-\theta}\right]^{-1}, \tag{5}$$

and

$$D \equiv \left[\frac{1}{M} + \frac{M-1}{M}d^{-\theta}\right]^{-1}, \tag{6}$$

[10]Note that $d, h^g \geq 1$ implies that if region m is using an intermediate good produced with a technology with home region s, then the only two options that could make sense are that the good is produced in m—i.e., $k = m$,or that it is produced in s—i.e., $k = s$. Thus, if $s \neq m$, there are two relevant options, local production with an outside technology at cost $h^g c^g/z_s^f(v)$, or importing the good at cost $dc^g/z_s^f(v)$. The assumption $d < h^g$ implies that, if $s \neq m$, then producing the good in region s—i.e., $k = s$— is the best option.

the equilibrium real wage is then given by

$$\frac{w}{P^f} = \tilde{\gamma} \left(M\overline{LT} \right)^{(1+\eta)/\theta} H^{-1/\theta} D^{-\eta/\theta}, \tag{7}$$

where $\tilde{\gamma} \equiv (\gamma^{1+\eta} A B^{\eta})^{-1}$. When regions are in isolation (i.e., $d, h \to \infty$), $D = H = M$, so that the real wage is $\tilde{\gamma}(\overline{LT})^{(1+\eta)/\theta}$. As d and h^f decrease towards one, D and H also decrease toward one and the real wage increases as regions get access to technologies from other regions either through trade (for the case of intermediate goods), or through MP (for the case of final goods). The term $(H)^{-1/\theta}$ captures the gains from MP in final goods, while the term $(D)^{-\eta/\theta}$ captures the gains from trade in intermediate goods. In the limit, when there are no trade or MP costs (i.e., $d = h^f = 1$), $D = H = 1$, and the real wage is $\tilde{\gamma}(M\overline{LT})^{(1+\eta)/\theta}$.

There are three implications derived from (7). First, consider two countries with identical population size L, but one of them with twice as many regions ($2M$) of half the size ($\overline{L}/2$) as the other country. In the standard model without internal geography (i.e., no domestic costs), both countries will exhibit the same real wage. In our model with domestic costs, however, the country with more regions will exhibit lower real wages even though, in the aggregate, the number of technologies available for production is the same in both countries. The effect comes exclusively from assuming that the movement of goods and ideas is costly across regions within a country. Second, larger countries will exhibit higher real income levels. This is due to the same aggregate economies of scale that play a critical role in semi-endogenous growth models (see Ramondo and Rodríguez-Clare, 2010). Formally, if $\bar{L}$ grows at a constant rate $g_L > 0$, then $g_T = g_L$ and the steady state growth rate of the real wage is $((1+\eta)/\theta)g_L$.[11] Finally, higher domestic trade and MP costs (reflected in higher D and H) diminish the strength of these economies of scale. This force will play a crucial role in solving the Danish Puzzle.

2.2 The World Economy

Consider a set of countries indexed by $n \in \{1, ..., N\}$ with preferences and technologies as described above. As for the case of the closed economy, each country is formed by a set of identical regions, each with population $\bar{L}$. The number of regions in country n is M_n, so that the population

[11] We will use this relationship as one of our calibration strategies for θ.

size of country n is $L_n = \bar{L} M_n$.

Intermediate goods are tradable across regions within a country and across regions in different countries, but final goods are not. International trade is subject to iceberg-type costs: $d_{nl} \geq 1$ units of any good must be shipped from any region in country l for one unit to arrive in any region in country n. We assume that the triangular inequality holds: $d_{nl} \leq d_{nj} d_{jl}$ for all n, l, j. For domestic trade, we also assume that it is subject to an iceberg-type cost: $d_{nn} \geq 1$ units of any good must be shipped from a region k in country n for one unit to arrive in a region s also in country n. Trade within a region is costless.

Each technology has a country of origin, but it can be used in other countries as well. When a technology from country i is used for production in country $l \neq i$, we say that there is "multinational production" or, simply, MP. We adopt the convention that the subscript n denotes the destination country, subscript l denotes the country of production, and subscript i denotes the country where the technology originates.

There are L_i technologies for each good in country i. Each technology is characterized by three elements: first, the country i from which it originates; second, a vector that specifies the technology's productivity parameter in each country, $\boldsymbol{z} = (z_1, ..., z_N)$; and third, a vector that specifies the technology's "home" region in each country, $\boldsymbol{m} = (m_1, ..., m_N)$.[12]

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 $h^f_{li} \geq 1$ for final goods and $h^g_{li} \geq 1$ for intermediates. 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 $h^f_{li} h^f_{ll}$ for final goods and $h^g_{li} h^g_{ll}$ for intermediate goods. These assumptions imply that the effective productivity of a technology $(\boldsymbol{z}, \boldsymbol{m})$ originated in country i and used in the technology's home region in country $l \neq i$ is z_l / h^f_{li}, or z_l / h^g_{li}, while if it is used in country $l \neq i$, but outside of the technology's home region, then the effective productivity is

[12]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 n are "born" in a particular region and then face an MP cost h_{nn} to be used in another region of country n. The analogous assumption for foreign technologies is that they also have a region in a foreign country where they are "reincarnated" (their home region), and then face an MP cost h_{nn} to be used in another region of country n.

$z_l/h^f_{li}h^f_{ll}$, or $z_l/h^g_{li}h^g_{ll}$. We assume that $d_{ii} \leq h^g_{ii}$, so that in equilibrium technologies to produce intermediate goods will always be used in their home region.

We assume that technologies are uniformly assigned to home regions in each country, i.e., for each good and each country i, the number of technologies from i for which the home region in country l is region m is the same as the number of technologies from i for which the home region in country l is region m'.[13] To clarify: There are L_i technologies for each good in each country (not in each region), and the number of technologies from any country i for which a particular region in country n is the home region is L_i/M_n.

Finally, we assume that each productivity z_i for technologies originating in country i is independently drawn from the Fréchet distribution with parameters $\bar{T}_i$ and θ. By the properties of the Fréchet distribution, $z^f_{m,ni}(u)$ and $z^g_{m,ni}(v)$ are also both distributed Fréchet with parameters $T_{ni} \equiv \bar{L}\bar{T}_i/M_n$, and θ.

2.3 Equilibrium Analysis

In this section, we derive expressions for the equilibrium price indices and the equilibrium trade and MP flows. The details of the analysis are relegated to the Appendix. The results of this section are used in the following section to express real wages and gains from openness in terms of variables that we observe in the data, namely trade and MP flows.

Prices. Let c^f_l and c^g_l denote the unit costs of the input bundle for final and intermediate goods in country l, respectively. Following a similar logic as in the equilibrium analysis of a closed economy, we can show that the price index for final goods is

$$\gamma^{\theta}\left(P^f_n\right)^{-\theta} = M_n T_n (c^f_n)^{-\theta} H_n^{-1} + \sum_{i \neq n} M_i T_i (h^f_{ni} c^f_n)^{-\theta} H_n^{-1}, \tag{8}$$

while the price index for intermediate goods is

[13] One interpretation of this assumption is as follows. First, recall that, for each good, the number of technologies in a country is the same as the number of people. Thus, we can link each technology to a person. Second, imagine that each person has a randomly assigned "friend" in every country. We can then assume that a technology's home region in country l for the technology linked to person X in country i is the region where X's friend resides in country l.

$$\gamma^{\theta}\left(P_n^g\right)^{-\theta} = M_n T_n (c_n^g)^{-\theta} D_n^{-1} + \sum_{i\neq n, l=n} M_i T_i (h_{ni}^g c_n^g)^{-\theta} D_n^{-1} \tag{9}$$
$$+ \sum_{i\neq n, l=i} M_i T_i (d_{ni} c_i^g)^{-\theta} + \sum_{l\neq n, l\neq i} M_i T_i \left(d_{nl} h_{li}^g c_l^g\right)^{-\theta},$$

where $T_i \equiv \bar{L}\bar{T}_i$, $H_n \equiv \left[1/M_n + ((M_n-1)/M_n)\left(h_{nn}^f\right)^{-\theta}\right]^{-1}$ and $D_n \equiv \left[1/M_n + ((M_n-1)/M_n) d_{nn}^{-\theta}\right]^{-1}$. In the case of final goods, the first term on the right-hand side of (8) 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 (9) 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 (exports) from country l to country n is

$$X_{nl} = \left(\gamma^{-1} P_n^g / c_l^g\right)^{\theta} d_{nl}^{-\theta} \left[\sum_{i\neq l} M_i T_i \left(h_{li}^g\right)^{-\theta} + M_l T_l\right] \eta w_n L_n, \tag{10}$$

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

$$X_{nn} = \left(\gamma^{-1} P_n^g / c_n^g\right)^{\theta} D_n^{-1} \left[\sum_{i\neq n} M_i T_i \left(h_{ni}^g\right)^{-\theta} + M_n T_n\right] \eta w_n L_n. \tag{11}$$

It is interesting to note that using (10) and the equivalent of (11) for X_{ll}, we obtain the gravity equation

$$\frac{X_{nl}/w_n L_n}{X_{ll}/w_l L_l} = D_l \times \left(d_{nl} \frac{P_l^g}{P_n^g}\right)^{-\theta}. \tag{12}$$

The term D_l is a country specific effect greater than one. When $d_{ll} = 1$, $D_l = 1$ and (12) collapses to the gravity expression in Eaton and Kortum (2002).

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

$$Y_{li}^{g} = M_i T_i \left(c_l^g h_{li}^g\right)^{-\theta} \left[D_l^{-1} \frac{\eta w_l L_l}{\left(\gamma^{-1} P_l^g\right)^{-\theta}} + \sum_{n \neq l} d_{nl}^{-\theta} \frac{\eta w_n L_n}{\left(\gamma^{-1} P_n^g\right)^{-\theta}} \right], \tag{13}$$

while total production in country n with domestic technologies is

$$Y_{nn}^{g} = M_n T_n (c_n^g)^{-\theta} \left[D_n^{-1} \frac{\eta w_n L_n}{(\gamma^{-1} P_n^g)^{-\theta}} + \sum_{j \neq n} d_{jn}^{-\theta} \frac{\eta w_j L_j}{\left(\gamma^{-1} P_j^g\right)^{-\theta}} \right]. \tag{14}$$

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

$$Y_{ni}^{f} = M_i T_i \left(\frac{c_n^f h_{ni}^f}{\gamma^{-1} P_n^f} \right)^{-\theta} H_n^{-1} w_n L_n, \tag{15}$$

while total production in n with domestic technologies is

$$Y_{nn}^{f} = M_n T_n \left(\frac{c_n^f}{\gamma^{-1} P_n^f} \right)^{-\theta} H_n^{-1} w_n L_n. \tag{16}$$

When $D_{nn} = H_{nn} = 1$, Y_{ni}^g and Y_{ni}^f collapse to the expressions in Ramondo and Rodríguez-Clare (2010), except that now MP flows in both sectors are multiplied by an extra L_i (from $M_i T_i = L_i \overline{T}_i$). This reflects the assumption that in our model countries are a collection of regions and not just a dot in space. When both international and domestic trade and MP costs are the same, $h_{ni}^f = h_{nn}^f$ and $d_{ni} = d_{nn}$, under the within-country symmetry assumption made (i.e., $\bar{L}_n = \bar{L}$), the world becomes "flat " in the sense that scale effects disappear.

2.4 Gains from Trade, MP, and Openness

We define the gains from openness as the change in the (equilibrium) real wage from a situation where countries are in isolation to a situation with trade and MP. We proceed as in Ramondo and Rodríguez-Clare (2010) to express real wages as a function of (endogenous) trade and MP flows, and then compute gains from openness as a function of these flows. Since we observe these flows in the data, this is sufficient to obtain a formula for gains that we can use for quantitative analysis.

Using the results in the previous section for the price indices and the trade and MP flows, we can get an expression for the real wage in each country n as a function of trade and MP flows (see the Appendix for details),

$$\frac{w_n}{P_n^f} = \widetilde{\gamma}\left(M_n \overline{T}_n \overline{L}_n\right)^{(1+\eta)/\theta} H_n^{-1/\theta} D_n^{-\eta/\theta} \left(\frac{Y_{nn}^f}{w_n L_n}\right)^{-1/\theta} \left(\frac{Y_{nn}^g}{\eta w_n L_n}\right)^{-\eta/\theta} \left(\frac{X_{nn}}{\eta w_n L_n}\right)^{-\eta/\theta}. \tag{17}$$

The gains from openness are easily calculated as the ratio of the real wage in (17) to the one in (7),

$$GO_n = \left(\frac{Y_{nn}^f}{w_n L_n}\right)^{-1/\theta} \left(\frac{Y_{nn}^g}{\eta w_n L_n}\right)^{-\eta/\theta} \left(\frac{X_{nn}}{\eta w_n L_n}\right)^{-\eta/\theta}. \tag{18}$$

Importantly, the gains from openness can be written as a function of trade and MP flows. We will exploit this convenient feature in the calibration below.[14]

It is worth noting that the steady state growth rate for the open economy is the same as for the closed economy, given by differentiating (17) with respect to time. Growth is driven by the same forces that generate the gains from openness in the static model, namely the aggregate economies of scale associated with the fact that a larger population is linked to a higher stock of non-rival ideas.

3 Quantitative Analysis

We consider a set of nineteen OECD countries: Australia, Austria, Belgium, Canada, Denmark, Spain, Finland, France, Great Britain, Germany, Greece, Italy, Japan, Netherlands, Norway, New Zealand, Portugal, Sweden and United States. This is the same set of countries considered by Eaton and Kortum (2002) and Ramondo and Rodríguez-Clare (2010).

As mentioned in the Introduction, the reason to restrict the sample to this set of richer countries is to make sure that countries do not differ much regarding, e.g., institutions and R&D. For poorer countries, the differences in these variables are so big relative to the United States that any other aspect considered would not have much impact.

[14]The gains from openness in (18) are the same as those in Ramondo and Rodríguez-Clare (2010) for the special case in which MP does not generate trade in inputs and productivity draws are uncorrelated across countries.

We compute real wages in the data as real GDP (PPP-adjusted) from the Penn World Tables (6.3) divided by a measure of equipped labor from Klenow and Rodríguez-Clare (2005) that controls both for physical and human capital.[15] The latter is also our measure of L_n. We consider averages over the period 1996-2001. The goal is to compare real wages from the data with those implied by the calibrated model.

3.1 Calibration of Key Parameters

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

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 observed in the data. If $\bar{L}$ grows at a constant rate $g_L > 0$ in all countries, then the model leads to a common long-run income growth rate of

$$g = \frac{1+\eta}{\theta} g_L. \tag{19}$$

Equation (19) simply follows from differentiating (7) with respect to time, and noting that $T = \bar{L}\bar{T}$ implies $g_T = g_L$.[16] Following Jones (2002), we set $g_L = 0.048$—the growth rate of research employment—and $g = 0.01$—the growth rate of income per capita. Together with $\eta = 0.5$ and (19), these two growth rates imply that $\theta = 7.2$.[17]

Our second calibration approach is to calibrate the parameter θ by using the fact that our model is fully consistent with the Eaton and Kortum (2002) model of trade. Eaton and Kortum (2002) estimate θ in the range from 3 to 12, with a preferred estimate of $\theta = 8$. More recent estimates using different procedures range from 2.5 to 5.5.[18]

Finally, a third approach is to use the results in Alcala and Ciccone (2004), who show that con-

[15] As in Klenow and Rodríguez-Clare (2005), real GDP per capita calculated in this way is proportional to TFP.

[16] Steady state growth rates are the same for all countries, and not affected by openness. This feature implies that the growth rate for the open economy is the same as the one for the closed economy.

[17] Jones and Romer (2010) follow a similar procedure and argue that $g/g_L = 1/4$, which implies $\theta = 6$. But they acknowledge that different interpretations of the mapping between model and data could also justify setting $(1+\eta)\theta$ as high as 1 or 2.

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

trolling 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.[19] This elasticity can be interpreted in the context of (17). If H_n and D_n control for geography, $\overline{T}_n$ controls for institutions, and the last three terms on the right-hand side of (17) control for trade and MP openness, the coefficient on $M_n = L_n/\overline{L}$, $(1+\eta)/\theta$, can be equated to 0.3, the value of the income-size elasticity in Alcala and Ciccone (2004). With $\eta = 0.5$, the implied θ equals 5.

Given these estimates, we choose $\theta = 6$ as our baseline value and explore robustness of our results to $\theta = 4$ and $\theta = 8$. The implied elasticity of the real wage with respect to size—i.e., $\partial \ln(w_n/P_n^f)/\partial \ln L_n$—is then $(1+\eta)/\theta = 1/4$, closer to 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 et al. (2012) find an elasticity of productivity with respect to density at the city level of between 0.04 to 0.1. The reader should keep in mind, however, that this is a reduced form elasticity, whereas our $1/4$ is a structural elasticity. Thus, the same reasons (i.e., internal frictions and 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-section data.

3.2 Preliminary Results: the Danish Puzzle

We start with the model of a closed economy with no domestic frictions. In that case, $H = D = 1$. Also, note that $M_n T_n = L_n \overline{T}_n$.[20] Thus, equation (7) implies that the real wage is given by

$$\frac{w_n}{P_n^f} = \tilde{\gamma} \left(L_n \overline{T}_n\right)^{(1+\eta)/\theta}. \tag{20}$$

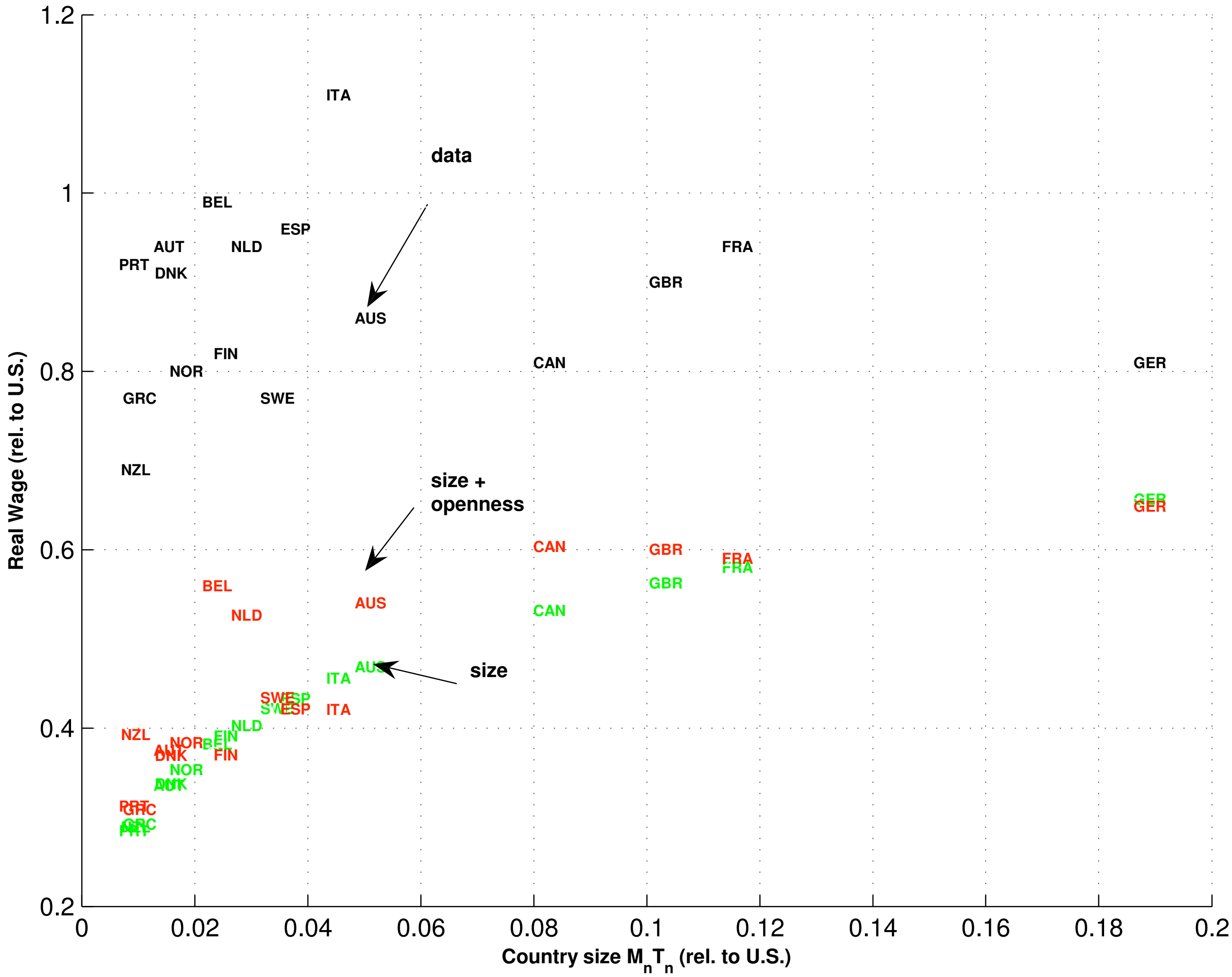
We calibrate $\overline{T}_n$ assuming that it varies directly with the share of R&D employment observed in the data.[21] We use data on R&D employment from the World Development Indicators averaged over the nineties. The variable L_n is a measure of equipped labor from Klenow and Rodríguez-Clare (2005), as mentioned above.

[19] 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 institutions, geography, and trade.

[20] Simply, $T_n = \overline{L}\overline{T}_n$, and $L_n = M_n \overline{L}$.

[21] If we calibrate $\overline{T}_n$ to the number of patents per equipped labor in country n, results are unchanged (not shown).

Figure 1: Real Wage, Size, and Openness: Data and Model.



Calibration with $\theta = 6$. "Size" refers to the first term on the right-hand side of (22); "Size + Openness" refers to the first times the second 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.

In Figure 1, we plot the model's implied real wage against our measure of size adjusted by R&D intensity, $L_n \overline{T}_n = M_n T_n$, both relative to the United States. The green dots depict the model's real wage under isolation and the black dots represent the data. It is easy to see that the closed economy model substantially under-predicts the income level of small countries.

As an example, consider Denmark. The model implies an income of 34 percent of the U.S.

As for the R&D employment share, small countries do not have a higher number of patents per capita.

level, while the relative income in the data is much higher, 91 percent. We refer to this gap as the Danish Puzzle, but it is common to all the small countries in our sample. In the remaining of this section, we explore quantitatively how important are openness and domestic frictions in resolving this puzzle.

3.3 The Gains from Openness

We first explore how much of the gap between the real wage under isolation and the one observed in the data can be explained by the gains from trade and MP in a model with no domestic frictions. In this context, the real wage in the open economy is the same as the one in isolation augmented by the gains from openness. From (17) and (18), the real wage is given by

$$\frac{w_n}{P_n^f} = \tilde{\gamma} \left(L_n \overline{T}_n \right)^{(1+\eta)/\theta} GO_n, \tag{21}$$

where GO_n is computed directly from the data as explained next.

3.3.1 Data on Trade and Multinational Production

The gains from openness can be directly calculated using data on trade flows, MP sales, GDP, and gross manufacturing production. We use data on manufacturing trade flows from country i to country n from STAN as the empirical counterpart for trade in intermediates in the model, X_{ni}, and data on total absorption in manufacturing (calculated as gross production minus total exports plus total imports) as the empirical counterpart of $\eta w_n L_n$ in the model.

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, $Y_{ni} \equiv Y_{ni}^f + Y_{ni}^g$. These MP flow data are not disaggregated by sector, so we do not separately observe MP flows in manufacturing (Y_{ni}^g) and non-manufacturing (Y_{ni}^f). We observe MP flows in manufacturing only for the United States where they represent approximately one half of the total MP flows –i.e., $\sum_{i \neq US} Y_{US,i}^g = \frac{1}{2} \sum_{i \neq US} Y_{US,i}$. This suggests using one half of the total MP flows as the empirical counterpart for Y_{ni}^g, and similarly for Y_{ni}^f. More details on the MP data are in the Appendix.

Finally, we use GDP in current dollars (from World Development Indicators) as the empirical

counterpart of $w_n L_n$ in the model.

All variables in the data are averages over the period 1996-2001. Table 8 in the Appendix presents domestic trade shares, $\frac{X_{nn}}{\eta w_n L_n}$, and the domestic MP shares in final and intermediate goods, $\frac{Y^f_{nn}}{w_n L_n}$ and $\frac{Y^g_{nn}}{\eta w_n L_n}$, respectively, for each country in our sample.

3.3.2 Does Openness Resolve the Danish Puzzle?

Figure 2 presents the gains from openness for country n (GO_n) against our R&D-adjusted measure of size, $L_n\overline{T}_n$. As expected, small countries gain much more than large countries. How much does openness help to explain the Danish puzzle?

With no domestic frictions, using (17), the relative real wage for country n in the open economy can be written as

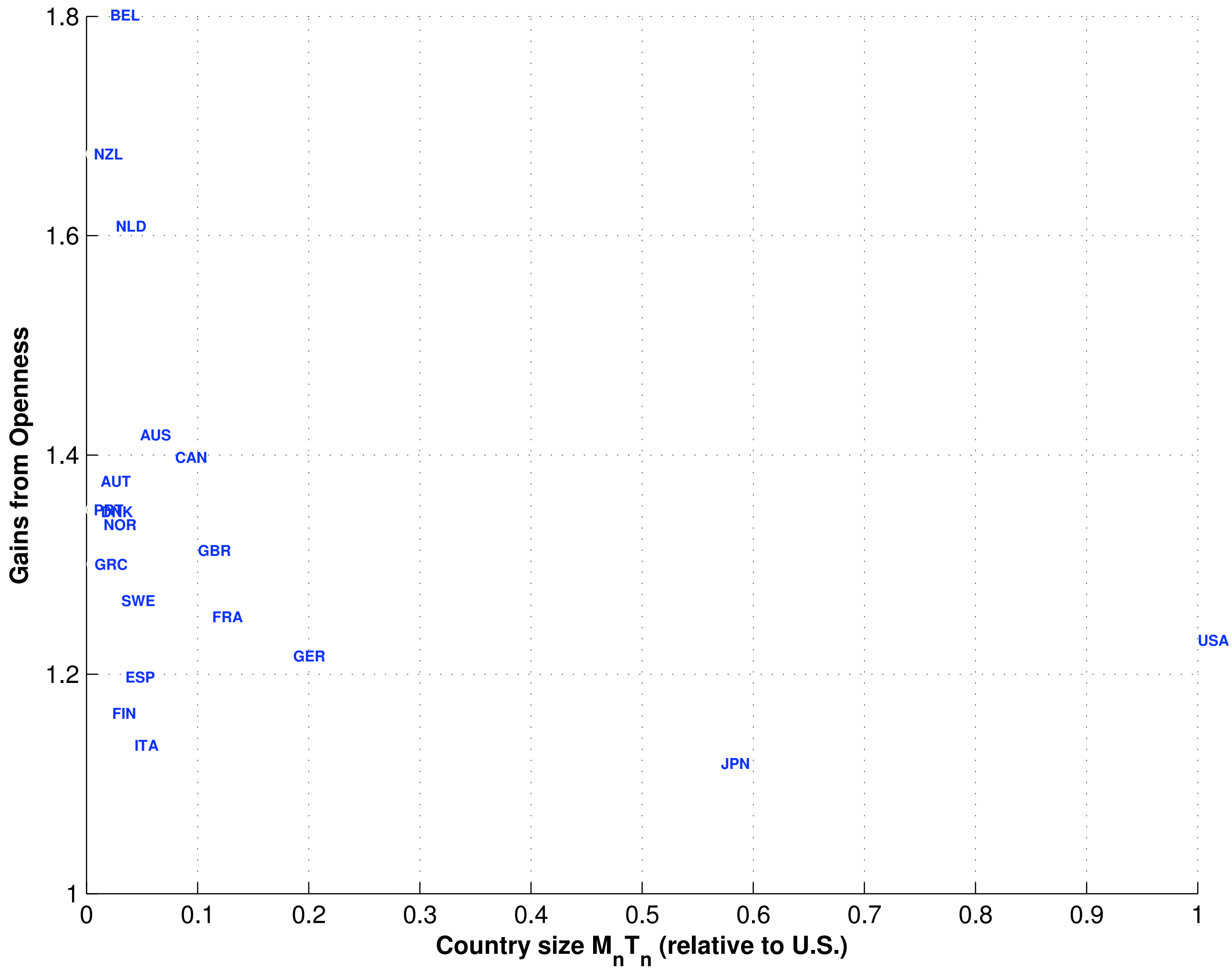
$$\frac{w_n/P^f_n}{w_{US}/P^f_{US}} = \underbrace{\left(\frac{L_n\overline{T}_n}{L_{US}\overline{T}_{US}}\right)^{(1+\eta)/\theta}}_{\text{size}} \underbrace{\frac{GT_n}{GT_{US}}\frac{GMP_n}{GMP_{US}}}_{\text{openness}}, \tag{22}$$

where GT refers to the gains from trade—last term on the right-hand side of (18)—and GMP refers to the gains from MP—the first and the second term on the right-hand side of the same equation.

The first column of Table 1 presents the real wage under isolation with no domestic frictions—the first term on the right-hand side of (22). As mentioned before, the model implies that small countries would be much poorer than in the data (column 1 versus column 6). Column 2 shows the gains from trade, while column 3 shows the real wage implied by a model with only trade. Column 4 presents the gains from openness. Column 5 presents the real wage implied by (22). We restrict our attention to the seven smallest countries in our sample. Table 10 in the Appendix shows results for the entire sample of countries.

It is important to emphasize that real wages are relative to the United States. Even though Denmark has large gains from openness (1.35), the ones for the United States are also substantial (1.23). Hence, the net effect of openness in solving the Danish puzzle is not as large. Overall, the real wage gap remains significant: The model implies that Denmark would be only 37 percent as rich as the United States, against 91 percent in the data. For Denmark, openness only explains

Figure 2: Gains from Openness and Size.



Calibration with $\theta = 6$. Gains from openness are calculated using (18) and the data on trade and MP shares. Country size is relative to the United States.

around five percent of the real wage gap between the data and the model under isolation. That openness contributes very little in closing the observed gap can be easily seen in Figure 1.

As an intermediate step, Table 1 shows the contribution of the gains from trade in solving the Danish Puzzle. Openness to trade has been the natural candidate to solve the Danish Puzzle in most of the previous literature. But except for Belgium, for which the gap between the model and the data is substantially reduced, trade does not contribute much in closing the gap: Small countries are much richer in the data than in the model even after adding the gains from trade.[22]

[22]This counterfactual implication is shared by trade-only models such as Eaton and Kortum (2002), Alvarez and

Table 1: The Gains from Openness and the Real Wage: Small Countries.

	Size (1)	GT (2)	Real wage model (3)=(1)×(2)	GO (4)	Real wage model (5)=(1)×(4)	Real wage data (6)
Austria	0.34	1.06	0.36	1.13	0.38	0.94
Belgium	0.38	1.30	0.50	1.52	0.58	0.99
Denmark	0.34	1.07	0.36	1.10	0.37	0.91
Greece	0.29	1.03	0.30	1.06	0.31	0.77
Norway	0.35	1.03	0.37	1.07	0.38	0.80
New Zealand	0.29	1.03	0.30	1.37	0.40	0.69
Portugal	0.29	1.03	0.29	1.12	0.32	0.92

Calibration with $\theta = 6$. Countries ordered by R&D-adjusted size ($T_n M_n = L_n \overline{T}_n$). Column 1 refers to the term "size," column 2 to the first term under "openness" (GT), and column 4 to the first and second term under "openness" (GO) in (22). Column 6 is the real GDP (PPP-adjusted) per unit of equipped labor in the data. All variables are calculated relative to the United States.

3.4 Domestic Frictions

With openness and domestic frictions, real wages are given by (17). The real wage relative to the United States for country n can be written as

$$\frac{w_n/P_n^f}{w_{US}/P_{US}^f} = \underbrace{\left(\frac{L_n\overline{T}_n}{L_{US}\overline{T}_{US}}\right)^{(1+\eta)/\theta}}_{\text{size}} \underbrace{\frac{GO_n}{GO_{US}}}_{\text{openness}} \underbrace{\left(\frac{H_n}{H_{US}}\right)^{-1/\theta}\left(\frac{D_n}{D_{US}}\right)^{-\eta/\theta}}_{\text{domestic frictions}}. \tag{23}$$

The role of domestic frictions is captured by the third term on the right-hand side of this expression. To quantitatively evaluate the role of these frictions, we need to calibrate d_{nn}, h_{nn}^f, and M_n, for all countries.[23]

3.4.1 Calibration of Domestic Frictions

In our baseline calibration we proceed as follows. First, for the number of regions, M_n, we start by setting $M_{USA} = 51$ and $\bar{L} = L_{USA}/M_{USA}$, for all countries in the sample. We then calculate $M_n = L_n/\bar{L}$, for each n, using L_n from the data (i.e. our measure of equipped labor previously described). Notice that our calibration of M_n implies that (i) the number of regions in a country is

Lucas (2007), and Waugh (2010). More precisely, all of them calibrate the parameter T to exactly match the data on real wage. But the counterfactual implication is then that T/L is much higher for small countries. This is another way of seeing the Danish Puzzle.

[23]Under the assumption that $h_{nn}^g > d_{nn}$, the value of h_{nn}^g is irrelevant.

proportional to its equipped labor, and (ii) the concept of a "region" is consistent across different countries.[24]

To calibrate the domestic trade cost, d_{nn}, we use data on shipments between the fifty one states of the United States (fifty states plus the District of Columbia), from the Commodity Flow Survey, for the years 2002 and 2007. Let $X_{mk,n}$ be the value of shipments from region k to region m in country n. The model establishes that (see derivation in the Appendix)

$$d_{nn}^{-\theta} = \frac{\sum_{k \neq m} X_{mk,n}/(M_n - 1)}{X_{mm,n}}. \tag{24}$$

The expression on the right-hand side is the ratio of the average purchases from other regions to local purchases for region m. This ratio will be lower than one because of domestic trade costs, $d_{nn} > 1$, with an elasticity given by θ. Using data on shipments between the fifty one states, and $M_{USA} = 51$, we compute the right-hand side of (24), for each state in $n = USA$. Given a value for the parameter θ, we calculate fifty one values for d_{nn} (one for each state). Our estimate for d_{nn} is just an average of these fifty one estimates. In the robustness section below, we consider different ways to use the domestic trade data to infer domestic frictions.

Table 2 reports the results of our estimation of d_{nn} for three different values of θ. The average estimates of domestic trade costs within the United States are very similar across years. Of course, the estimate decreases with the value of θ.

Table 2: Domestic trade cost for United States: Summary statistic.

	2002			2007		
	$\theta = 4$	$\theta = 6$	$\theta = 8$	$\theta = 4$	$\theta = 6$	$\theta = 8$
Average	2.27	1.72	1.50	2.33	1.76	1.52
Standard Deviation	0.31	0.16	0.11	0.30	0.15	0.10
Maximum	3.02	2.09	1.74	3.17	2.16	1.78
Minimum	1.21	1.14	1.10	1.63	1.39	1.28

Own calculations using data from the Commodity Flow Survey for the Unites States, for 2002 and 2007.

Domestic frictions for both trade and MP are crucial variables in our empirical exercise. First, we assume that d_{nn} is the same as the one for the United States for the remaining countries in our

[24]Our calibrated M_n is highly correlated (0.90) with the number of towns with more than 250,000 habitants in each country observed in the data. Columns 1 and 5 of Table 12 in the Appendix, respectively, show these two variables.

sample. Our baseline estimate is $d_{nn} = 1.7$, corresponding to $\theta = 6$ and data for 2002. Second, we assume that MP frictions in final goods are as large as trade frictions ($h^f_{nn} = d_{nn}$). We perform various alternative calibrations as robustness exercises below.

3.4.2 Do Domestic Frictions Resolve the Danish Puzzle?

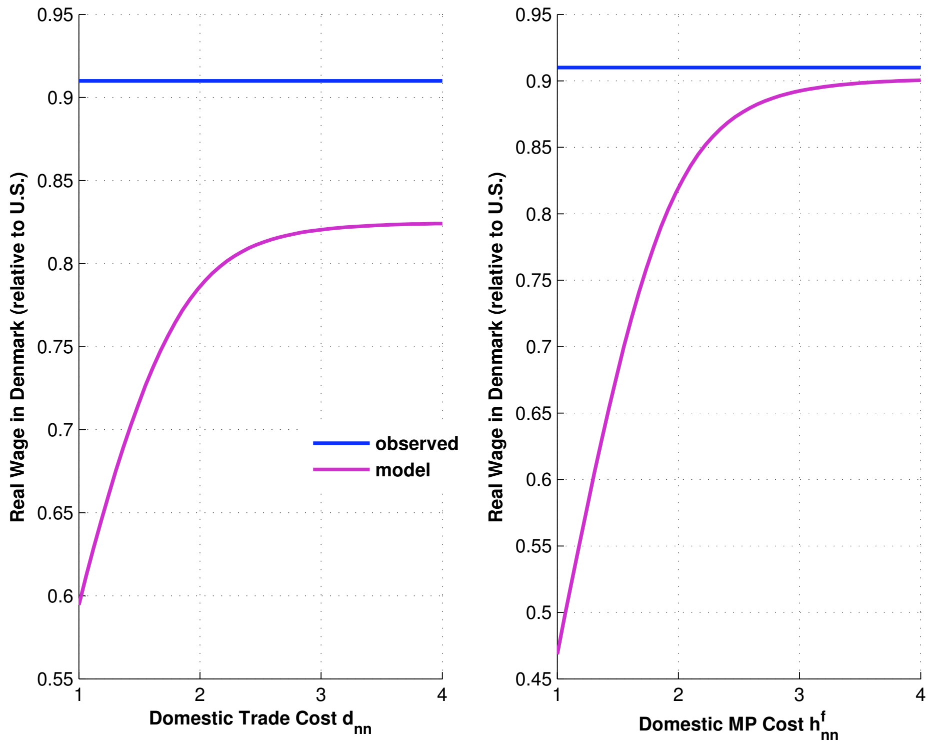
Before turning to the results for the calibrated model, we show how h^f_{nn} and d_{nn} independently matter for our results. Figure 3 shows the relationship between these two domestic frictions and the relative real wage implied by the model for Denmark. The left panel of Figure 3 considers changes in d_{nn} while keeping $h^f_{nn} = 1.7$. In the data, Denmark's relative real wage is 0.91. In the model, Denmark's relative real wage increases with d_{nn}: Increasing d_{nn} from 1 (no frictions) to 4 (for both Denmark and the United States) increases Denmark's relative real wage from less than 0.6 to almost 0.85. Notice that domestic frictions in MP in final goods only would resolve the Danish puzzle by 45 percent (from 0.34 to 0.60, versus 0.91 in the data).

Similarly, the right panel of Figure 3 considers changes in h^f_{nn} for both Denmark and the United States while keeping $d_{nn} = 1.7$. In particular, with $h^f_{nn} = 4$, the model would almost match the relative real wage observed in the data. With such high frictions for final goods, the scale effect becomes very weak, and Denmark's higher gains from openness relative to the U.S. (1.36 against 1.23, respectively) compensate for its smaller size and lower employment shares in R&D. Conversely, if domestic MP in final goods were frictionless ($h^f_{nn} = 1$), the real wage for Denmark would be 0.45 (relative to U.S.), resolving 20 percent of the Danish puzzle (from 0.34 to 0.45, versus 0.91 in the data).

Not surprisingly, higher domestic frictions in either trade or MP hurt the larger country more than the small country, allowing the smaller country to catch up. But as the MP domestic frictions increase, Denmark catches up faster with the United States. The reason is that domestic frictions in final goods have a stronger effect on the real wage than domestic frictions in intermediate goods (reflected in the exponents of the terms $H_n^{-1/\theta}$ and $D_n^{-\eta/\theta}$ in (17), with $1/\theta > \eta/\theta$).

Table 3 presents the results for the (relative) real wage when domestic frictions are calibrated as described above, $d_{nn} = h^f_{nn} = 1.7$. Again, we restrict our attention to the seven smallest countries

Figure 3: Domestic Frictions and the Real Wage: Denmark.



in our sample; the Appendix presents the results for all countries.

Column 1 presents the real wage under isolation, while column 2 presents the gains from openness. Column 3 presents the domestic frictions. Finally, column 4 shows the real wage implied by the model when both domestic frictions and openness are considered, while column 5 shows the real wage observed in the data.

As expected, domestic frictions diminish the strength of the aggregate economies of scale, thus helping small countries relative to larger ones.[25] For example, Denmark's relative real wage more than doubles when domestic frictions are considered. Interestingly, domestic frictions help to resolve the Danish puzzle much more than openness. For Denmark, domestic frictions bring the relative real wage from 0.34 under isolation (without frictions) to 0.69, whereas openness takes it to only 0.37. Domestic frictions alone are able to close more than two thirds of the gap in the

[25]Notice that data limitations prevent us from considering differences in d_{nn} (and h^f_{nn}) across countries. But clearly, we are allowing for differences in H_n and D_n across countries that come from differences in country size (M_n); this is precisely what leads the model to generate higher relative income levels for small countries.

Table 3: Domestic frictions and the Real Wage: Small Countries.

	Size (1)	GO (2)	Domestic Frictions (3)	Real Wage Model (4)=(1)×(2)×(3)	Real Wage Data (5)
Austria	0.34	1.13	1.73	0.66	0.94
Belgium	0.38	1.52	1.73	1.00	0.99
Denmark	0.34	1.10	2.04	0.76	0.91
Greece	0.29	1.06	1.73	0.54	0.77
Norway	0.35	1.07	2.04	0.77	0.80
New Zealand	0.29	1.37	2.04	0.81	0.69
Portugal	0.29	1.12	2.04	0.65	0.92

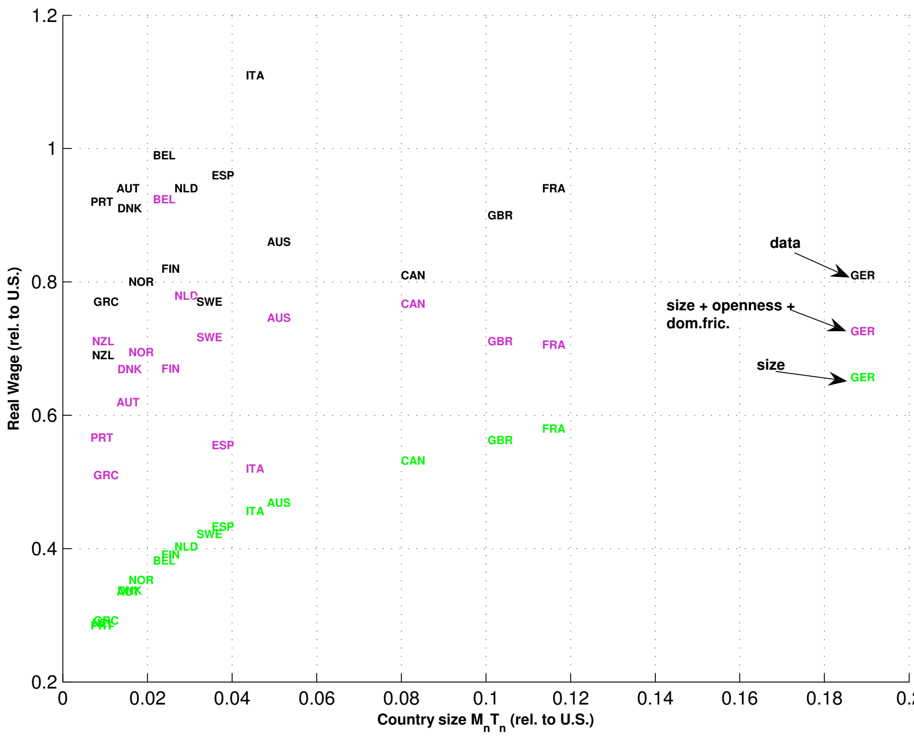
Calibrations with $\theta = 6$. Countries ordered by R&D-adjusted size ($T_n M_n = L_n \overline{T}_n$). Column 1 refers to the term "size", column 2 to the term "openness", column 3 to the term "domestic frictions", and column 4 to the product of the three terms in (23). Column 5 is the real GDP (PPP-adjusted) per unit of equipped labor in the data. All variables are calculated relative to the United States.

relative real wage between data and model.

Overall, adding both openness and domestic frictions to the scale effect implies a calibrated relative real wage for Denmark of 0.76, much closer to the 0.91 observed in the data. As in Denmark, in most of the small countries, there is still an unexplained gap between the relative real wage in our calibrated model and in the data. The only exceptions are Belgium and New Zealand, for which the model with domestic frictions and openness actually over-predicts the relative real wage.

Figure 4 shows the observed real wage (black dots), the calibrated real wage in isolation (green dots), and the calibrated real wage in a world with trade, MP, and domestic frictions (purple dots). Countries are ordered by their R&D-adjusted size, $L_n \bar{T}_n = T_n M_n$. All variables are relative to the ones in the United States. This figure makes clear that the factor that contributes the most to close the income gap between small countries and the United States is not openness to trade and MP, but the presence of frictions in the flows of goods and ideas within a country (green against red in Figure 1, and green against purple in Figure 4).

Figure 4: Real Wage, Size, Openness, and Domestic Frictions: Data and Model.



Calibration with $\theta = 6$. "Size," "Openness," and "Domestic Frictions " refer to the respective terms on the right-hand side of (23). 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.

3.4.3 Robustness

Table 4 illustrates how the gap between calibrated and observed real wage varies with different values of θ.[26] Table 11 in the Appendix shows the results for all countries in the sample.

A higher value for θ increases the relative real wage implied by the model with domestic frictions, trade, and MP. The Danish puzzle disappears when $\theta = 8$: Openness and domestic frictions alone reconcile the data and model. For $\theta = 4$, the full model is able to close more than 40 percent of the gap between the relative real wage observed in the data and the calibrated model with only scale effects (from 0.20 to 0.48, versus 0.91 in the data).

To better understand the effect of θ on the real wage gap, first notice that by simultaneously changing θ and d_{nn} such that (24) is satisfied, neither H_n nor D_n are affected by changes in θ. To

[26] Domestic frictions are recalibrated accordingly as shown in Table 2.

Table 4: Calibration for different values of θ: Small Countries.

	$\theta=4$				$\theta=6$				$\theta=8$			
	size	GO	dom.fric.	real wage	size	GO	dom.fric.	real wage	size	GO	dom.fric.	real wage
Austria	0.19	1.20	1.72	0.40	0.34	1.13	1.73	0.66	0.44	1.10	1.67	0.81
Belgium	0.24	1.87	1.72	0.76	0.38	1.52	1.73	1.00	0.49	1.37	1.67	1.11
Denmark	0.20	1.16	2.14	0.48	0.34	1.10	2.04	0.76	0.44	1.08	1.90	0.91
Greece	0.16	1.10	1.72	0.30	0.29	1.06	1.73	0.54	0.40	1.05	1.67	0.70
Norway	0.21	1.10	2.14	0.50	0.35	1.07	2.04	0.77	0.46	1.05	1.90	0.92
New Zealand	0.16	1.61	2.14	0.53	0.29	1.37	2.04	0.81	0.39	1.27	1.90	0.95
Portugal	0.15	1.19	2.14	0.39	0.29	1.12	2.04	0.65	0.39	1.09	1.90	0.81

"Size", "GO", and "dom.fric." refer to the first, second, and third terms, respectively, on the right-hand side of (23). The real wage is the product of those three terms. All variables are calculated relative to the United States.

proceed, define

$$O_n \equiv \left(\frac{Y_{nn}^f}{w_n L_n}\right)^{-1}\left(\frac{Y_{nn}^g}{\eta w_n L_n}\right)^{-\eta}\left(\frac{X_{nn}}{\eta w_n L_n}\right)^{-\eta}.$$

Equation (18) implies that $GO_n = O_n^{1/\theta}$, where O_n is independent of θ. Equation (23) can now be rewritten as

$$\frac{w_n/P_n^f}{w_{US}/P_{US}^f} = \left[\left(\frac{M_n T_n}{M_{US} T_{US}}\right)^{1+\eta}\left(\frac{H_n}{H_{US}}\right)^{-1}\left(\frac{D_n}{D_U S}\right)^{-\eta}\frac{O_n}{O_{US}}\right]^{1/\theta}. \tag{25}$$

The term in brackets is smaller than one for countries with calibrated relative real wage lower than one. For these countries, a higher θ increases the relative real wage towards one.

In the Appendix, we present alternative calibrations for the domestic trade costs, d_{nn}, and the number of regions, M_n, and show that they entail similar results regarding the Danish puzzle.[27]

Following the same procedure as for the fifty one states of the United States, we use more disaggregated data from the Commodity Flow Survey for the Unites States, for 2007. 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 ($M_{USA} = 100$). Estimates are slightly higher than the estimates using states. As shown in Table 5, for $\theta = 6$, we get $d_{nn} = 1.85$, against $d_{nn} = 1.76$ using U.S. states.

We also use data on trade flows between 10 provinces and 3 territories of Canada, $M_{CAN} = 13$,

[27] We also explored the idea of using the gravity equation in (12) to estimate D_l as a dummy in a standard gravity equation. Unfortunately, we cannot disentangle D_l from an importer specific and an exporter specific effects on bilateral trade costs. That is, we can recover D_l from a gravity regression with exporter and importer fixed effects only if we assume that trade costs d_{nl} have no exporter or importer specific components, an assumption that runs against the findings in Eaton and Kortum (2002) and Waugh (2010).

for 2002 and 2007. For the three different values of θ, we obtain a remarkably similar estimate for d_{nn} as the one obtained using U.S. data.[28] Results are presented in Table 6.

Each of the three different data sets on internal trade discussed above entail a different M_n. Columns 1 to 3 in Table 12 present the implied number of regions in each case for all countries in the sample. We set $\overline{L} = M_R/L_R$, with M_R corresponding to the fifty one U.S. states, 100 U.S. sub-regional units (CSA-MSA), and thirteen Canadian provinces, alternately, and $M_n = L_n/\overline{L}$, for $n \neq R$. The results do not change in any significant way as we consider these alternative data.

Our third robustness exercise incorporates data on population density of countries into our measure of M_n. We use data on density (population per square kilometer of land space), from United Nations (2007), for each country in the sample.[29] We now allow population per region to vary across countries directly with density (i.e., $\overline{L}_n \neq \overline{L}$). Specifically, we assume that $\overline{L}_n$ is proportional to population density defined as habitants per unit of land, $v_n = L_n/A_n$. Rather than fixing the size of all regions to the size of a U.S. region in terms of equipped labor ($\overline{L}_{USA} = L_{USA}/M_{USA}$), we fix the area of all regions to the area of a U.S. region, $\overline{A}_{USA} = A_{USA}/M_{USA}$, with $M_{USA} = 51$ as in our baseline case. Then, $\overline{L}_n = \overline{A}_{USA} v_n$, and $M_n = L_n/\bar{L}_n$, for $n \neq USA$ (see column 4 in Table 12). With this alternative calibration, low-density countries will be larger (i.e., 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 to the number of towns with more than 250,000 habitants observed in the data, for each country. This calibration naturally implies that $\overline{L}_n$ is different for each country n. Column 5 in Table 12 shows these data.[30]

Columns 6 to 10 in Table 12 present the implied relative real wage for the five different calibrations described above. The gap between data and model for Denmark remains virtually the same across all calibrations. The exceptions among the small countries are Belgium and Netherlands for which the calibration that assumes regions of fixed land areas overestimates the relative real wage with respect to the data.

Our final robustness exercise involves an alternative calibration of d_{nn} using *all* the bilateral

[28] Our results for d_{nn} for $n = CAN$ are very similar to those in Tombe and Winter (2012).

[29] Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat.

[30] In the two alternative calibrations just described (i.e., using density or using the number of towns with more than 250,000 habitants), we keep d_{nn} as in our baseline estimate that uses the data for the fifty one U.S. states, for 2002.

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. Our procedure applies the index of trade costs developed by Head and Ries (2001), and Head, Mayer, and Ries (2009), to these internal flows. In particular,

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

where the assumption is that $d_{mk}^{HR} = d_{km}^{HR}$, and m and k are geographical units within a country. Descriptive statistics for this index are shown in Table 7, while Figure 6 shows the distribution of the index across U.S. state pairs, in 2002. In all cases, the average trade cost index is higher than the value used in our baseline calibration, suggesting that our estimates of the importance of domestic frictions to the resolution of the Danish puzzle are, *de facto*, on the conservative side.

4 Discussion

Our results show that openness and domestic frictions account for a large share of the Danish Puzzle. Both channels together explain more than 70 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.[31] Our strategy has been to keep the model very parsimonious—as summarized by (23)—so that income differences across countries only come from differences in R&D-adjusted size $\left(L_n\overline{T}_n\right)$, gains from openness (GO_n), and domestic frictions (D_n, H_n).

Which key forces may we be leaving out of the model that could explain the remaining part of the Danish Puzzle?

One possibility is that small countries may 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 intensity, as a proxy for $\overline{T}_n$ in our quantitative exercise.

[31] We calculate this number from Table 4 as the ratio of the relative real wage in column 4 minus the relative real wage in column 1 over the relative real wage in column 5 minus the relative real wage in column 1. For Denmark this yields 0.72. For the other countries in Table 4 the respective numbers (in the same order as in the table) are 0.7, 1.16, 0.70, 0.69, 0.97, and 0.98.

Our baseline results do not change.[32] We also checked whether small countries are somehow better in terms of schooling, corruption in government, bureaucratic quality, or rule of law. The correlations between these variables and R&D-adjusted size ($\overline{T}_i L_i$) are 0.30, -0.17, 0.12, 0.22, respectively (see Table 13 in the Appendix). We conclude that the data do not support the idea that smallness confers some productivity advantage through better institutions.

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.[33]

Some indirect evidence points out 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.[34] They estimate that most of the productivity growth in OECD countries—except the United States— is due to foreign research. The integration of such a model with the model of domestic frictions, trade, and MP that we developed here, is a challenge left for future research. For now, we pursue a simpler exercise to see how diffusion may solve the Danish Puzzle in the context of our model.

Assume that a share ϕ of the value of production in country i that is done with country l technologies is not recorded as MP. For example, the iPhone is produced in China by Foxconn. This reflects the use of a U.S. technology for production in China, but since it is produced by a Chinese firm, it is not recorded as MP. Setting $\phi > 0$ is a simple way of capturing this phenomenon and exploring its quantitative importance. The value of ϕ affects the calculation of the gains from openness. Consider the case of final goods, for which we have $\sum_i Y_{ni}^f = w_n L_n$. As explained above, we measure Y_{ni}^f for $n \neq i$ from MP data, and we set $w_n L_n$ as GDP in country n. We then get Y_{nn}^f as a residual, $Y_{nn}^f = w_n L_n - \sum_{i \neq n} Y_{nn}^f$. When $\phi > 0$ then the actual value of production in n

[32] 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—$P_i/(\overline{T}_i L_i)$—and country's R&D-adjusted size—$\overline{T}_i L_i$—is positive and around 0.7, when the United States and Japan are included, decreasing to 0.35 when those two countries are exclude.

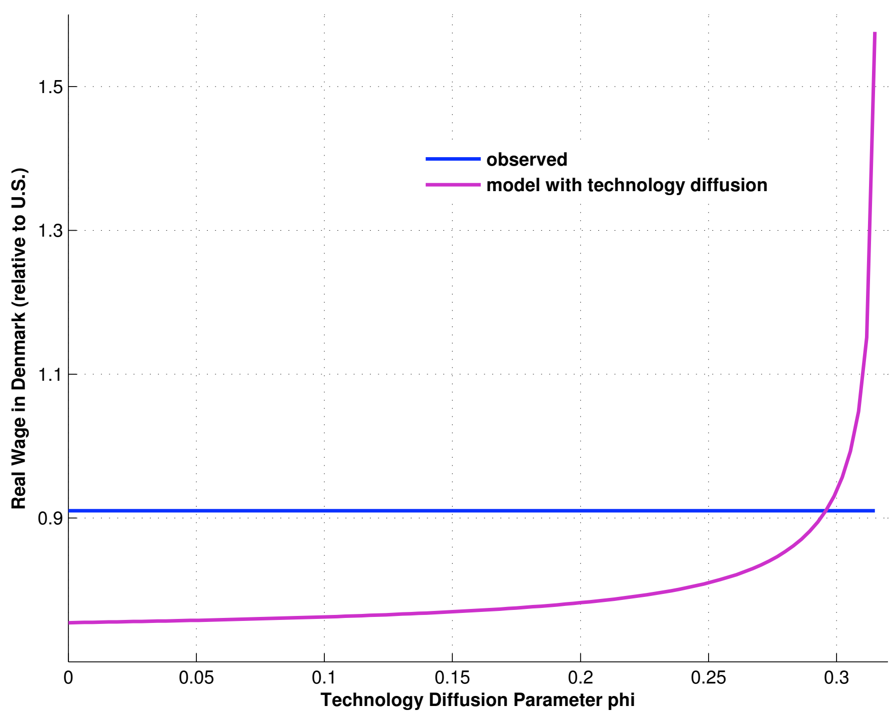
[33] According to the data published by the Bureau of Economic Analysis, royalties and licenses paid to U.S. parents and foreign affiliates by unaffiliated parties for the use of intangibles represented only one percent of total affiliates sales, in 1999.

[34] For instance, a country like Belgium has 97 percent of patents registered by foreigners.

with foreign technologies is $\frac{1}{1-\phi}\sum_{i\neq n} Y_{ni}^f$ and hence $Y_{nn}^f = w_n L_n - \frac{1}{1-\phi}\sum_{i\neq n} Y_{ni}^f$. A higher value of ϕ implies a lower value for Y_{nn}^f and hence higher gains from MP in final goods. Something similar happens for intermediate goods.

We assume that ϕ is the same across countries and think of higher values of ϕ as implying higher technology diffusion. Figure 5 shows how ϕ affects the implied relative real wage for Denmark. For $\phi = 0$, the (relative) real wage for Denmark is 0.75 as implied by our baseline model. As ϕ increases, the (relative) real wage for Denmark increases to finally match the one observed in the data at a value of ϕ just below 0.30. For $\phi > 0.30$, Denmark rapidly catches up with the United States, becoming even richer when ϕ is sufficiently high. To us, this exercise suggests that reasonable levels of diffusion would be enough to close the remaining gap between model and data regarding real income across countries of different size.

Figure 5: Technology Diffusion and the Real Wage: Denmark



5 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.

The goal of this paper is to explore this apparent inconsistency between idea-based growth models and the cross-country data. We start by studying the implications of Kortum's (1997) model for country-level scale effects and note that it would imply that, *ceteris paribus*, small countries would be much poorer than larger ones. For example, according to our calibration, Denmark would have an income level of 34 percent of the U.S. level, much lower than the observed 91 percent. We refer to this gap as the "Danish Puzzle."

We explore and quantify two candidates to solve the puzzle: First, countries are not fully isolated from each other; and second, countries are not fully integrated domestically. To such end, we build a quantitative model of trade and multinational production (MP) with frictions to move goods and ideas not only across, but also within countries.

For the case of Denmark, our calibrated model implies a real per-capita income of 75 percent (relative to the U.S.), versus 91 percent in the data. Thus, our two channels together are able to explain more than 70 percent of the puzzle. We find that domestic frictions are quantitatively much more important than openness, as they explain more than two thirds of the Danish Puzzle, while trade and MP explain just five percent of the puzzle. We are left with one fourth of the gap unexplained, suggesting the presence of other forms of openness not associated with trade and MP, such as international diffusion of ideas taking place outside the firm.

References

[1] **Ades, Alberto, and Edward L. Glaeser**. 1999. "Evidence on Growth, Increasing Returns, and the Extent of the Market". *Quarterly Journal of Economics*, MIT Press, vol. 114(3), pages 1025-1045, August.

[2] **Alcala, Francisco, and Antonio Ciccone.** 2004. "Trade and productivity". *Quarterly Journal of Economics* 119 (2), 613-646.

[3] **Alesina, Alberto, Enrico Spolaore, and Romain Wacziarg.** 2000. "Economic Integration and Political Disintegration". *American Economic Review*, Vol. 90, No. 5 (Dec., 2000), pp. 1276-1296.

[4] **Alvarez, Fernando, Fraciso J. Buera, and Robert E. Lucas.** 2011. "Idea Flows, Economic Growth, and Trade". Mimeo, University of Chicago.

[5] **Alvarez, Fernando, and Robert E. Lucas.** 2007. "General Equilibrium Analysis of the Eaton-Kortum Model of International Trade". *Journal of Monetary Economics*. Volume 54, Issue 6.

[6] **Aghion, Philippe and Peter Howitt.** 1992. "A model of growth through creative destruction". *Econometrica* 60 (2), 323–351.

[7] **Aghion, Philippe and Peter Howitt.** 1992. Endogenous Growth Theory. MIT Press, Cambridge, MA.

[8] **Arkolakis, Costas, Natalia Ramondo, Andrés Rodríguez-Clare, and Stephen Yeaple.** 2011. "Innovation and Production in the Global Economy". Mimeo, Arizona State, Penn State, and Yale University.

[9] **Aten, Bettina, Alan Heston, and Robert Summers**. 2009. Penn World Table Version 6.3. Center for International Comparisons of Production, Income, and Prices at the University of Pennsylvania.

[10] **Backus, David, Patrick Kehoe, and Timothy Kehoe.** 1992. "In search of scale effects in trade and growth". *Journal of Economic Theory,* 58 (August), 377–409.

[11] **Barro Robert J., and Jong-Wha Lee**. 2000. "International Data on Educational Attainment: Updates and Implications". CID Working Paper 42.

[12] **Beck, Thorsten, George Clarke, Alberto Groff, Philip Keefer, and Patrick Walsh.** 2001. "New Tools in Comparative Political Economy: The Database of Political Institu- tions". *World Bank Economic Review* (1), 165–

[13] **Combes, Pierre-Philippe, Gilles Duranton, Laurent Gobillon, Diego Puga, and Sébastien Roux.** 2012. "The productivity advantages of large cities: Distinguishing agglomeration from firm selection". *Econometrica*, forthcoming.

[14] **Dinopoulos, Elias, and Peter Thompson.** 1998."chumpeterian growth without scale effects". *Journal of Economic Growth*, 3 (4), 313–335.

[15] **Eaton, Jonathan, and Samuel Kortum.** 1996. "Trade in ideas Patenting and productivity in the OECD". *Journal of International Economics*, 40(3-4), 251-278.

[16] **Eaton, Jonathan, and Samuel S. Kortum.** 1999. "International Technology Diffusion: Theory and Measurement". *International Economic Review*, 40(3), 1999, 537-570.

[17] **Eaton, Jonathan, and Samuel S. Kortum.** 2001. "Technology, Trade, and Growth: A Unified Framework". *European Economic Review*, 45, 742-755.

[18] **Eaton, Jonathan, and Samuel S. Kortum.** 2002. "Technology, Geography and Trade". *Econometrica*, Vol. 70(5).

[19] **Frankel, Jacob, and David Romer.** 1999. "Does trade cause growth?" *American Economic Review,* 89 (3), 379–399.

[20] **Grossman, Gene, and Elhanan Helpman.** 1991. Innovation and Growth in the Global Economy. MIT Press, Cambridge, MA.

[21] **Head, Keith and John Ries.** 2001. "Increasing Returns versus National Product Di§er- entiation as an Explanation for the Pattern of U.S.-Canada Trade". *American Economic Review*, Vol. 91(4): 858-876.

[22] **Head, Keith, Thierry Mayer and John Ries.** 2009. "The erosion of colonial trade linkages after independence". CEPR Discussion Paper.

[23] **Jones, Charles I.** 1995. "R&D-Based Models of Economic Growth". *Journal of Political Economy*, Vol. 103, pp. 759-784.

[24] **Jones, Charles I.** 2002. "Sources of U.S. Economic Growth in a World of Ideas", *American Economic Review*, Vol. 92, No. 1 (March), 220-239.

[25] **Jones, Charles I.** 2005. "Growth and Ideas", *Handbook of Economic Growth*, Vol. 1A, P. Aghion and S. Durlauf, eds., 1064-1108 (chapter 16).

[26] **Jones, Charles I. and Paul M. Romer** 2010. "The New Kaldor Facts: Ideas, Institutions, Population, and Human Capital", *American Economic Journal: Macroeconomics*, 2:1, 224–

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

[28] **Kortum, Samuel S.** 1997. "Research, Patenting and Technological Change". *Econometrica* 65, 1389-1419.

[29] **Lucas, Robert E., and Benjamin Moll.** 2011. "Knowledge Growth and the Allocation of Time". NBER Working Paper No 17495.

[30] **Peretto, Pietro.** 1998. "Technological change and population growth". *Journal of Economic Growth*, 3 (4), 283–311.

[31] **Ramondo, Natalia, and Andrés Rodríguez-Clare.** 2010. "Growth, Size, and Openness: A Quantitative Approach". *American Economic Review, Papers and Proceedings*, Volume 100, Issue 2, pp. 62-67.

[32] **Ramondo, Natalia, and Andrés Rodríguez-Clare.** 2010. "Trade, Multinational Production, and the Gains from Openness". NBER Working Paper 15604.

[33] **Redding, Stephen J.** 2012. "Goods Trade, Factor mobility, and Welfare". NBER Working Paper 18008.

[34] **Rose, Andrew K.** 2006. "Size Really Doesn't Matter: In Search of a National Scale Effect". *Journal of the Japanese and International Economies*, 20, 4: 482-507.

[35] **Simonovska, Ina, and Michael Waugh.** 2011. "The Elasticity of Trade for Developing Nations: Estimates and Evidence ". Mimeo, UC Davis and NYU-Stern.

[36] **Trevor, Tombe, and Jennifer Winter.** 2012. "Internal Trade and Aggregate Productivity: Evidence from Canada". Mimeo, Wilfrid Laurier University.

[37] **Waugh, Michael.** 2010. "International Trade and Income Differences". *American Economic Review*, 100(5): 2093 - 2124.

[38] **Young, Alwyn.** 1998. "Growth without scale effects". *Journal of Political Economy*, 106 (1), 41–63.

A Derivations

Price indices. We now derive the price indices for final and intermediate goods in the open economy. We let $z^f_{m,ni}(u)$ be the highest productivity among the set of technologies for final good u originating in country i with home region m in country n, and let $z^g_{m,ni}(v)$ be the highest productivity among the set of technologies for intermediate good v originating in country i with home region m in country n. By the properties of the Fréchet distribution, $z^f_{m,ni}(u)$ and $z^g_{m,ni}(v)$ are distributed Fréchet with parameters $L_i\bar{T}_i/M_n$ and θ. Finally, let $z^g_{li}(v) = \max_m z^g_{m,li}(v)$.

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 $c^f_n/z^f_{m,nn}(u)$; (b) technologies from $i \neq n$ with home region m at unit cost $h^f_{ni}c^f_n/z^f_{m,ni}(u)$; (c) technologies from n with home region different than m at unit cost $\min_{s\neq m} h^f_{nn}c^f_n/z^f_{s,nn}(u)$; (d) technologies from $i \neq n$ with home region different than m at unit cost $\min_{s\neq m} h^f_{nn}h^f_{ni}c^f_n/z^f_{s,ni}(u)$. This implies that

$$p^f_{m,n}(u) = \min\left(\frac{c^f_n}{z^f_{m,nn}(u)}, \frac{h^f_{ni}c^f_n}{z^f_{m,ni}(u)}, \min_{s\neq m}\frac{h^f_{nn}c^f_n}{z^f_{s,nn}(u)}, \min_{i\neq n}\min_{s\neq m}\frac{h^f_{nn}h^f_{ni}c^f_n}{z^f_{s,ni}(u)}\right).$$

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 $c^g_n/z^g_{m,nn}(v)$; (b) technologies from $i \neq n$ with home region m at unit cost $h^g_{ni}c^g_n/z^g_{m,ni}(v)$; (c) technologies from n with home region different than m at unit cost

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

(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 imply that the price indices for final and intermediate goods are given respectively by

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

and

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

With $H_n \equiv (1/M_n + ((M_n - 1)/M_n)(h^f_{nn})^{-\theta})^{-1}$, and $D_n \equiv (1/M_n + ((M_n - 1)/M_n) d_{nn}^{-\theta})^{-1}$, we get the result in (8) and (9).

Real Wage. Here, we derive equation (17). First, we rewrite (14) as

$$Y^g_{nn} = \frac{M_n T_n \left(c^g_n\right)^{-\theta} \Psi'_n}{\left(\gamma^{-1} P^g_n\right)^{-\theta}},$$

where

$$\Psi'_n = D_n^{-1} \eta w_n L_n + \sum_{j\neq n} d_{jn}^{-\theta} \left(\gamma^{-1} P^g_n\right)^{-\theta} \eta w_j L_j \left(\gamma^{-1} P^g_j\right)^{\theta}. \tag{26}$$

Using the expression above for Y^g_{nn} and (16), we can write the real wage as

$$w_n / P^f_n = \tilde{\gamma} (M_n T_n)^{(1+\eta)/\theta} H_n^{-1/\theta} \left(Y^g_{nn}\right)^{-\eta/\theta} \left(\frac{Y^f_{nn}}{w_n L_n}\right)^{-1/\theta} \left(\Psi'_n\right)^{\eta/\theta}. \tag{27}$$

We then rewrite (26) as

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

and we use the gravity equation in (12) and $\sum_{j=1}^{N} X_{jn} = \eta w_n L_n$ to get

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

Replacing in (27), we obtain (17).

Flows between regions. Expenditure on goods from region k going to region m in country n is

$$X_{mk,n} = d_{nn}^{-\theta}\left(\gamma c_n^g / P_n^g\right)^{-\theta}\left[M_n T_n + \sum_{i\neq n} M_i T_i (h_{ni}^g)^{-\theta}\right]\eta w_n L_n.$$

Thus, expenditure by region m on goods from all other regions in the same country is simply $\widetilde{X}_{m,n} = (M_n - 1)X_{mk,n}$. In region m in country n, the expenditure on goods coming from the same region is

$$X_{mm,n} = \left(\gamma c_n^g / P_n^g\right)^{-\theta}\left[M_n T_n + \sum_{i\neq n} M_i T_i (h_{ni}^g)^{-\theta}\right]\eta w_n L_n.$$

B Data on Multinational Production: Description

Data on MP is from UNCTAD, Investment and Enterprise Program, FDI Statistics, FDI Country Profiles, published and unpublished data.[35] A foreign affiliate is defined in the data as a firm who has more than ten percent of its shares owned by a foreigner. Most countries report magnitudes for majority-owned affiliates only (more than 50 percent of ownership).[36] The data refer to non-financial affiliates in all sectors.

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

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

[36] Majority-owned affiliates are the largest part of the total number of foreign affiliates in a host economy.

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).

C Alternative Calibrations of Domestic Frictions

This section shows results for domestic trade frictions calculated using different data on domestic trade flows, for the United States and Canada. We also calculate a domestic trade cost index following the methodology in Head and Ries (2001). All these alternative calibrations of domestic frictions within a country deliver results similar to the ones in our baseline calibration.

C.1 Trade between Sub-regional Units in the United States

We calculate domestic trade costs for sub-regional geographical units within the United States. We compute internal trade for 99 geographical units, from which 48 are Consolidated Statistical Areas (CSA), 18 are Metropolitan Statistical Areas (MSA), and 33 represent remaining portions of (some of) the states. The data source is the Commodity Flow Survey, for 2007. For each of the 99 geographical units, we compute the total purchases from the United States and subtract trade with themselves. Then, we use (24) in the text to calculate d_{nn}, for different values of θ. We consider $M_{USA} = 100$ where the 100th geographical unit represents the "rest" of the United States. Table 5 presents the results. The estimates using sub-regional geographical units are around ten percent higher than the baseline that uses U.S. states (1.72 versus 1.85, for $\theta = 6$).

Table 5: Domestic Trade Cost for the United States (CSA and MSA): Summary Statistics.

	$M_{USA} = 100$			
	$\theta = 4$	$\theta = 6$	$\theta = 8$	$X_{mm,n} / \sum_k X_{mk,n}$
Average	2.52	1.85	1.58	0.29
Standard Deviation	0.39	0.19	0.12	0.12
Maximum	3.71	2.40	1.93	0.66
Minimum	1.29	1.19	1.14	0.03

Own calculations using data from CFS, 2007, on trade between each of the 100 sub-regional unit and the rest of the United States. The last column records expenditures that m purchases from m, as a share of total expenditure in m.

C.2 Trade between Canadian Provinces

Data on internal trade are available for Canada. In particular, bilateral trade of goods and services, respectively, is recorded among the thirteen Canadian provinces, for the years 1999-2007.[37] We follow the same procedure described in the paper as for trade in goods within the United States, and use (24) with $M_{CAN} = 13$. The following table summarizes the results.

Table 6: Domestic Trade Cost for Canada: Summary Statistics.

	2002			2007		
	$\theta = 4$	$\theta = 6$	$\theta = 8$	$\theta = 4$	$\theta = 6$	$\theta = 8$
Average	2.25	1.72	1.50	2.31	1.75	1.52
Standard Deviation	0.24	0.12	0.08	0.27	0.14	0.09
Maximum	2.74	1.96	1.65	2.81	1.99	1.68
Minimum	2.00	1.59	1.41	1.94	1.56	1.39

Own calculations using data from BCStats, for 2002 and 2007.

The statistics in Table 6 are remarkably similar to the ones presented in Table 2 for inter-state trade in the United States. In particular, for Canada, the average domestic trade cost is 1.72 in 2002, for $\theta = 6$, the same as in our baseline calibration.

C.3 The Head and Ries Index for Domestic Trade Costs

[37] The source is British Columbia Statistics, at $http://www.bcstats.gov.bc.ca/data/bus_stat/trade.asp$.

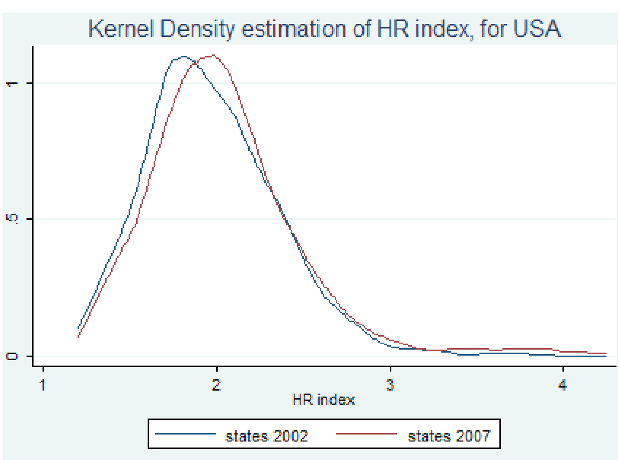
Table 7: Domestic Trade Costs Index: Descriptive statistics, by data source.

	U.S. states					
	2002			2007		
	$\theta = 4$	$\theta = 6$	$\theta = 8$	$\theta = 4$	$\theta = 6$	$\theta = 8$
Average	2.80	1.97	1.66	2.96	2.04	1.70
Standard Deviation	0.82	0.38	0.24	0.99	0.43	0.27
Maximum	7.30	3.76	2.70	8.70	4.23	2.95
Minimum	1.33	1.21	1.15	1.36	1.23	1.16
No. of Observations		911			1,002	
	U.S. sub-regional units					
	2002			2007		
	$\theta = 4$	$\theta = 6$	$\theta = 8$	$\theta = 4$	$\theta = 6$	$\theta = 8$
Average		n/a		3.28	2.19	1.79
Standard Deviation		n/a		1.05	0.47	0.28
Maximum		n/a		11.04	4.96	3.32
Minimum		n/a		1.17	1.11	1.08
No. of Observations		n/a			3,000	
	Canadian Provinces					
	2002			2007		
	$\theta = 4$	$\theta = 6$	$\theta = 8$	$\theta = 4$	$\theta = 6$	$\theta = 8$
Average	3.85	2.40	1.91	3.74	2.36	1.89
Standard Deviation	1.71	0.72	0.43	1.73	0.72	0.43
Maximum	7.59	3.86	2.75	8.70	4.23	2.95
Minimum	1.60	1.37	1.27	1.69	1.42	1.30
No. of Observations		69			66	

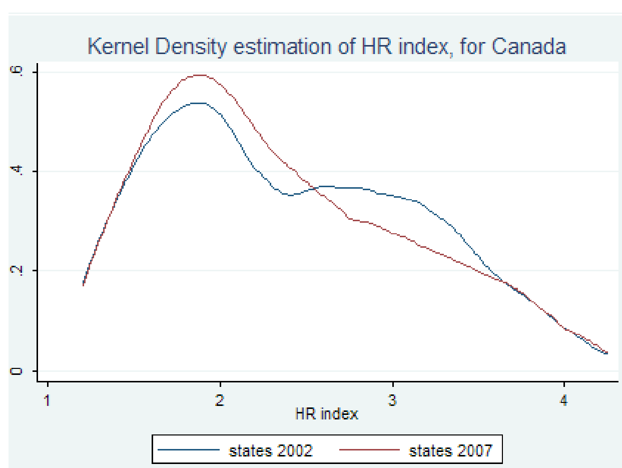
Own calculations using data from CFS, and BCStats, for 2002 and 2007.

Figure 6: Domestic Trade Costs: Head and Ries Index.

(a) U.S. States



(b) Canadian Provinces



D Additional Tables

Table 8: 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.

Table 9: 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.

Table 10: Real Wage, Size, Openness, and Domestic Frictions: All Countries.

	Size (1)	GO (2)	Domestic Frictions (3)	Real Wage Model (4)=(1)×(2)×(3)	Real Wage Data (5)
Australia	0.47	1.14	1.48	0.79	0.86
Austria	0.34	1.13	1.73	0.66	0.94
Belgium	0.38	1.52	1.73	1.00	0.99
Canada	0.53	1.14	1.36	0.82	0.81
Denmark	0.34	1.10	2.04	0.76	0.91
Spain	0.43	0.98	1.42	0.60	0.96
Finland	0.39	0.95	2.04	0.76	0.82
France	0.58	1.01	1.29	0.76	0.94
Great Britain	0.56	1.19	1.26	0.85	0.90
Germany	0.66	1.00	1.17	0.77	0.81
Greece	0.29	1.06	1.73	0.54	0.77
Italy	0.46	0.94	1.32	0.57	1.11
Japan	0.87	0.92	1.07	0.86	0.70
Netherlands	0.40	1.37	1.58	0.88	0.94
Norway	0.35	1.07	2.04	0.77	0.80
New Zealand	0.29	1.37	2.04	0.81	0.69
Portugal	0.29	1.12	2.04	0.65	0.92
Sweden	0.42	1.04	1.73	0.76	0.77
United States	1.00	1.00	1.00	1.00	1.00

Calibration with $\theta = 6$. Countries ordered by R&D-adjusted size ($T_n M_n = L_n \overline{T}_n$). Column 1 refers to the term "size," column 2 to the term "openness," column 3 to the term "domestic frictions," and column 4 to the product of the three terms in (23). Column 5 is the real GDP (PPP-adjusted) per unit of equipped labor observed in the data. All variables are calculated relative to the United States.

Table 11: Calibration for Different Values of θ: All countries.

	$\theta = 4$				$\theta = 6$				$\theta = 8$			
	size	GO	dom.fric.	real wage	size	GO	dom.fric.	real wage	size	GO	dom.fric.	real wage
Australia	0.32	1.21	1.42	0.55	0.47	1.14	1.48	0.79	0.57	1.10	1.48	0.92
Austria	0.19	1.20	1.72	0.40	0.34	1.13	1.73	0.66	0.44	1.10	1.67	0.81
Belgium	0.24	1.87	1.72	0.76	0.38	1.52	1.73	1.00	0.49	1.37	1.67	1.11
Canada	0.39	1.21	1.29	0.61	0.53	1.14	1.36	0.82	0.62	1.10	1.38	0.94
Denmark	0.20	1.16	2.14	0.48	0.34	1.10	2.04	0.76	0.44	1.08	1.90	0.91
Spain	0.29	0.97	1.35	0.37	0.43	0.98	1.42	0.60	0.53	0.99	1.42	0.75
Finland	0.24	0.93	2.14	0.49	0.39	0.95	2.04	0.76	0.49	0.97	1.90	0.91
France	0.44	1.02	1.22	0.55	0.58	1.01	1.29	0.76	0.66	1.01	1.31	0.88
Great Britain	0.42	1.30	1.20	0.66	0.56	1.19	1.26	0.85	0.65	1.14	1.28	0.95
Germany	0.53	1.00	1.12	0.59	0.66	1.00	1.17	0.77	0.73	1.00	1.19	0.87
Greece	0.16	1.10	1.72	0.30	0.29	1.06	1.73	0.54	0.40	1.05	1.67	0.70
Italy	0.31	0.91	1.25	0.35	0.46	0.94	1.32	0.57	0.56	0.95	1.34	0.71
Japan	0.81	0.88	1.05	0.75	0.87	0.92	1.07	0.86	0.90	0.94	1.09	0.92
Netherlands	0.26	1.61	1.53	0.63	0.40	1.37	1.58	0.88	0.51	1.27	1.56	1.00
Norway	0.21	1.10	2.14	0.50	0.35	1.07	2.04	0.77	0.46	1.05	1.90	0.92
New Zealand	0.16	1.61	2.14	0.53	0.29	1.37	2.04	0.81	0.39	1.27	1.90	0.95
Portugal	0.15	1.19	2.14	0.39	0.29	1.12	2.04	0.65	0.39	1.09	1.90	0.81
Sweden	0.27	1.07	1.72	0.50	0.42	1.04	1.73	0.76	0.52	1.03	1.67	0.90
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," "GO," and "dom.fric." refer to the first, second, and third terms, respectively, on the right-hand side of (23). The real wage is the product of those three terms. All variables are calculated relative to the United States.

Table 12: Alternative Calibrations.

	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)
Australia	4	7	8	42	10	0.80	0.75	0.73	0.55	0.69
Austria	2	3	3	1	2	0.65	0.62	0.63	0.77	0.67
Belgium	2	3	4	1	1	0.97	0.92	0.87	1.14	1.17
Canada	6	11	13	54	14	0.82	0.77	0.75	0.60	0.73
Denmark	1	2	3	1	1	0.75	0.67	0.62	0.75	0.77
Spain	5	9	11	3	16	0.60	0.56	0.54	0.67	0.50
Finland	1	2	2	2	2	0.76	0.67	0.68	0.64	0.66
France	8	16	19	3	7	0.76	0.71	0.69	0.93	0.80
Great Britain	9	17	20	2	18	0.76	0.71	0.70	1.04	0.69
Germany	14	26	32	2	27	0.76	0.73	0.72	1.13	0.71
Greece	2	3	3	1	2	0.54	0.51	0.51	0.63	0.55
Italy	7	13	16	2	12	0.56	0.52	0.51	0.73	0.52
Japan	26	51	62	3	89	0.85	0.83	0.82	1.25	0.78
Netherlands	3	5	6	1	4	0.83	0.78	0.76	1.08	0.80
Norway	1	2	3	3	2	0.78	0.69	0.64	0.61	0.68
New Zealand	1	2	2	2	3	0.80	0.71	0.72	0.68	0.64
Portugal	1	2	3	1	1	0.64	0.57	0.52	0.64	0.66
Sweden	2	3	4	3	3	0.75	0.72	0.68	0.69	0.71
United States	51	100	121	51	74	1.00	1.00	1.00	1.00	1.00

Calibration with $\theta = 6$. Columns 1 to 3 refer to the calibrated number of regions calculated using $M_n = L_n/\overline{L}$ where $\overline{L} = L_R/M_R$, 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 (17) 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 13: Human Capital, Institutions, and Patents.

	Schooling (1)	Corruption in Gov. (2)	Rule of Law (3)	Bureaucracy Quality (4)	Patents per capita (5)	Real Wage Gap data to model (6)
Australia	10.24	5	6.00	6.00	0.58	1.00
Austria	6.64	4.96	6.00	5.98	0.61	1.26
Belgium	9.15	4.68	5.87	5.97	0.62	0.93
Canada	10.37	6.00	6.00	6.00	0.83	0.96
Denmark	10.33	6.00	6.00	6.00	0.70	1.16
Spain	5.58	4.33	5.50	4.27	0.13	1.54
Finland	9.49	6.00	6.00	5.81	1.03	1.03
France	6.52	5.05	5.61	5.80	0.70	1.24
Great Britain	8.65	4.90	5.75	6.00	0.63	1.16
Germany	8.54	5.53	5.81	6.00	1.23	1.05
Greece	6.73	5.00	4.98	3.90	0.0004	1.25
Italy	6.28	3.60	5.31	4.85	0.67	1.97
Japan	8.46	4.96	5.68	5.85	1.17	0.83
Netherlands	8.57	6.00	6.00	6.00	1.28	1.06
Norway	10.38	5.81	6.00	5.42	0.21	0.98
New Zealand	12.04	5.81	5.96	6.00	0.25	0.75
Portugal	3.83	4.88	5.32	3.90	n/a	1.43
Sweden	9.45	6.00	6.00	6.00	0.93	0.95
United States	11.79	4.86	6.00	6.00	2.40	1.00

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 (i.e., $\overline{T}_n L_n$) from country i registered in all other countries in the sample (including itself), from the World Intellectual Property Organization (WIPO), average over 2000-2005. The real wage gap in column 6 is the ratio between the real wage (relative to the U.S.) in the data and in the model. The real wage in the data is real GDP (PPP-adjusted), from Penn World Tables (6.3) divided by equipped labor from Klenow and Rodríguez-Clare (2005). The real wage in the model is from the baseline calibration with $\theta = 6$.

E Online Appendix (Not for Publication)

E.1 A Simplified Redding (2012)'s Model

We want to evaluate the assumption on identical regions within countries. To this end, we present a simplified version of Redding (2012)'s model (section 2) of domestic and international trade that we use to compute the gains from trade assuming symmetric and asymmetric regions, alternately. The model is an Eaton and Kortum (2002)-type model extended to incorporate domestic trade costs and labor mobility within a country.

There are two countries, N and S. Country N has two regions, N_1 and N_2, and country S has only one region (denoted also by S). Country N's size is $L_N = \overline{L}_{N_1} + \overline{L}_{N_2}$, and country S's size is simply $L_S = \overline{L}_S$. There are three iceberg-type trade costs: d_N is the cost between regions N_1 and N_2 in country N; d_{N_1} is the cost between regions N_1 and S; and d_{N_2} is the cost between regions N_2 and S. All costs are symmetric. Labor is freely mobile within a country. The wage in region N_1 is normalized to one, $w_{N_1} = 1$. In any region m, consumer preferences are defined over the (tradable) consumption good, C_m, and residential land use, H_m, and take the following Cobb-Douglas form:

$$U = C_m^{\alpha} H_m^{1-\alpha},$$

where $0 < \alpha < 1$ The good C_m is the CES composite good defined as $C_m \equiv (\int_0^1 q_m(v)^{(\sigma-1)/\sigma} dv)^{\sigma/(\sigma-1)}$, as in the body of this paper. The parameter α is the share of expenditures on the aggregate consumption good. All the remaining parameters are defined as in the body of (this) paper.[38]

In region m, indirect utility is given by

$$V_m = (\lambda_{mm})^{-\alpha/\theta} (T_m)^{\alpha/\theta} \left(\frac{H_m}{\overline{L}_m}\right)^{1-\alpha}, \tag{28}$$

where λ_{mm} is the domestic (trade) share for region m, and $T_m \equiv \overline{T L}_m$. With free mobility of labor within a country, indirect utility is equalized across regions, in a given country.

The Gains from Trade. The gains from trade in country n are computed as the change in indirect utility from isolation to a situation with positive trade, $GT_n = V_n^{trade}/V_n^{isol}$. For country S, which

[38]For simplicity, we drop the input-output loop; production is done with only labor.

has only one region, the gains from trade are simply

$$GT_S = (\lambda_{SS})^{-\alpha/\theta}. \tag{29}$$

For country N, free labor mobility implies that indirect utility is equated across regions, $V_{N_1} = V_{N_2}$, both in the isolation and the trade equilibrium. Thus, the gains from trade are given by

$$GT_N^{asy} = \left(\frac{\lambda_{mm}^{trade}}{\lambda_{mm}^{isol}}\right)^{-\alpha/\theta} \left(\frac{\overline{L}_m^{trade}}{\overline{L}_m^{isol}}\right)^{-(1-\alpha)}, \tag{30}$$

for either $m = N_1$ or $m = N_2$.

Assume that regions are symmetric. This assumption requires that $d_m = d$, $\overline{T}_m = \overline{T}$, and $H_m = H$, for $m = N_1, N_2$. Thus, $\overline{L}_m^{isol} = \overline{L}_m^{trade} = L_N/2$ (and $w_m = 1$), for $m = N_1, N_2$. From (30), the gains from trade for country N under symmetry are simply

$$GT_N^{sym} = \left(\frac{\lambda_{mm}^{trade}}{\lambda_{mm}^{isol}}\right)^{-\alpha/\theta}.$$

But

$$\lambda_{mm}^{trade} = \frac{1}{1 + d_N^{-\theta} + \overline{T}\,(w_S d)^{-\theta}},$$

and

$$\lambda_{mm}^{isol} = \frac{1}{1 + d_N^{-\theta}}.$$

Hence,

$$\frac{\lambda_{mm}^{trade}}{\lambda_{mm}^{isol}} = \frac{1 + d_N^{-\theta}}{1 + d_N^{-\theta} + \overline{T}\,(w_S d)^{-\theta}}.$$

This expression is precisely λ_{NN}. Thus, under symmetry,

$$GT_N^{sym} = (\lambda_{NN})^{-\alpha/\theta}. \tag{31}$$

Numerical Examples. We consider two examples in which the sources of asymmetries among regions in country N are different. In the first example, the asymmetries arise from differences in the (international) trade costs from each region in country N to country S. In the second example, regions in country N differ in their technology parameters and amount of land. Let

$K_m \equiv \overline{T}_m^{\alpha/\theta} H_m^{1-\alpha}$. We set $H_m = \overline{T}_m^{1/\theta}$ so that $K_m = \overline{T}_m^{1/\theta}$. Additionally, we pick $T_N = T_{N_1} + T_{N_2}$, $L_N = L_S = 1$, and $T_S = 1$. Finally, we set $\theta = 6$, $\alpha = 0.5$, and $d_N = 1.7$.

In the first numerical example, we assume that $d_{N_2} < d_{N_1}$ (and the triangular inequality, $d_{N_1} \leq d_N d_{N_2}$ and $d_{N_2} \leq d_N d_{N_1}$); otherwise, regions are identical. In particular, we set $\overline{T}_m = 0.5$ so that $K_m = 0.891$, for $m = N_1, N_2$. Inspection of (30) makes clear that the gains from trade in country N are a function of domestic trade shares and the amount of labor in a given region m, that, in turn, depend, among others, on the domestic trade cost d_N. We simulate GT_N in (30) for different values of d_{N_1} and d_{N_2}. We compare these gains from trade calculated assuming asymmetric regions with the gains from trade in (31), a measure that disregards labor mobility across regions. Table 14, left panel, summarizes the results.[39]

Table 14: Numerical Examples.

Asymmetric International Trade Costs					Asymmetric Technologies				
d_{N_1}	d_{N_2}	GT_N^{asy}	GT_N^{sym}	error	$\overline{T}_{N_1}$	$\overline{T}_{N_2}$	GT_N^{asy}	GT_N^{sym}	error
1.8	1.7	1.0062	1.0062	0.0002	0.2	0.5	1.0147	1.0146	0.0113
1.8	1.1	1.0451	1.0428	0.2289	0.8	0.5	1.0148	1.0148	0.0031
1.5	1.4	1.0184	1.0184	0.0022	0.2	0.9	1.0145	1.0143	0.0271
1.5	1.1	1.0499	1.0470	0.2686	0.8	0.9	1.0148	1.0148	0.0002

The last column refers to the difference, in percentage, between GT_N^{asy} and GT_N^{sym}.

Clearly, if the international trade costs are more similar across regions (e.g., 1.8 versus 1.7, or 1.5 versus 1.4), the two measures of the gains from trade are almost identical. The miscalculation in the gains from trade due to not considering labor mobility within country rises with differences in the international trade costs across regions, but it never reaches one percent.

Next, we assume that $\overline{T}_{N_1} \neq \overline{T}_{N_2}$ (so that $K_{N_1} \neq K_{N_2}$), while keeping $d_{N_1} = d_{N_2} = 1.5$. Results are presented in the right panel of Table 14. Again, the difference between the two measures of the gains from trade for country N is always less than one percent.[40]

[39]For values of d_N below 1.7, the difference between both measures of the gains from trade is smaller than the ones shown in the table. For values of d_N between 1.7 and 4, the differences between GT_N^{asy} and GT_N^{sym} are never larger than one percent.

[40]For different values for d_N, d_{N_1}, and d_{N_2}, the differences between GT_N^{asy} and GT_N^{sym} are never larger than one percent.