Growth, Size, and Openness: A Quantitative Approach

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It seems reasonable to argue that countries enjoy substantial gains from their interactions with the rest of the world. These *gains from openness* take place through several different channels. In this paper we focus on trade, multinational production (MP), and the diffusion of ideas. Our aim is to get some sense about the magnitude of these gains. Quantifying the gains from diffusion represents a significant challenge because, in contrast to the case for trade and MP, it is quite difficult to measure diffusion in the data. Here we pursue an indirect approach based on a simple application of the semi-endogenous growth (SEG) model developed by Charles I. Jones (1995), Samuel S. Kortum (1997), and in particular by Jonathan Eaton and Samuel S. Kortum (2001).

Semi-endogenous growth theory postulates that growth is possible in the long run thanks to the ever expanding set of non-rival ideas associated with a growing population. The central equation in this theory is that the steady state growth rate of labor productivity is proportional to the growth rate of population, $g = \varepsilon g_L$. The cross-section implication of this dynamic relationship is that, if countries were in isolation, large countries would be more productive than small countries. In this paper we perform a simple calibration of the critical parameter ε using the SEG model and then explore the associated cross-country implications.

The figure below shows the labor productivity levels implied by the calibrated SEG model and the real output per worker in the data against a model-consistent measure of country size. The figure reveals that the pattern of real income in the data is much flatter than the one implied by the SEG model. For example, a small country like Belgium (highlighted in the figure), whose size relative to the U.S. is 2.2%, is much richer (90% of the U.S. level) than what it would be under isolation according to the calibrated SEG model (45% of the U.S. level). The figure also reveals that there are several small and rich countries that exhibit this same gap between their observed and implied income. We refer to this phenomenon as

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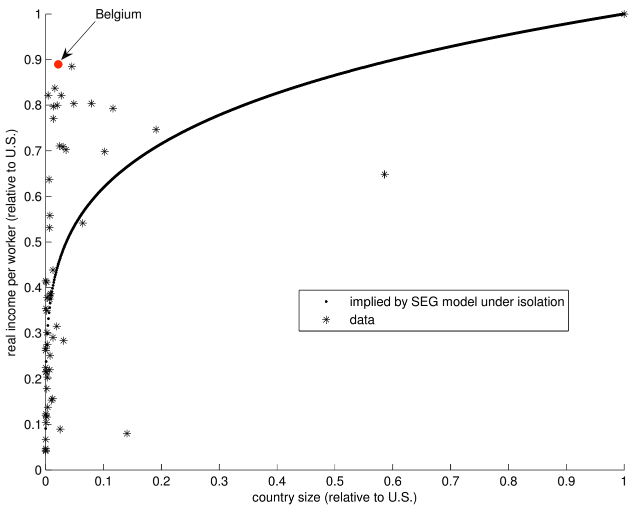
the "Belgium Puzzle". The question is the following: given the strong aggregate economies of scale implied by the SEG model, why are some small countries so rich?



An obvious possible resolution of this puzzle is that countries are not isolated. In fact, when proponents of SEG models are confronted with the fact that their model generates a counter-factually strong relationship between size and productivity, the common response is that small countries are not as poor as implied by the model because they benefit from openness. One first question is whether trade and MP are enough to bridge the gap between the implications of the SEG model and the data -are the gains from trade and MP large enough to explain the "Belgium puzzle"? The empirical exercise we carry out in this paper suggests a negative answer. To resolve the puzzle we add a third channel through which countries potentially interact: the direct diffusion of ideas. In other words, we argue that diffusion is necessary to make the SEG model consistent with the data.

The quantitative exercise in this paper is based on previous research in Natalia Ramondo and Andrés Rodríguez-Clare (2009), and Costas Arkolakis, Ramondo, and Rodríguez-Clare (2009). In Ramondo and Rodríguez-Clare (2009) we extended Eaton and Kortum's (2002) model of trade to incorporate MP and investigated how various sources of complementarity and substitutability between trade and MP affected the gains from trade and MP. Here we consider a special case of that model in which these sources of complementarity and substitutability are absent but extend the model to incorporate international diffusion of ideas.

I Trade, Multinational Production, and Diffusion

A Basic Assumptions

The model is an extension of Eaton and Kortum (2002) and Fernando Alvarez and Robert E. Lucas (2007) to incorporate MP (as in Ramondo and Rodríguez-Clare, 2009) and diffusion of ideas. Consider a set of countries $i \in \{1, ..., I\}$. The representative agent has CES preferences over a continuum of final goods $u \in [0,1]$. There is also a continuum of intermediate goods $v \in [0,1]$ that are aggregated into a CES composite intermediate good. This composite intermediate good and labor are used to produce final goods via a Cobb-Douglas technology with labor share α. In turn, each intermediate good is produced via a Cobb-Douglas technology from the composite intermediate good and labor, with labor share β. We denote the price index of final and intermediate goods in country i by P_{fi} and P_{gi}, respectively. Letting $c_{fi} \equiv w_i^{\alpha} P_{gi}^{1-\alpha}$ and $c_{gi} \equiv w_i^{\beta} P_{gi}^{1-\beta}$, the unit cost of final good u produced in country i is $c_{fi}/z_f(u)$ while the unit cost of intermediate good v produced in country i is $c_{gi}/z_g(v)$. The terms $z_f(u)$ and $z_g(v)$ are productivity parameters described next.

Each country i has a *national technology* to produce each final and each intermediate good. A national technology can be used to produce the good at home or in each foreign country with varying productivity levels determined by the vectors of productivity parameters $\mathbf{z_{fi}^N(u)} \equiv (z_{f1i}^N(u), ..., z_{fIi}^N(u))$ and $\mathbf{z_{gi}^N(v)} \equiv (z_{g1i}^N(v), ..., z_{gIi}^N(v))$. When a national technology from country i is used to produce in another country $l \neq i$, we say that there is multinational production or MP by country i in country l. The corresponding productivity parameter in this case is $z_{fli}^N(u)$ or $z_{gli}^N(v)$. Each country i also has a *diffused technology* for each final and each intermediate good. These technologies are described by vectors of productivity parameters $\mathbf{z_{fi}^D(u)} \equiv (z_{f1i}^D(u), ..., z_{fIi}^D(u))$ and $\mathbf{z_{gi}^D(v)} \equiv (z_{g1i}^D(v), ..., z_{gIi}^D(v))$. In contrast to national technologies, diffused technologies can be used anywhere without the need for this to take place as part of MP -that is, a diffused technology originated in country i can be used for "domestic" production in country $l \neq i$. This distinction between national and diffused technologies is irrelevant for the equilibrium analysis but matters for the way in which we think of the data. In particular, whereas the use of national technologies abroad generates MP flows as recorded in the data, the use of diffused technologies abroad does not generate any observable flow.

Intermediate goods are tradable but final goods are not. Trade is subject to iceberg-type costs: $d_{nl} \geq 1$ units of any good must be shipped from country l for one unit to arrive in country n. We assume that $d_{nn} = 1$ for all n and the triangle inequality holds: $d_{nl} \leq d_{nj} d_{jl}$ for all n, l, j. Similarly, MP incurs an iceberg-type efficiency loss of $h^N_{li} \geq 1$ associated with using an idea from i to produce in l, with $h^N_{ii} = 1$ for all i. Thus, production of final good u in country l with a national technology from country i entails unit cost $c_{fl} h^N_{li} / z_{fli}(u)$ (analogously for intermediate good v, $c_{gl} h^N_{li} / z_{gli}(v)$). The use of diffused ideas in countries different from where they originate also entails efficiency losses, captured by h^D_{li} with $h^D_{ii} = 1$ for all i.

Finally, we assume that the productivity vectors $\mathbf{z^M_{fi}(u)}$, $\mathbf{z^M_{gi}(v)}$ for $u, v \in [0, 1]$, $i = 1, ..., I$ and $M = N, D$ are random variables drawn independently across goods and countries from a multivariate Fréchet distribution with zero correlation across draws, $F_i(\mathbf{z}^M_{si}) = \exp\left(-\sum_l T^M_i \left(z^M_{sli}\right)^{-\theta}\right)$, where $s = f, g$.

B Equilibrium analysis

Since final goods are identical except for their productivity parameters, following Alvarez and Lucas (2007), we drop the index u and label final goods by $\mathbf{Z_f} \equiv (\mathbf{z^N_{f1}}, \mathbf{z^D_{f1}}, ..., \mathbf{z^N_{fI}}, \mathbf{z^D_{fI}})$. We proceed analogously for intermediate goods. In a competitive equilibrium the price of final good $\mathbf{Z_f}$ in country n is simply the minimum unit cost at which this good can be obtained, $p_{fn}(\mathbf{Z_f}) = \min_{i,M} c_{fn} h^M_{ni} / z^M_{fni}$, while the price of intermediate good $\mathbf{Z_g}$ in country n is $p_{gn}(\mathbf{Z_g}) = \min_{i,l,M} c_{gl} d_{nl} h^M_{li} / z^M_{gli}$. As in Ramondo and Rodríguez-Clare (2009), we can show that in equilibrium: (a) The shares of expenditure by country n on final and intermediate goods produced with country i national and diffused technologies are, respectively, $\phi^M_{sni} = \Phi^M_{sni} / \Phi_{sn}$, where $M = N, D$ and $s = f, g$, and $\Phi^M_{fni} \equiv T^M_i \left(c_{fn} h^M_{ni}\right)^{-\theta}$, $\Phi^M_{gni} \equiv \sum_l T^M_i \left(c_{gl} d_{nl} h^M_{li}\right)^{-\theta}$, $\Phi_{sn} \equiv \sum_i \Phi^N_{sni} + \sum_i \Phi^D_{sni}$; and (b) Of the total expenditure by country n on intermediate goods produced with country i technologies, the share spent on goods produced in country l is $\pi^M_{gni,l} = T^M_i \left(c_{gl} d_{nl} h^M_{li}\right)^{-\theta} / \Phi^M_{gni}$. The price index in country n for final and intermediate goods are given by $P_{sn} = \gamma_s \Phi^{-1/\theta}_{sn}$ for some constant γ_s. As in Alvarez and Lucas (2007), these I price equations implicitly determine P_{gn} and P_{fn} as a function of $\mathbf{w} = (w_1, ..., w_I)$. Total expenditures on final goods by country n are equal to the country's total income, $w_n L_n$. We refer to the total value of final goods produced in n with country i technologies as the value of MP in final goods by i in n, denoted by Y_{fni}. The results above imply that $Y_{fni} = \phi^M_{fni} w_n L_n$. Moreover, since total expenditure on intermediates by country n is $\eta w_n L_n$, where $\eta \equiv (1-\alpha)/\beta$, the value of MP in intermediates by country i in l to serve n is $\phi^M_{gni} \pi^M_{gni,l} \eta w_n L_n$. Thus, $Y_{gli} = \sum_n \phi^M_{gni} \pi^M_{gni,l} \eta w_n L_n$. Total imports by country n from l are given by the sum of intermediate goods produced in country l with technologies from any other country, $X_{nl} = \eta \sum_i \left[\phi^N_{gni} \pi^N_{gni,l} + \phi^D_{gni} \pi^D_{gni,l} \right] w_n L_n$. For country n, trade balance entails the equality between aggregate imports ($\sum_{l \neq n} X_{nl}$) and aggregate exports ($\sum_{l \neq n} X_{ln}$). These conditions constitute a system of I equations in $\mathbf{w}$, and with some normalization of wages, yields the equilibrium wage vector $\mathbf{w}$.

C Gains

We think of the gains from openness for country n (GO_n) as the percentage change in the real wage $y_n \equiv w_n / P_{fn}$ as country n moves from isolation to the actual equilibrium, $GO_n = y_n / y_n^{ISOL}$. Isolation entails no trade (i.e., $d_{ni} \to \infty$, for all $i \neq n$), no MP (i.e., $h^N_{ni} \to \infty$, for all $i \neq n$), and no diffusion of ideas (i.e., $h^D_{ni} \to \infty$, for $i \neq n$). It is easy to show that the real wage in this case is

$$y_n^{ISOL} = \widetilde{\gamma} T_n^{\frac{1+\eta}{\theta}}, \tag{1}$$

where $\widetilde{\gamma}$ is a positive constant and $T_n \equiv T^N_n + T^D_n$ can be seen as the total stock of ideas in country n (see Eaton and Kortum, 2001). It is natural to assume that T_n is proportional to the size of the economy (see below), hence this expression shows that the model features aggregate economies of scale: larger economies sustain higher real wages with an elasticity given by $(1+\eta)/\theta$. The gains from openness can be expressed as the product of two terms: (1) a term GD_n defined as the increase in the real wage in country n as it moves from isolation to an equilibrium with no trade and no MP (i.e., $d_{ni}, h^N_{ni} \to \infty$, for all $i \neq n$) and (2) the gains from trade and MP, $GTMP_n$, defined as the increase in the real wage in country n as it moves from a situation with no trade and no MP to the actual equilibrium. That is,

$GO_n = GTMP_n \cdot GD_n$. Moreover, it is easy to show that

(2) $$GD_n = \left(1 + \frac{\sum_{i \neq n} T_i^D (h_n^D)^{-\theta}}{T_n^N + T_n^D}\right)^{(1+\eta)/\theta}$$

whereas

(3) $$GTMP_n = \left(1 - \frac{\sum_{i \neq n} X_{ni}}{Y_{gn}}\right)^{-\eta/\theta} \cdot \left(1 - \frac{\sum_{i \neq n} Y_{gni}}{Y_{gn}}\right)^{-\eta/\theta} \cdot \left(1 - \frac{\sum_{i \neq n} Y_{fni}}{Y_{fn}}\right)^{-1/\theta}.$$

where $Y_{gn} = \sum_i Y_{gni}$ is the total value of production of (or total expenditures on) intermediates in country n and $Y_{fn} = \sum_i Y_{fni} = w_n L_n$ is country $n's$ GDP.

II Quantitative Exercise

A Calibration

Identifying diffusion in the data requires to calculate the gains from trade and MP in equation (3), and labor productivity under isolation equation (1). To proceed, 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 $\eta \equiv (1-\alpha)/\beta = 0.5$. To calibrate θ we exploit the dynamic implications of the static model presented above (see Ramondo and Rodríguez-Clare, 2009, for details). In particular, the static model is fully consistent with a dynamic model where the productivity evolves according to an exogenous "research" process whereby the arrival of ideas is proportional to the workforce. Growth rates in the steady state are the same for all countries, and not affected by openness. This implies that the growth rate for the open economy is the same as the one for the closed economy. Differentiating (1) with respect to time yields the common steady state growth rate,

(4) $$g = \left[\frac{1+\eta}{\theta}\right] g_T,$$

where g_T is the common growth rate of all T's. Assuming that the arrival of ideas is proportional to the workforce, in the long run g_T is equal to the growth rate of labor, g_L, which we assume common across countries and equal to the growth rate of research employment, calculated as 0.048 by Jones (2002). Using (4), $\eta = 0.5$, $g_T = 0.048$ and setting $g = 0.01$ (also from Jones, 2002), then $\theta = 7.2$. The implied efficiency-size elasticity is then $(1+\eta)/\theta = 0.21$. Controlling for the effects of trade, institutions, and geography, Francisco Alcala and Antonio Ciccone (2004) find an efficiency-size elasticity ranging from 1/6 to 1/4.5, values that encompass ours.

In this SEG model, the total stock of ideas T_i is proportional to population, L_i, with the ratio T_i/L_i possibly varying across countries. For L_i we use a measure of equipped-labor from Peter J. Klenow and Andrés Rodríguez-Clare (2005) that controls both for physical and human capital. The ratio T_i/L_i is assumed to vary directly with the share of R&D employment observed in the data.[1] Our model-consistent measure of country size in Figure is precisely T_n. Finally, for some of the results below, we need to distinguish between T_n^N and T_n^D. We assume that $T_n^D/T_n^N = \kappa$ for all n.[2]

We use data on manufacturing trade flows from country i to country n as the empirical counterpart for trade in intermediates in the model, X_{ni}, and data on the gross value of production for multinational affiliates from i in n as the empirical counterpart of bilateral MP flows in the model.[3] Our analysis includes fifty eight developed and developing countries.

B Results

Using our calibrated model, we compare labor productivity in the data and the one implied by the SEG model under isolation in equation (1), for each country n. We attribute the gap between these two magnitudes to the gains arising from trade, MP, and potentially, diffusion. Since we have no direct empirical counterpart for diffusion, we compute such gains as a "residual" in the following way.

Assume that $h_{ni}^D = h_n^D$, for all $i \neq n$. To recover the gains from diffusion for each country, we first calibrate $\kappa(h_{ni}^D)^{-\theta}$ for the United States. Eaton and Kortum (1999) calculated that

[1]Source: World Development Indicators, average over the nineties.

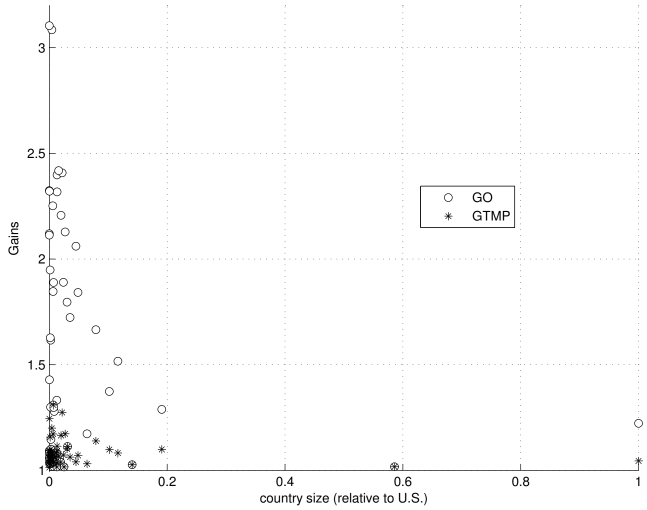
[2]Assume that ideas are born as national and then diffuse at a rate ι so that $\dot{T}_i^D = \iota T_i^N$. In steady state, $\dot{T}_i^D/T_i^D = \dot{T}_i^N/T_i^N = g_L$, so that $T_i^D/T_i^N = \iota/g_L \equiv \kappa$.

[3]We thank Mike Waugh for facilitating these data (see Waugh, 2009). MP data are from UNCTAD, an average over 1990-2002. The share of MP in final goods relative to all MP is available for the United States from the Bureau of Economic Analysis (BEA), an average over 1990-2002. We assume that this share applies to the remaining countries so that we can disentangle Y_{fn} and Y_{gn}.

on average 95% of potentially useful domestic ideas are eventually adopted, against 60% for foreign ideas. In our model, this implies $\kappa(h_{US}^{D})^{-\theta} = 0.60/0.95 = 0.63$. We then calibrate $\kappa\left(h_n^D\right)^{-\theta}$ for each country to match the implied labor productivity under isolation according to the SEG model. This entails first to adjust the income observed in the data by GTMP (calculated using equation 3), and compare it with the income implied by the SEG model under isolation. We ask: is this adjustment enough to resolve the "Belgium puzzle"? If the answer is negative, we interpret the residual as the gains from diffusion for country n.

Our procedure shows that there are two different sets of countries. First, there is a set of small and rich countries for which $\kappa\left(h_n^D\right)^{-\theta}$ is high, implying that GO are significantly larger than GTMP, or equivalently, the gains from diffusion are large. Second, there is a set of poor countries for which this procedure is not able to close the gap -the model cannot explain why these countries are so poor. For these countries, the implied $\kappa\left(h_n^D\right)^{-\theta}$ is infinity, implying zero gains from diffusion and $GO_n = GTMP_n$.

The figure below shows GO and $GTMP$ for each country in the sample. The average implied gains from openness are large in comparison to the average gains from trade and MP: 55% against 8%. Thus, diffusion generates average gains of 43%. These gains are particularly large for the set of small and developed countries where the "Belgium puzzle" is pronounced. Conversely, in twenty out of fifty eight countries in our sample, the gains from diffusion are zero. Our exercise suggests that the gains from openness among these countries are only 7% on average.



It is instructive to contrast the case of Belgium with that of China. A small and rich country like Belgium is 90% as productive as the U.S., while the SEG model implies that under isolation Belgium's relative labor productivity would be only 0.45. Since the gap between these two magnitudes is 2 and $GTMP_{BEL}/GTMP_{US} = 1.22$, the residual left to be explained by diffusion is $2/1.22 = 1.61$. This implies that trade and MP are not enough to bridge the income gap. Since our calibrated model (with $\kappa(h_{US}^D)^{-\theta} = 0.63$) implies $GD_{US} = 1.17$, the implication is that the gains from diffusion for Belgium are $GD_{BEL} = 1.61 \cdot 1.17 = 1.90$, or 90%, which is quite high compared to Belgium's gains from trade and MP, which are 27%. Turning to the case of China, this country is much poorer than implied by its size: 8% against to 66% (relative to the U.S.). With $GTMP_{CHN}/GTMP_{US} = 0.98$, and $GD_{US} = 1.17$, our calculations imply zero gains from diffusion for China. Even with infinite costs of using foreign technologies ($\kappa(h_{CHN}^D)^{-\theta} \to \infty$), the model is unable to bridge the gap between the SEG model's prediction and the data.

Data and results for each country are shown in the supplemental material posted in the *AER* Web site.

III Conclusion

The gains from openness for a country arise from many possible channels. We focus on trade, multinational production (MP), and the direct diffusion of ideas. We show that to reconcile key facts about trade, MP, growth, and size, we need to include international diffusion of ideas. This conclusion hinges on the finding that small developed countries tend to be significantly much richer than implied by their small size (what we termed the "Belgium Puzzle"), and that the gains from trade and MP are not large enough to explain this phenomenon. Moreover, the gains from diffusion are large compared to the gains from trade and MP. At the same time, we have found that there are several developing countries which are significantly poorer than what they should be given their size and their exposure to trade and MP. The model implies that these countries not benefiting from the use of foreign technologies except through MP -there is no direct adoption of foreign ideas. In broader terms, our main conclusion is that the direct diffusion of ideas is quantitatively more important than trade and MP in accounting for the gains from openness. Our approach here has been to quantify the importance of diffusion through an indirect approach. Clearly much more attention should be devoted to understand where these gains come from and which are the main barriers that countries face to access and absorb foreign ideas.

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