

Federal Reserve Bank of Minneapolis
Research Department Staff Report 396

Revised July 2008

Openness, Technology Capital, and Development*

Ellen R. McGrattan

Federal Reserve Bank of Minneapolis
and University of Minnesota

Edward C. Prescott

Arizona State University
and Federal Reserve Bank of Minneapolis

ABSTRACT

In this paper, we extend the growth model to include firm-specific technology capital and use it to assess the gains from opening to foreign direct investment. A firm's technology capital is its unique know-how from investing in research and development, brands, and organization capital. Technology capital is distinguished from other forms of capital in that a firm can use it simultaneously in multiple domestic and foreign locations. A country can exploit foreign technology capital by permitting direct investment by foreign multinationals. In both steady-state and transitional analyses, the extended growth model predicts large gains to being open.

*Corresponding author: Ellen McGrattan, Research Department, Federal Reserve Bank of Minneapolis, 90 Hennepin Avenue, Minneapolis, MN 55401-2171, USA, erm@ellen.mpls.frb.fed.us, 612-204-5523, fax 612-204-5515. We thank the National Science Foundation for financial support for this research (grant SES-0422539) and Loris Rubini, Johanna Wallenius, and particularly Simona Cociuba for exceptional research assistance. This paper was presented at the April 2007 conference at the University of Chicago honoring the contributions of Robert E. Lucas, Jr. Discussions by Bob Lucas and Paul Romer were extremely helpful for us in revising an earlier draft of this paper. The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.

1. Introduction

Economists generally agree that being open has large economic benefits. This view is based mostly on empirical evidence [9, 13] because existing economic theory provides little support for large benefits. Here we develop a theoretical framework and use it to conclude that openness to foreign direct investment (FDI) by multinationals yields large gains in productivity. The theoretical framework is an extension of the standard growth model that has proven so useful in macroeconomics.

The extension has two key features: firm-specific technology capital and locations. A firm's technology capital is its unique know-how, accumulated from investing in such things as research and development (R&D), organization capital, and brands. Technology capital is distinguished from other types of capital in that a firm can use it simultaneously in multiple domestic and foreign locations.¹ A firm with technology capital realizes rents at every location in which it operates because its location technology production sets display decreasing returns to scale beyond some point. Permitting FDI is the mechanism by which foreign technology capital is exploited in a given country. Opening to FDI benefits both the country that opens up and the countries that make the foreign direct investment.

We derive the aggregate production function and find that it displays constant returns to scale, as does the aggregate production function for the standard growth model. Consequently, price taking is assumed. We show that even though there is a constant returns to scale technology, there are increasing returns with respect to the size of a country as measured by the number of its locations, but there are no increasing returns with respect to the factor inputs: technology capital, plant-specific capital, and services of labor.²

We quantify our model with standard parameter values and use it to predict steady

¹In the language of classical general equilibrium theory, a unit of technology capital is a set of technologies, with one technology for each location.

²In [11], to address current account issues, we find it necessary to introduce two varieties of plant-specific capital, namely, tangible and production-unit specific intangible capital. Differences in tax treatments and reporting necessitated this distinction. For the issues addressed in this paper, however, we need not and do not make the distinction between plant-specific tangible and intangible capital. The extension is straightforward, but complicates the notation. All that needs to be done is to introduce an aggregator at the production-unit level.

states and transition paths as countries move from being closed to being open. We find that overall, the model predicts what the empirical evidence has suggested: large gains to openness. More specifically, we find large increases in productivity when similar countries form an economic union that requires openness between members. We also find that unilateral opening is mutually beneficial, with most of the benefits going to the country that opens and allows foreign multinationals to produce within its borders. When countries are open, the world stock of technology capital, not its distribution across countries is what matters.

Our abstraction focuses on the role of openness to FDI in making possible the use of foreign production know-how in other countries. Also associated with economic integration are the almost certain gains to total factor productivity (TFP), which amplify the direct gains from openness. We thus do some additional analysis that assumes the TFP of a country that becomes open increases over time and eventually reaches the TFP level of the already open countries. Our results strongly suggest that these indirect benefits of opening are as quantitatively important as the direct benefits.

Ramondo [12] and Burstein and Monge-Naranjo [3] are two related papers that consider the gains of countries becoming more open. Ramondo modifies the static trade model of Eaton and Kortum [5] by assuming that country-level productivities, rather than goods, are mobile. In Ramondo, countries become more open as they lower the fixed costs of establishing a foreign plant, which in turn leads to more multinational production and higher real incomes. Burstein and Monge-Naranjo modify the standard growth model by modeling the firm as a manager that employs capital and labor as in Lucas [8]. Countries become more open as they lower tax rates on managerial earnings, which leads to a reallocation of managers. Neither Ramondo nor Burstein and Monge-Naranjo include a factor like technology capital that is both accumulated know-how and used in multiple locations.

Our paper is organized as follows. In Section 2 we present empirical evidence that becoming open to FDI and becoming economically integrated with advanced industrial economies leads to the previously closed country catching up to already open countries in terms of economic development. In Section 3 we present theoretical support for the em-

pirical evidence that a strong, positive association exists between economic integration and productivity gains. We start by developing an aggregation theory underlying our aggregate production function. We then develop formulas for the steady state and for the transition paths, and use these formulas to assess the importance of openness for productivity and consumption. Section 4 concludes.

2. Empirical evidence

Empirical evidence clearly suggests that, in general, becoming economically integrated with other countries leads to improvements in the economic development of countries previously closed. Our measure of development is gross domestic product (GDP) per hours worked, which is what we mean by the term *productivity*. We examine what has happened to productivity in various countries over time as they have become more economically integrated. Some of the countries we study have joined economic unions of countries, while others have opened their economies in less formal ways. We compare the productivities of countries that are opening to those of others that were already relatively open during the same time periods. In all the newly opened countries, we see that economic integration appears to have boosted productivity. We also see that relatively closed countries have low or even falling productivity.

2.1. Europe

Here we review the empirical evidence that membership in the European Union (EU), a relatively open set of countries, results in a country catching up to the industrial leader.

In 1957, six countries—Belgium, France, Italy, Luxembourg, the Netherlands, and West Germany—signed the Treaty of Rome to form what became the European Union. We will call this group the EU-6. Figure 1 plots our GDP per hour measure of productivity for 1900–2005 for these six countries compared to that of the United States during the same time period. Over the 30 years following the signing of the treaty, the productivity of these countries rose nearly to the U.S. level. After 40 years, it surpassed that level.

Figure 1: EU-6 LABOR PRODUCTIVITY AS A PERCENTAGE OF US (1900–2005)

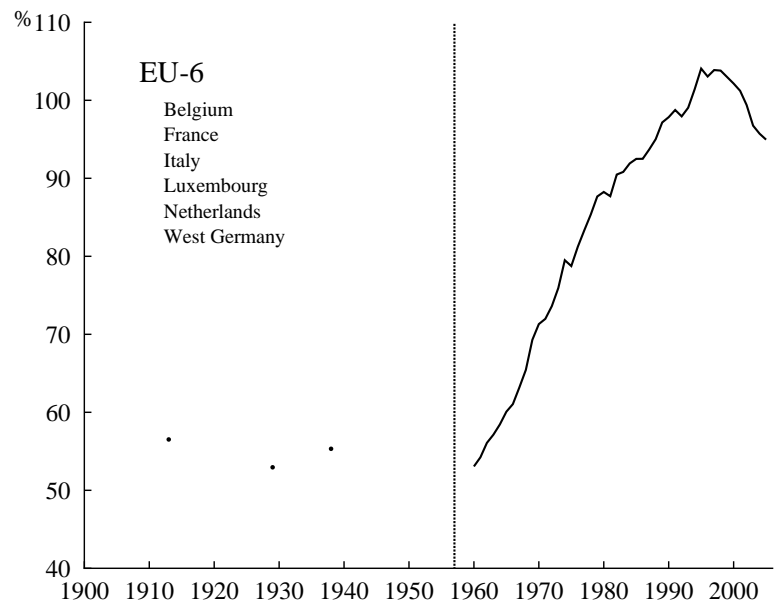


Figure 2: 1973 JOINERS' LABOR PRODUCTIVITY AS A PERCENTAGE OF EU-6 (1960–2005)

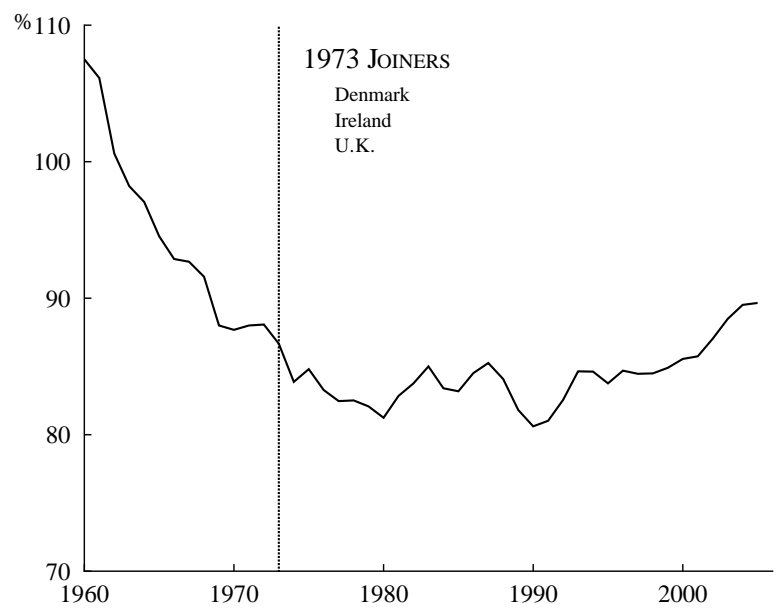


Figure 3: 1995 JOINERS' LABOR PRODUCTIVITY AS A PERCENTAGE OF EU-6 (1960-2005)

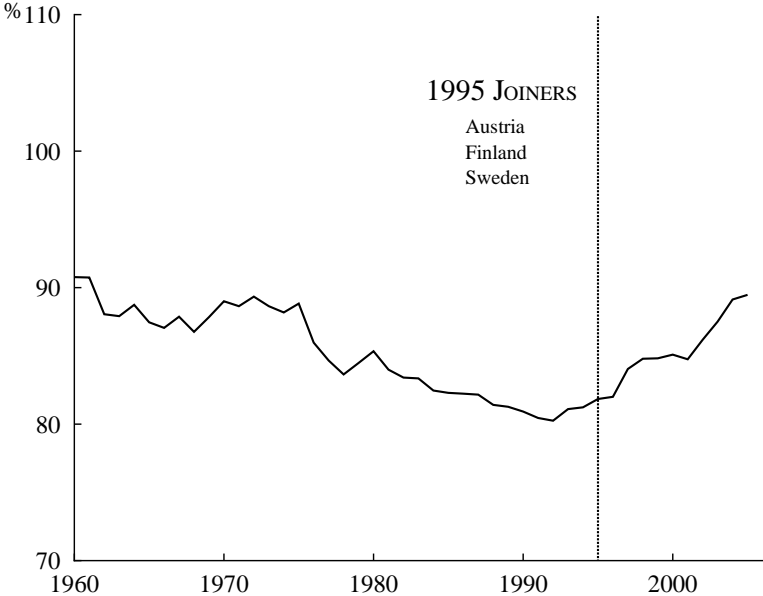
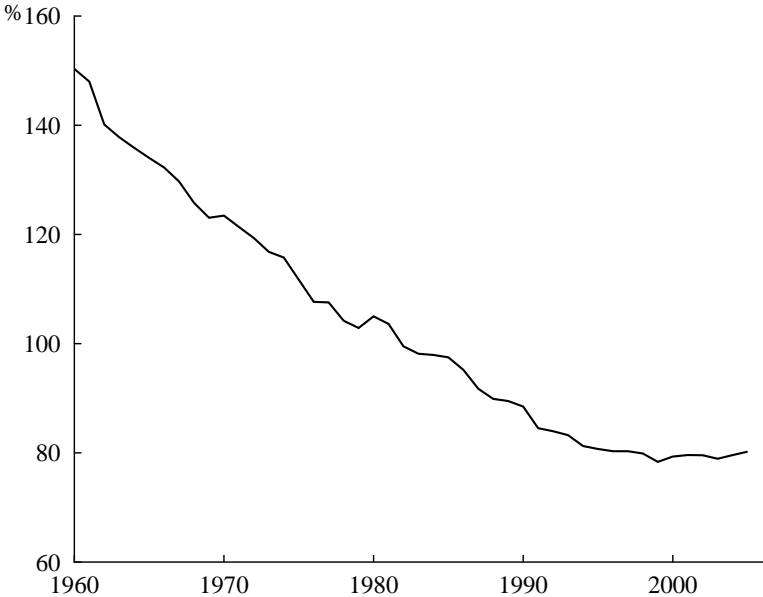


Figure 4: SWITZERLAND'S LABOR PRODUCTIVITY AS A PERCENTAGE OF EU-6 (1960-2005)



The EU has expanded several times since 1957, so we can review the productivity of the joining countries in each expansion to see if they, too, seem to have gained from the experience. Figure 2 plots the aggregate productivity of the three countries that joined the EU in 1973—Denmark, Ireland, and the United Kingdom—relative to the productivity of the original EU-6. The 1973 group is dominated by the experience of the United Kingdom because its population is by far the largest among the three. Still, we can see in the figure that the relative productivity of the 1973 group fell dramatically just before the countries joined the EU. Just after joining, their relative productivity leveled off and then rose slightly.³

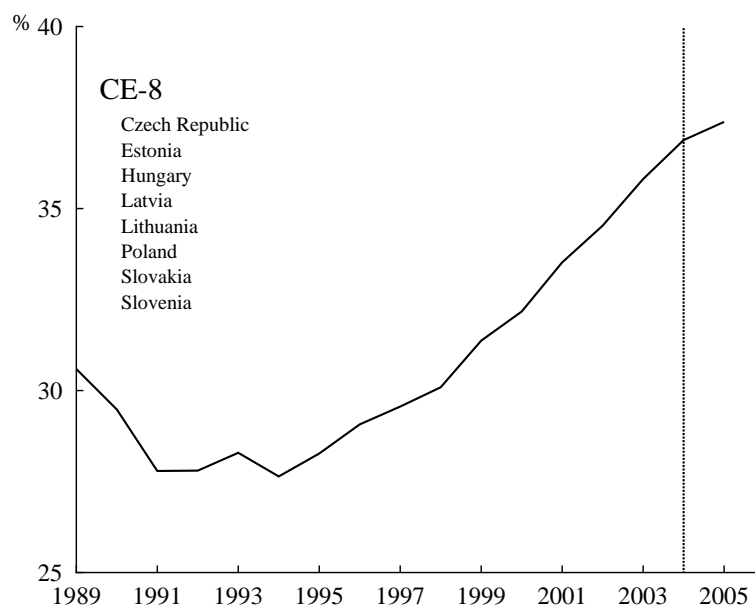
Another group of three countries—Austria, Finland, and Sweden—joined the EU in 1995. Figure 3 shows that collectively, the productivity of these countries relative to that of the EU-6 was also falling until the countries joined the EU; then it turned around and gained ground.

Switzerland serves as an example of what has happened to a Western European country that has not joined the EU. Figure 4 shows that its relative productivity, like that of the 1995 joiners, lost ground before 1995. Unlike the 1995 joiners, however, Switzerland's productivity lost ground after 1995 as well. Not opening its economy to a large group of industrialized European countries did not help Switzerland's productivity.

More recently, in 2004, eight Central European countries—the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia—joined the European Union. We will call this group the CE-8. Figure 5 plots their post-1989 performance, again compared to that of the original EU-6. The figure shows some impressive gains beginning around the time of the collapse of the Soviet Union and continuing as these countries moved toward EU membership. After joining the EU in 2004, they had further gains. The fact that EU membership fosters openness suggests that these 2004 EU joiners are on their way to productivity closer to that of the rest of the EU.

³Bourlès and Cette [2] make a human capital adjustment for France and estimate that French 2002 productivity is actually 8 percent lower than U.S. productivity, and not 7 percent higher, when corrections are made for workforce composition. This suggests that the productivities of the 1973 joiners relative to the EU-6 since 1985 could well be 5 to 10 percent higher than the plotted values in Figure 2.

Figure 5: CE-8 LABOR PRODUCTIVITY AS A PERCENTAGE OF EU-6 (1989–2005)



2.2. Other regions

A region of the world that has been relatively closed in the last half of the 20th century is South America [4]. Figure 6 shows the aggregate productivity of nine countries relative to the United States. The nine included are Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Peru, Uruguay, and Venezuela. As Figure 6 shows, during the years between 1960 and 2005, the productivity of these relatively closed countries shrank from 36 percent of the U.S. level to only 26 percent.

Asia, in contrast, has done much better. Economic openness has increased lately in 12 Asian countries, including China, Hong Kong, India, Indonesia, Japan, Malaysia, Pakistan, the Philippines, Singapore, South Korea, Taiwan, and Thailand. Figure 7 shows that as these countries have become more economically integrated with advanced industrialized countries, their productivity has benefited. It is still low compared to that of the United States, but unlike that of the relatively closed South American countries, the gap is narrowing fast. Between 1960 and 2005, it increased from 8.4 percent to 17 percent of U.S. productivity.

Figure 6: SOUTH AMERICAN LABOR PRODUCTIVITY AS A PERCENTAGE OF US (1960–2005)

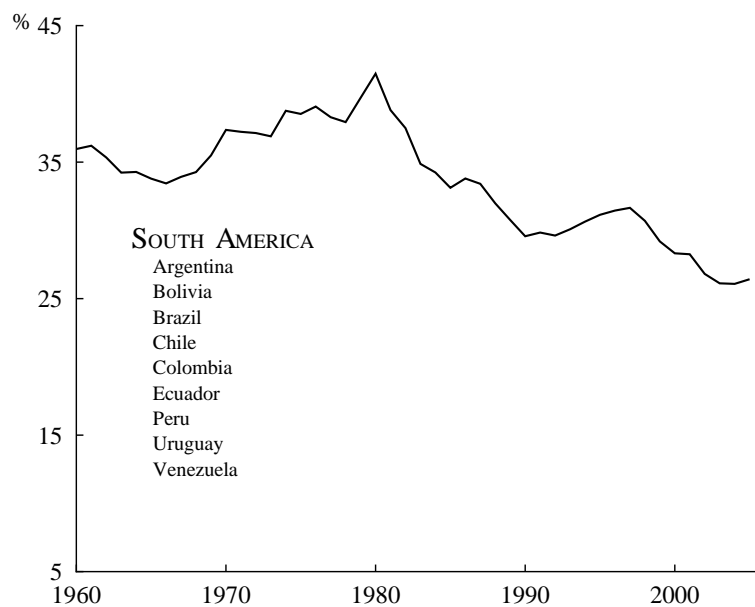
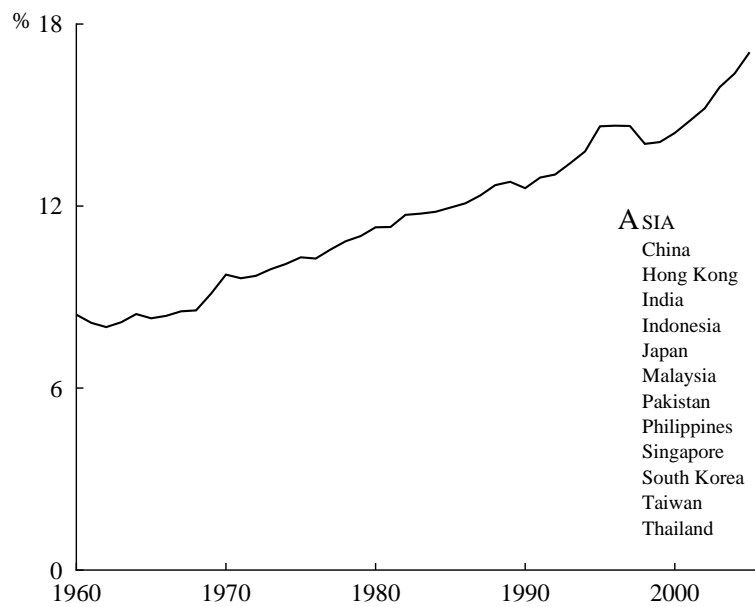


Figure 7: ASIAN LABOR PRODUCTIVITY AS A PERCENTAGE OF US (1960–2005)



To summarize the empirical evidence, we see a strong positive association between economic integration of countries and gains in their productivity.

3. Theoretical evidence

We now provide theoretical support for a strong positive association between economic integration and productivity gains, in the case in which opening up leads to increased foreign direct investment. We do this by extending the growth model to include technology capital and work out the implication of that extension for the aggregate production of a country and the model's equilibrium under various degrees of openness. We quantify the steady-state gains as well as the gains during the transition of an economy as it adjusts from being closed to being open. By way of a set of empirically relevant examples, we demonstrate that the gains to opening to FDI are large.

3.1. The model extension

In this section, we extend the growth model to include technology capital. We start with assumptions on the production technology and then derive the aggregate production function of a country that is partially open. The final step is laying out the rest of the model.

Production Technology

The model that we develop retains the standard inputs to production. They are plant-specific capital k_i and labor l_i of country i , which can be combined into a composite input:

$$z_i = k_i^\alpha l_i^{1-\alpha}, \quad \alpha \in (0, 1).$$

One unit of domestic technology capital and z_i units of the composite input at a given domestic location produce

$$y_i = A_i z_i^{1-\phi}, \quad \phi \in (0, 1) \tag{1}$$

units of country i final output. Here, A_i is the country-specific TFP parameter.

Note that the owner of a unit of technology capital “owns” the location production function specified by (1) for *every* domestic location. A given unit of the composite input z_i can be used at one and only one location in country i .

Technology capital can also be used to set up operations in a foreign location. Foreign multinationals hire capital and labor services within country i and use their own technology capital. In this case, one unit of $j \neq i$ technology capital operated at a location in country i produces

$$y_i = \sigma_i A_i (k_i^\alpha l_i^{1-\alpha})^{1-\phi}, \quad \sigma_i \in [0, 1]$$

units of country i final output. Here, σ_i is the measure of openness of country i . We assume that the degree of openness of a country affects the relative productivity of foreign operations within its borders. If $\sigma_i = 1$, then country i is totally *open* to the use of foreign technology capital within its borders. If $\sigma_i = 0$, then country i is totally *closed* to that use.

Aggregate production function

We now derive the maximal output that can be produced in a country i , $i \in \{1, \dots, I\}$, with technology level A_i , openness measure σ_i , and a population that we denote by N_i . As we show below, the maximal output can be expressed as a function of aggregate factor inputs, including the vector of technology capitals from the I countries in the world.

To derive this function, we need some notation for the measure of locations in a country and for the stock of its technology capital. We assume that the measure of a country’s production locations is proportional to its population, since locations correspond to markets and some measure of people defines a market. Without loss of generality, we set the proportionality factor relating the measure of locations and N_i to 1. Thus, N_i is used for both the population in i and the number of locations in i . A country i firm is a stock m_i of technology capital or know-how embodied within the firm. Country i has aggregate technology capital stock of M_i , which is the sum of the technology capital stocks

of all domestic firms in country i .

We are now ready to derive the maximal output for country i that can be produced given an aggregate quantity of the composite input, denoted Z_i , and the technology capital stocks $\{M_j\}_{j=1}^I$. It is the solution to

$$\begin{aligned} \max_{z_d, z_f} & \{M_i N_i A_i z_d^{1-\phi} + \sigma_i \sum_{j \neq i} M_j N_i A_i z_f^{1-\phi}\} \\ \text{subject to} & \quad M_i N_i z_d + \sum_{j \neq i} M_j N_i z_f \leq Z_i. \end{aligned} \quad (2)$$

The amount of the composite input used at each plant operated by a domestic firm is z_d , while the amount used at each plant operated by a foreign firm is z_f . The fact that the quantity z_d is the same at each domestic plant follows from the diminishing returns assumption in (1). For the same reason, z_f is the same at each foreign plant in country i . The first term in (2) is the total output of domestic firms operating in i , and the second term is the total output of foreign firms operating in i .

The resulting country i aggregate production function, after substituting for Z , is given by

$$F_i(M_1, \dots, M_I, K_i, L_i) = Y_i = A_i N_i^\phi \left(M_i + \omega_i \sum_{j \neq i} M_j \right)^\phi \left(K_i^\alpha L_i^{1-\alpha} \right)^{1-\phi}, \quad (3)$$

where K_i, L_i are aggregate plant-specific capital stocks and labor services in country i and $\omega_i = \sigma_i^{1/\phi}$. Here, we used $Z_i = K_i^\alpha L_i^{1-\alpha}$.

The parameter ω_i in (3) is an alternative measure of openness that can be interpreted as the fraction of country j foreign technology capital that is permitted to be used in country i for all $j \neq i$. A generalization of our framework has ω_{ij} be the fraction of country j technology capital that can be used in country i . This generalization is straightforward and is needed to deal with organizations such as the European Union.

The aggregate production functions F_i in (3) have two noteworthy features. First, the functions display constant returns to scale in the inputs $\{K_i, L_i, \{M_j\}_{j=1}^I\}$. Despite this fact,

the total output of a set of open economies (with $\omega_i > 0$) is greater than the total output of a set of closed economies. It is as if there were increasing returns, when in fact there are none. Second, if a country is totally open ($\omega_i = 1$), then the stock of technology capital used in this country is the world aggregate stock of technology capital ($\sum_j M_j$). Therefore, if we compare living standards of two totally open countries with different populations, we would find no economic advantage or disadvantage to being large.

Rest of the model

Before we can estimate the gains of openness, we must specify household preferences, asset ownership, and the global resource constraint.

Each country has a stand-in household with preferences ordered by

$$\sum_{t=0}^{\infty} \frac{1}{(1 + \rho)^t} u(c_t, l_t), \quad (4)$$

where c_t and l_t are per capita consumption and per capita leisure at time t , respectively. The utility function u is strictly increasing in both arguments and is strictly concave as well as continuously differentiable. When we deal with balanced growth, further restrictions will be imposed that are sufficient for the existence of a balanced growth equilibrium.

We assume that households in each country i collectively own K_i and M_i , and the current account is in balance each period. Rents on the capital stocks plus labor income are used to purchase consumption and investment goods.

The economy-wide resource constraint is

$$Y_i = C_i + X_{ik} + X_{im} + NX_i,$$

which states that a country i 's output Y_i equals consumption C_i plus investment in plant-specific capital X_{ik} plus investment in technology capital X_{im} plus net exports NX_i . The

laws of motion of the two capital stocks are the usual ones:

$$K_{i,t+1} = (1 - \delta_k)K_{it} + X_{ikt}$$

$$M_{i,t+1} = (1 - \delta_m)M_{it} + X_{imt},$$

where the depreciation rates δ_k , δ_m are positive and less than one.

Fixed parameters

To quantify the gains to opening to foreign direct investment, we need to parameterize the model. Here, we describe those parameter values that are used in both our steady-state analysis and our transitional analysis.

These parameter values are reported in Table I. The parameters were selected to match (i) a labor income share of 65 percent, (ii) a plant-specific capital to output ratio of 3, (iii) a real interest rate of 4 percent, and (iv) a technology capital to output ratio of 0.5 for a country that is totally closed.⁴

3.2. Steady-state analysis

Having specified the details of the model, we are now ready to use it to make steady-state predictions. We first prove the existence of a steady state and provide an algorithm for finding one. Because the elasticity of labor supply does not matter quantitatively for our steady-state comparisons, we will assume here that labor is supplied inelastically.

Existence of a steady state

The world steady-state interest rate is ρ given preferences (4). The rental price of K is therefore $\rho + \delta_k$. Equating the marginal product of K to its rental prices yields the first

⁴Originally, we chose $\phi = 0.06$ and $\delta_m = 0.08$. In [11], we found that a higher technology capital share ϕ was needed to match U.S. current account flows. The main results in [11] are not sensitive to the choice of the depreciation rate for technology capital, δ_m .

equilibrium condition

$$(\rho + \delta_k)K_i = (1 - \phi)\alpha Y_i. \quad (5)$$

A second equilibrium condition is $L_i = N_i$, since each person is assumed to have one unit of time and to supply it to the market.

An equilibrium relation that we use in subsequent analysis is the one obtained by substituting $L_i = N_i$ and equilibrium condition (5) into the production function (3):

$$Y_i = \psi \mathcal{A}_i N_i \left(M_i + \omega_i \sum_{j \neq i} M_j \right)^{\phi/(1-\alpha(1-\phi))}, \quad (6)$$

where $\mathcal{A}_i = A_i^{1/(1-\alpha(1-\phi))}$ and

$$\psi = \left(\frac{\alpha(1-\phi)}{\rho + \delta_k} \right)^{\alpha(1-\phi)/(1-\alpha(1-\phi))}.$$

We turn now to developing a set of equilibrium conditions that the technology capital stocks M_i must satisfy.

The *domestic return* on country i technology capital M_i is

$$\frac{\partial F_i}{\partial M_i} = \phi \psi N_i \left(M_i + \omega_i \sum_{j \neq i} M_j \right)^{\theta}, \quad (7)$$

where $\theta = (\alpha - 1)(1 - \phi)/(1 - \alpha(1 - \phi))$. This follows from differentiating country i production function (3) with respect to M_i , then using (5) and $L_i = N_i$ to eliminate K_i and L_i , and finally using (6) to eliminate the Y_i that comes in when K_i is eliminated.

The *foreign return* on country i technology capital in country $j \neq i$ is

$$\frac{\partial F_j}{\partial M_i} = \omega_j \phi N_j \psi \left(M_j + \omega_j \sum_{k \neq j} M_k \right)^{\theta}.$$

This is determined in essentially the same way as (7).

The total return on country i technology capital is

$$r_i(M) = \sum_j \frac{\partial F_j}{\partial M_i},$$

where $M = \{M_1, \dots, M_I\}$. Equilibrium conditions for M , which do not depend upon the other inputs, are

$$r_i(M) \leq \rho + \delta_m \tag{8}$$

with equality if $M_i > 0$.

PROPOSITION 1. *A non-zero steady state exists.*

Proof. We develop a function $f(M)$ whose fixed points are steady-state \hat{M} . We use the Kakutani fixed point theorem to establish existence of a fixed point.

We first define the functions $g_i(M_{-i})$ to be the solution to (8) given M_{-i} , which denotes the $I - 1$ dimensional vector of the M_j for $j \neq i$. The function $g_i(M_{-i})$ is decreasing, and therefore

$$g_i(M_{-i}) \leq g_i(0).$$

The convex compact set over which the mapping f is defined is

$$\Delta = \{M \in \mathbb{R}_+^I : M_i \leq g_i(0) \ \forall \ i\}.$$

The function $f: \Delta \rightarrow \Delta$ is defined as follows: function g_1 is used to compute $f_1(M) = g_1(M_{-1})$. The vector $(f_1(M), M_2, \dots, M_I)$ and g_2 are used to determine $f_2(M)$, and so forth. This I -stage updating defines the function f .

The function f is continuous and maps convex compact set Δ into itself. Therefore, it has a fixed point \hat{M} . This fixed point is not zero, for the following reason. If components

M_1 to M_{I-1} were all zero, then M_I would be strictly positive. Thus, a non-zero steady-state equilibrium exists. ■

Algorithm for finding a steady state

We now show how to construct a steady state.

Consider the system that we analyzed in the last section:

$$\rho + \delta_m = \sum_{j \in I} \frac{\partial F_j}{\partial M_i}, \quad i \in J \subseteq I$$

$$M_i = 0, \quad i \notin J.$$

Given J , this system can be solved uniquely for $M = \{M_i\}_{i \in I}$. This involves solving two systems of linear equations. The task here is to find J such that $M_i \geq 0$ for all i .

After initializing with $J = I$, the iterative procedure is as follows:

- *Step 1.* Solve the system and check if a steady-state vector with $M \geq 0$ has been found. If not, go to step 2.
- *Step 2.* Remove the i from the set J for which M_i is most negative. Go to step 1.

With this algorithm, because I is a finite set, a J will eventually be found with solution $M \geq 0$.

If the M vector obtained satisfies (8), then we have a steady state. For the examples considered below, the algorithm finds the unique steady-state M vector. These examples have special structures on the $\{\omega_i, \mathcal{A}_i N_i\}$ that ensure uniqueness.

Steady-state predictions

We now apply the algorithm in four empirically motivated examples. These examples show that there is an advantage to size even if countries are not open to FDI and there are large gains to countries that do open to FDI.

Example 1: Size Advantage If Countries Are Closed

The first example considers the advantage of size for a set of totally closed economies. This example is motivated by country comparisons prior to the rise of foreign direct investment.

Let $\omega_i = 0$ for all i . The per capita output is a function of size $\mathcal{A}N$; that is,

$$y \propto (\mathcal{A}N)^{\phi/[(1-\phi)(1-\alpha)]}.$$

According to the model, the quantitative implication of being ten times larger than other countries, as measured by $\mathcal{A}N$, is that steady-state output will be 23.4 percent larger. This implies large productivity gains for smaller countries forming a large economic union in which they are open with respect to each other.

Example 2: Large Gain to Small Countries Opening

The second example has two countries, a big country and a small country with common levels of openness. This example is motivated by Canada and the United States.

Here, we assess how productivity and consumption vary with openness for a two-country world. One country has a much larger population than the other. The two countries could be thought of as the United States with population N_1 and Canada with population N_2 . Since the U.S. population is almost ten times that of Canada, we set $N_1 = 10$ and $N_2 = 1$. The parameters that matter for this comparison are α and ϕ in the production function (3). We assume that only N_i differ. The openness measure is ω for both countries. We set $A_i = 1$ for $i = \{1, 2\}$, since this is just a normalization.

The equilibrium M_1 and M_2 can be found from equilibrium condition (8). If the solution to

$$\rho + \delta_m = r_i(M), \quad i = 1, 2$$

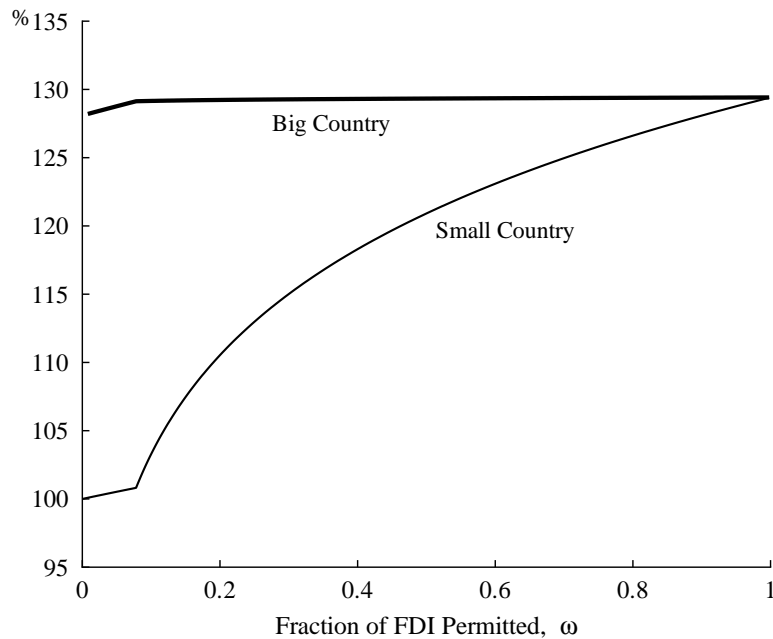
is non-negative, then this solution is the equilibrium M vector. Otherwise, $M_2 = 0$, and M_1

is the solution to

$$\rho + \delta_m = r_1(M_1, 0).$$

We turn now to a comparison of productivity in the two countries. Figure 8 plots the productivity of the two countries measured against the productivity of a totally closed small country. If $\omega = 0$, the countries are totally closed and the ratio of productivities for the two countries is the same as in Example 1. If $\omega = 1$, the countries are totally open and there is no advantage to size. By moving from totally closed to perfectly open, the big country's productivity rises only modestly, but the small country's productivity increases by 29.4 percent, which is sizable.

Figure 8: STEADY-STATE PRODUCTIVITIES AS A FUNCTION OF ω



As Figure 8 shows, there is a nonlinear relation between relative productivities and ω . Notice, for example, that there is a kink in the small country productivity at $\omega = 0.078$. For this and higher values of ω , the small country chooses optimally to invest only in plant-

specific capital, since it can use the big country's stock of technology capital. For large values of ω , the big country's stock is 0.55 times its own output and 0.5 times world output.

If we take into account the fact that most investment in technology capital is not counted in GDP, we find that the small country's *measured* productivity eventually surpasses that of the big country. Gross domestic product is output Y_i less any expensed investment. Investment in technology capital is, for the most part, intangible investment of multinationals such as R&D and advertising, which is expensed from accounting profits. As this example shows, the big country (say, the United States) does all of the investment in M for $\omega > 0.078$. Thus, the measured productivity of the small country eventually exceeds that of the big country. At $\omega = 1$, the measured productivity of the small country is 5 percent higher than that of the big country.

We turn now to predictions for consumption. Steady-state aggregate consumption in the two countries is given by

$$\begin{aligned} C_1 &= Y_1 - \delta_m M_1 - \delta_k K_1 + \phi Y_2 \frac{\omega M_1}{M_2 + \omega M_1} - \phi Y_1 \frac{\omega M_2}{M_1 + \omega M_2} \\ C_2 &= Y_2 - \delta_m M_2 - \delta_k K_2 - \phi Y_2 \frac{\omega M_1}{M_2 + \omega M_1} + \phi Y_1 \frac{\omega M_2}{M_1 + \omega M_2}. \end{aligned}$$

Based on these formulas and our Table I parameter values, the model predicts the Table II values of consumption per capita when $\omega = 0$ and when ω approaches 1. The gain for the big country is only 1.3 percent, but the gain for the small country is 26.1 percent—similar in magnitude to the gain in productivity.

The argument for two countries generalizes to I countries. First, order the countries so that $N_1 > N_2 > \dots > N_I$. The value i^* must be found such that the solution to

$$\begin{aligned} r_i(M) &= \rho + \delta_m, & i \leq i^* \\ M_i &= 0, & i > i^* \end{aligned} \tag{9}$$

satisfies the equilibrium condition (8). The equations in (9) can be violated in two ways. One is if $M_i < 0$ for some i . Then a smaller i^* is needed. The other way is if $r_{i^*+1}(M) > \rho + \delta_m$.

Then a larger i^* is needed.

Example 3: Large Gain to Forming Unions

Our third example is designed to determine the gains from expanding the size of an economic union when the entering country adopts the same degree of openness as the existing union members. This example is motivated by a country joining the European Union.

We define an economic union as a set of economies (typically, countries) with common openness policy ω and totally closed with respect to the rest of the world. Let the number of economies be I . For these examples, all members of the union have equal size, that is, $\mathcal{A}_i N_i = \mathcal{A}N$ for all i .

In this case, steady-state output per effective person as a function of the number of union members is

$$y(I) \propto [1 + (I - 1)\omega]^{\phi/[(1-\alpha)(1-\phi)]}.$$

Using estimates from Table I, we see that the ratio of $y(I)$ for $\omega = 1$ and $\omega = 0$ is $I^{.108}$. Table III reports relative per capita output for several values of I . As can be seen from Table III, forming a union of 20 members increases the members' per capita output and consumption 27 percent if $\omega = 2/3$.

Now, suppose a country joins a union of size $I = 20$, thereby making the union size $I = 21$ with $\omega = 2/3$. As can be seen from Table III, this has a small effect on existing members, with balanced growth per capita output increasing only 0.5 percent. But the increase of the joiner is large: 33.2 percent.

Example 4: Large Gain to Countries Opening Unilaterally

Now we consider and assess the gains to a country unilaterally opening to a group of closed economies. This is similar to the situation of Chile in South America. We find that opening yields large gains to the opening country.

We assume that countries are of equal size, which is normalized to $\mathcal{A}N = 1$. At

the start, they are totally closed ($\omega_i = 0$). Then, one country becomes totally open to foreign direct investment while the others remain totally closed. Assume the world has $I + 1$ countries. We use Eq. (5) and the production function (3) with $L_i = N_i$ to obtain

$$Y_c = \psi M_c^{\phi/[1-\alpha(1-\phi)]} \quad (10)$$

for a closed country c .

The country opening up exploits the world stock of technology capital IM_c . We assume I is sufficiently large that $M_o = 0$ for the open country o . Thus,

$$\frac{Y_o}{Y_c} = I^{\phi/[1-\alpha(1-\phi)]} = I^{0.097}.$$

The important point is that unilaterally becoming open benefits the country that becomes open. For example, if $I = 10$, then the gains to the opened country are 25 percent. If $I = 100$, then the gains are 56 percent. These estimates of the gains to opening are large.

3.3. Transition analysis

Now we turn from analysis of a country's situation when the economy is in a steady state to analysis of the equilibrium adjustment path of a country that gradually opens. We first treat TFP growth rates as exogenous and equal to the same constant in all countries. Next we model the relative TFP of the opening country as increasing with openness. The examples analyzed are motivated by actual observations. In all cases, theory predicts large gains for a country undergoing the transition to openness. We find some interesting non-monotonic patterns in consumption and technology capital investments when the time paths of opening are different across countries.⁵ Per capita consumptions and productivities eventually converge, but stocks of technology capital can be very different across countries even in the limit. When countries are totally open, what matters is the sum of the technology

⁵The case of symmetric time paths of opening is not considered here because the transition paths are similar to a sequence of steady states.

capital stocks, not the distribution of stocks across countries.

For our transition analysis, we relax several assumptions made earlier. Here, we allow for elastically supplied labor and growth in population and technology. Utility flow in this case is given by

$$u(c, l) = \log c + \varphi \log(1 - l),$$

with $\varphi = 2.5$ so that hours of work are consistent with observations. The growth rate in populations is $\gamma_N = .01$. The TFP parameters evolve according to $A_{it} = (1 + \gamma_A)^t$, where γ_A is set so that the interest rate ($= \rho$) is 4 percent after the transition occurs. In the limit, output grows at rate γ_Y given by

$$\gamma_Y = [(1 + \gamma_A)(1 + \gamma_N)]^{(1-(1-\phi)\alpha)/[(1-\phi)(1-\alpha)]} - 1$$

and per capita output grows at rate $\gamma_y = (1 + \gamma_Y)/(1 + \gamma_N) - 1$. In the example with TFP rising as a country opens, we set A_{it} equal to a function of σ_{it} . Because we consider both the direct effects of changing σ_{it} and the indirect effects of its change on A_{it} , we find it convenient to work here with the openness measure σ rather than with ω . Along the transition paths, we constrain investments in both types of capital to be positive.

Transition with TFPS on trend

Here we consider the equilibrium paths in two examples. In Example 5, a small, closed country joins a large, open country (or existing union). In Example 6, two similar-sized countries open to each other at different times.

Example 5. Joining a Larger Open Economy

In this example, we reconsider the situation of the steady state of Example 2: a small country opening to a larger country or group of countries that are already open. This, again, is motivated by the situation of Canada forming an economic union with the United States. It also applies to that of a small European country joining the EU.

The two countries here are, again, of size $N_1 = 10$ and $N_2 = 1$. We normalize the initial TFP parameters by setting them equal to one across time and countries. The big country is actually a union of countries or states that are open to each other but not to the small country. In period 1, this big country opens up to the small country. The small country starts out closed and gradually opens to the big country.

Figure 9: OPENNESS PARAMETERS PATH (EXAMPLE 5)

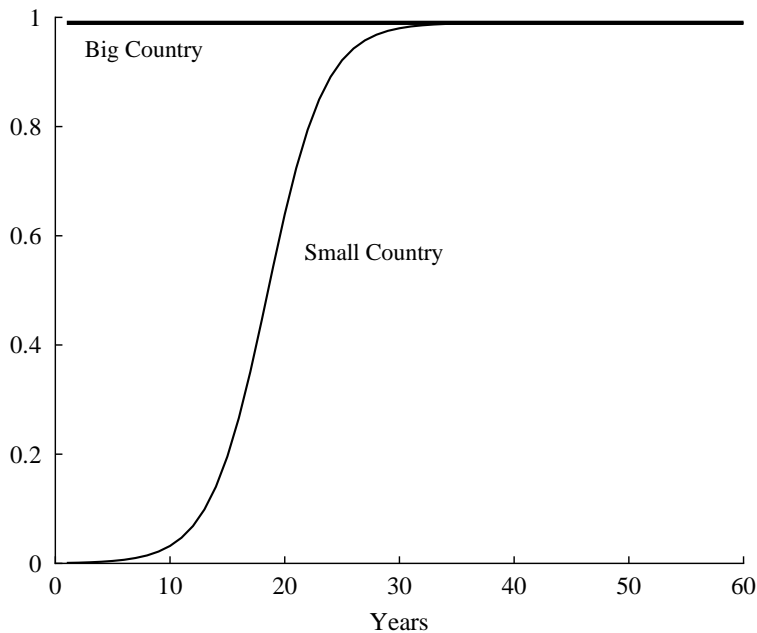


Figure 9 plots the paths of the openness parameter for the two countries, namely σ_{it} , for $i = 1, 2$. For $t \geq 1$, the openness parameter for the big country is $\sigma_{1,t} = 0.99$, which implies $\omega_{1,t} = 0.85$.⁶ In year 1, the small country is closed. Subsequently, the degree of openness for the small country increases to that of the big country. This choice of paths is motivated by evidence on the slow adjustments of GDP per hour after economic unions are formed. The slow adjustment of σ_{2t} is due in part to political forces—which we treat exogenously here—preventing an immediate opening to foreign multinational activity.⁷

⁶Because of numerical issues with investment constraints near 1, we choose the maximum value for the degree of openness σ_{it} to be 0.99 for all i and t .

⁷When the openness parameters are equal and fixed in all periods of the transition, the results can be

We also need to set initial conditions for the capital stocks. We set the capital stocks in year 0 to the balanced growth values for closed economies with $N_1 = 10$ and $N_2 = 1$.

Figure 10: PER CAPITA CONSUMPTION RELATIVE TO $c_{2,0}(1 + \gamma_y)^t$ (EXAMPLE 5)

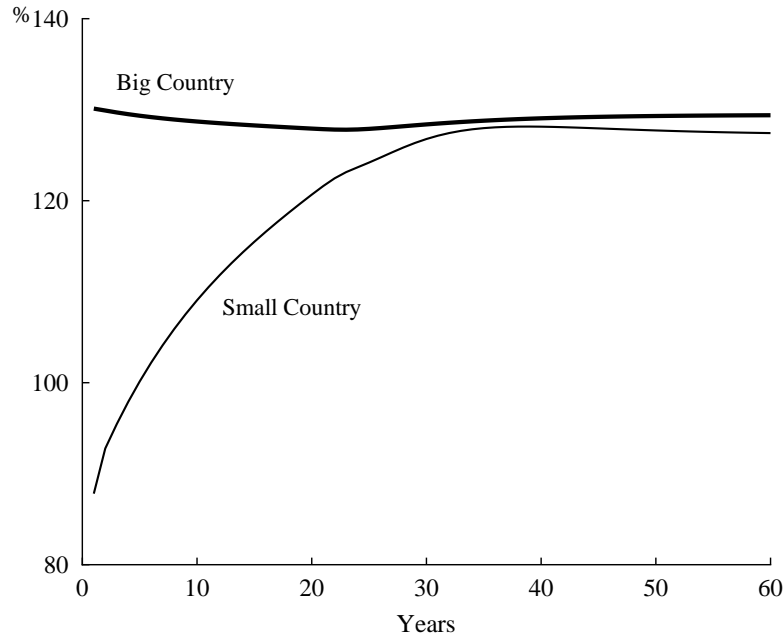


Figure 10 shows the paths of per capita consumption for the two countries. Both series are divided by the growth trend of per capita output $(1 + \gamma_y)^t$ times the small country's initial per capita consumption level $c_{2,0}$, which is the level of consumption for a closed economy with a population of size 1. The paths are clearly quite different. The consumption in the big country remains relatively stable and converges to a level that is about 1 percentage point above the level of consumption it had prior to opening. In contrast, consumption in the small country initially falls relative to $c_{2,0}$ and then increases dramatically as it opens up to foreign direct investment from the big country. In the limit, the small country's consumption level is about 27 percent higher than the level prior to opening.

Initially, virtually all of the small country consumption gains are from returns on

read off our steady-state formulas.

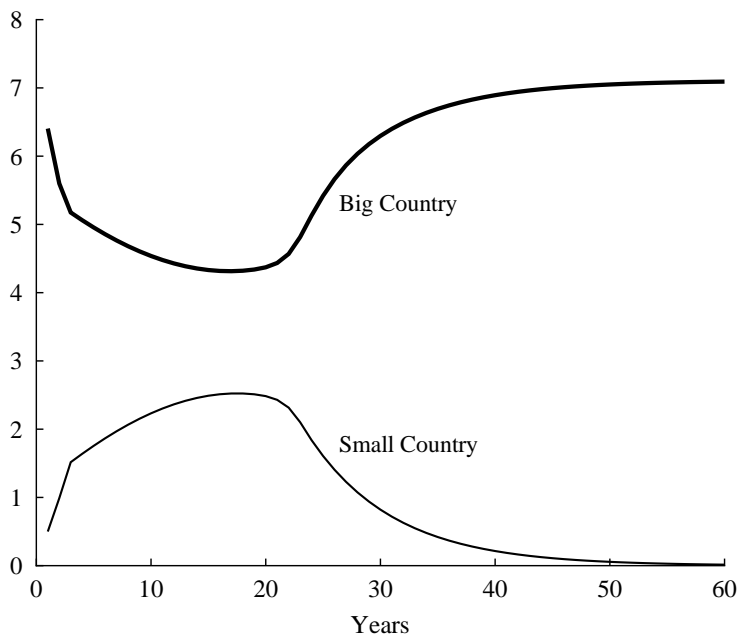
its technology being used in the big country. Figure 11 shows the paths for technology capital in the two countries relative to trend output in the small country. More specifically, the figure plots technology capital stocks divided by the growth trend of aggregate output $(1 + \gamma_Y)^t$ times the small country's initial output level. Although both countries start with a technology capital stock equal to 0.5 times output, the big country is ten times bigger and, therefore, does most of the world's investment in technology capital. In year 1, when the big country opens to FDI from the small country, investment in technology capital soars in the small country because the small country takes advantage of the fact that its capital can now be used in more locations.

As the small country opens to FDI by multinationals in the big country, it becomes advantageous for the small country to exploit the large stock of technology capital from abroad. Because of its size disadvantage, there comes a time during the transition when the small country stops investing in technology capital and lets its own stock depreciate thereafter. For this example, this occurs in year 23. When both countries are effectively open, their per capita consumption and labor input are equal, but specialization in production persists, with only the big country investing in technology capital.

The equilibrium path of the small country's actual productivity, but not its measured productivity, is similar to that of per capita consumption. As Figure 11 makes clear, measured and actual productivity have very different paths because measured output excludes investment in technology capital. The large initial increases in the small country's investment in technology capital implies that its measured productivity is initially low relative to the period before opening up to foreign technologies. For two years, the small country does not invest in plant-specific capital K but instead builds M . During this time, measured productivity is roughly half of its initial level. After that, investment in technology capital slows, but measured productivity does not recover to its initial level until after year 22.

An important lesson to be drawn from this example is that *measured* productivity will seem to show that opening has an adverse effect on the small country, when in fact it has a very positive effect. Rapid growth in measured productivity occurs at the point where

Figure 11: TECHNOLOGY CAPITAL RELATIVE TO $Y_{2,0}(1 + \gamma_Y)^t$ (EXAMPLE 5)



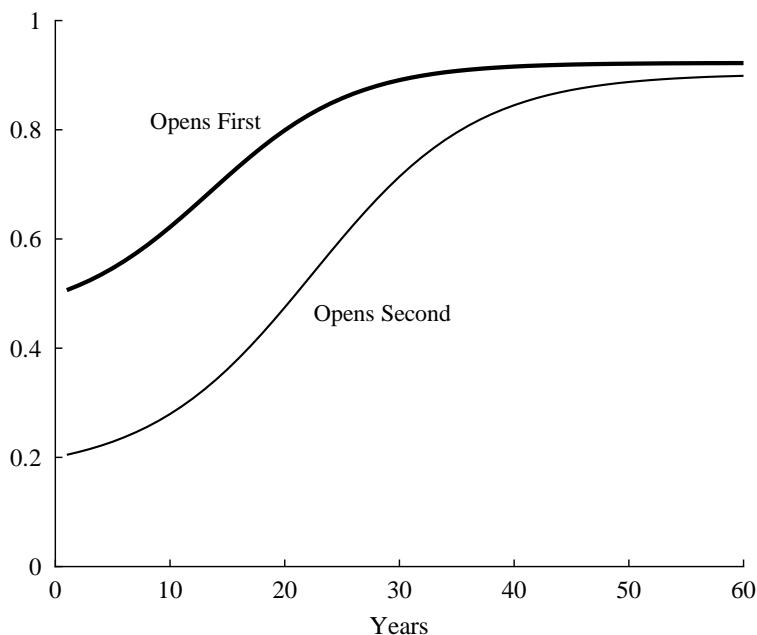
the small country's technology capital starts to decline, and it takes five years to catch up to that of the big country. Eventually, measured productivity surpasses that of the big country because true productivities are the same, but only the big country invests in technology capital. This example thus shows that measured productivity can give a distorted picture of actual economic performance.

Example 6. Opening at Different Times

Now we turn to a different situation: two similar-sized countries opening to each other at different times. We think of this as the EU opening to FDI from the United States and later the United States opening to FDI from the EU. That is because after World War II, the EU-6 countries had a population similar to that of the United States, but European companies did little foreign direct investment in the United States compared to what U.S. companies did in Europe. According to a report of the U.S. Secretary of Commerce [14], both currency undervaluation under the Bretton Woods system of exchange rates and high taxes on foreign

borrowing as a result of the interest equalization tax acted as strong disincentives to foreign direct investment in the United States.

Figure 12: OPENNESS PARAMETERS PATH (EXAMPLE 6)

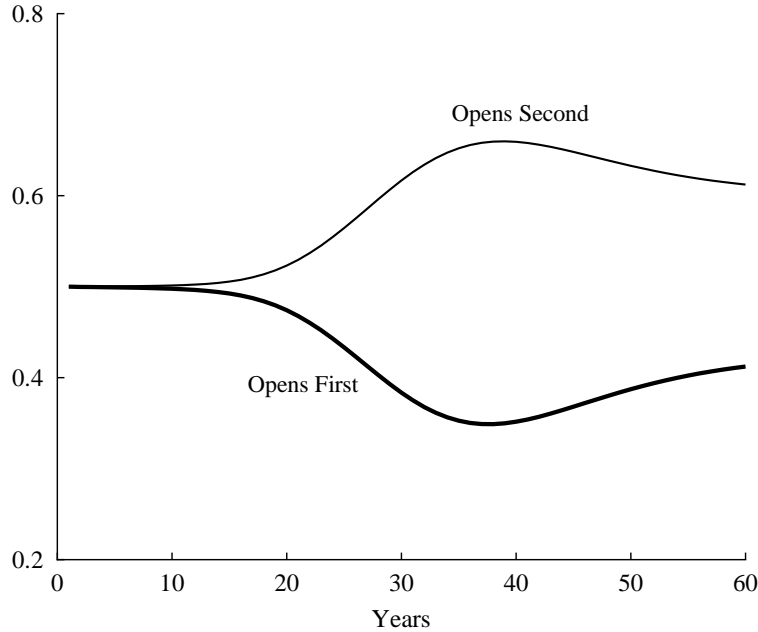


Here, we set $N_1 = 10$ and $N_2 = 10$ and assume that the initial capital stocks are equal for the two countries in year 0. In this example, the only difference between the countries is the timing of their opening. The assumed paths of the openness parameters are plotted in Figure 12.

Figure 13 shows how seemingly similar-sized economies, such as the United States and the European Union, can be very different in terms of their multinational activity. The country opening first exploits the more closed economy by using its technology capital. Therefore, it drops its investment in technology capital during the period when the relative σ 's are most different. Eventually, the country opening first does increase its investment in technology capital, although the level of this investment is much lower than that in the country opening second.

If the countries were to open up further, then the paths of technology capital would

Figure 13: TECHNOLOGY CAPITAL RELATIVE TO $Y_{2,0}(1 + \gamma_Y)^t$ (EXAMPLE 6)



depend on the relative sizes of the parameter σ . When the countries are both fully open, nothing in the theory pins down the relative sizes of the technology capital stocks. Thus, it is possible for countries to have the same standard of living but very different levels of foreign direct investment.

Transition with TFP increasing with openness

Recall that up to now, we have assumed that the TFP parameters in our economies are unaffected by openness. Yet, a country's relative TFP parameter might increase (relative to trend) when it becomes open for at least three reasons. One is that the TFP parameter is likely to be increased by the increased competition resulting from opening. Studies have examined the role of competition on productivity [6, 7] and found that competition leads to increased productivity. Others [1] have reviewed firm-level data that suggest that when a country's industry faces new foreign competition, its productivity increases to world levels. A second reason to think that the TFP parameter increases with opening is that the entry

of foreign multinational production diffuses knowledge into the opening country. A third reason is that when a country enters into a formal or informal association of open countries, typically it is required or finds it in its interest to adopt regulatory labor market and other policies that foster productivity. In particular, to attract FDI, a country must create a good environment for businesses. This is part of being open.

Example 7. Increasing Efficiency

In our final example, we assume that TFP rises in the economy that opens to foreign direct investment. This example is motivated by the experience of the Central European countries gaining efficiency as they have opened.⁸

Here, we slightly modify Example 5 (where a small closed country joined a larger open one) by assuming that the small country gains in efficiency as it opens up. Our measure of the efficiency gains is the increase in $A_{2,t}/A_{1,t}$ over time, with the rate of increase proportional to the rate of increase in $\sigma_{2,t}$, which we saw in Figure 9. In year 0, when closed, the small country has a TFP parameter $A_{2,0} = 0.9A_{1,0}$. During the transition, we assume that $A_{2,t}/A_{1,t} = 0.9 + 0.1\sigma_{2,t}$ and that $A_{1,t} = (1 + \gamma_A)^t$.

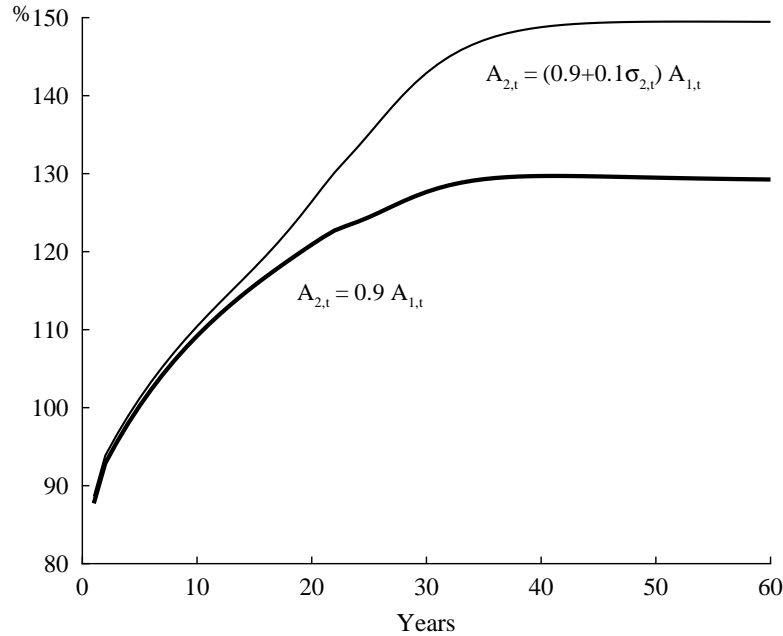
Figure 14 shows the result for per capita consumption. There we plot the consumption path of the small country joining the big country, again as a percentage of the initial consumption in the small country. For comparison, we also plot the per capita consumption path in the case with no diffusion. The result for this case is the line marked $A_{2,t} = 0.9A_{1,t}$. If there is no diffusion, the relative TFP parameters remain at 0.9 and do not increase with openness.

Without diffusion, the gains to openness for the small country are about 30 percent by year 60. The additional gains to an increase in TFP of 10 percentage points is 20 percent, implying an overall gain to the smaller country joining the union of about 50 percent when compared to the consumption level when closed.

In summary, we have demonstrated here and with our earlier examples that the

⁸Lucas [9] has emphasized the importance of diffusion of knowledge and its role in development.

Figure 14: PER CAPITA CONSUMPTION RELATIVE TO $c_{2,0}(1 + \gamma_y)^t$ (EXAMPLE 7)



potential gains from opening to FDI are large, providing theoretical support for a widely held view that the gains to economic integration are large.

4. Conclusions

In this paper, we extend the neoclassical growth model by introducing *technology capital*, which is a firm's unique know-how, and the concept of *location*, which permits the introduction of technology capital without requiring aggregate nonconvexities. The theoretical structure interacts well with the national accounts and the international accounts.

We used our extended model to provide quantitative theoretical support buttressing the empirical evidence that openness leads to large gains in the opening economy. The main avenue for gains in our theory is the exploitation of other countries' technology capital, which is done by permitting FDI.

One conclusion that can be drawn from our work is that there are gains to openness

even for countries that do little or no investment in technology capital. If countries are open, the world level of technology capital, not its distribution, is what matters. Furthermore, as countries open, those firms that are making technology capital investments have sufficient private incentives to engage in direct investment abroad. Thus, our framework provides little theoretical support for proposals such as the Barcelona European Council's proposal to provide direct public funding to ensure that R&D spending is 3 percent of EU's GDP.

We view the framework developed here as potentially useful for further theoretical and applied research in the areas of economic development, international macroeconomics, and trade. More detailed studies could and should be done to analyze the economic benefits of economic integration in specific cases. Elsewhere [11], we use the model developed here to address a puzzle in the U.S. current account and net asset position. With some extensions to include different industries, the model may also prove useful for studying issues in trade, especially as it relates to the trade-off of exporting versus direct investment.

Acknowledgments

We thank the National Science Foundation for financial support for this research (grant SES-0422539) and Loris Rubini, Johanna Wallenius, and particularly Simona Cociuba for exceptional research assistance. This paper was presented at the April 2007 conference at the University of Chicago honoring the contributions of Robert E. Lucas, Jr. Discussions by Bob Lucas and Paul Romer were extremely helpful for us in revising an earlier draft of this paper. The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.

Appendix: Data details

1. Definitions and units

Europe and the United States. For European countries and the United States, labor productivity is defined as total gross domestic product (GDP) per annual hours worked. The labor productivity is calculated as

$$\frac{\sum_{i \in I} \text{GDP}_i}{\sum_{i \in I} \text{Hours Worked}_i},$$

where i denotes a country in the group considered—for example, EU-6. Hence, the implicit assumption is that countries are weighted by their share of hours worked in total hours of the group.

South America and Asia. Data for GDP per annual hour worked in South America and Asia are scarce, so we measure productivity in these regions as GDP per person employed. This labor productivity is calculated as

$$\frac{\sum_{i \in I} \text{GDP per person employed}_i \times \text{Population}_i}{\sum_{i \in I} \text{Population}_i}.$$

The total GDP and GDP per person employed for a given country are measured in millions of U.S. dollars (converted at Geary-Khamis PPPs). Hence, labor productivity is expressed in 1990 Geary-Khamis dollars.

2. Sources

Before 1950. For all countries, data before 1950 are from [10]. *Table C-16a* (p. 249) reports GDP in 1990 Geary-Khamis dollars, and *Table J-5* (pp. 180–183) reports labor productivities in 1990 Geary-Khamis dollars per hour.

1950–2005. For all countries, data for the years 1950–2005 are from Groningen Growth and Development Center (GGDC), Total Economy Database. Go to <http://www.ggdc.net/>, then Total Economy Database and download data. The data used here are Total Economy Database, January 2007.

References

- [1] M. Baily and R. Solow, International productivity comparisons built from the firm level, *J. Econ. Perspect.* 15 (2001) 151–172.
- [2] R. Bourlès and G. Cette, A comparison of structural productivity levels in the major industrialised countries, *OECD Econ. Stud.* 41 (2005) 75–108.
- [3] A. Burstein and A. Monge-Naranjo, Foreign know-how, firm control, and the income of developing countries, NBER WP 13073, National Bureau of Economic Research, 2007.
- [4] H. Cole, L. Ohanian, A. Riascos, and J. Schmitz, Latin America in the rearview mirror, *J. Monet. Econ.* 52 (2005) 69–107.
- [5] J. Eaton and S. Kortum, Technology, geography, and trade, *Econometrica* 70 (2002) 1741–1779.
- [6] T. Holmes and J. Schmitz, Resistance to new technology and trade between areas, *Fed. Reserve Bank Minneapolis Quart. Rev.* 19 (Winter 1995) 2–17.
- [7] T. Holmes and J. Schmitz, A gain from trade: From unproductive to productive entrepreneurship, *J. Monet. Econ.* 47 (2001) 417–446.
- [8] R. Lucas, On the size distribution of business firms, *Bell J. Econ.* 9 (1978) 508–523.
- [9] R. Lucas, Trade and the diffusion of the industrial revolution, NBER WP 13286, National Bureau of Economic Research, 2007.
- [10] A. Maddison, *Monitoring the World Economy, 1820–1992*, Organisation for Economic Co-operation and Development, Paris, 1995.
- [11] E.R. McGrattan and E.C. Prescott, Technology capital and the U.S. current account, Staff Report 406, Fed. Reserve Bank Minneapolis, 2008.
- [12] N. Ramondo, Size, geography, and multinational production, Mimeo, University of Texas at Austin, 2007.
- [13] J. Sachs and A. Warner, Economic reform and the process of global integration, *Brookings Pap. Econ. Act.* 1 (1995) 1–95.

[14] U.S. Department of Commerce, Foreign Direct Investment in the United States, Report of the Secretary of Commerce in Compliance With the Foreign Investment Study Act of 1974, Government Printing Office, Washington, DC, 1976.

TABLE I. PARAMETER VALUES

Production parameters	$\alpha = 0.3, \phi = 0.07$
Depreciation rates	$\delta_k = 0.053, \delta_m = 0.10$
Interest rate	$\rho = 0.04$

TABLE II. PER CAPITA CONSUMPTION (WITH $Y_2 = 100$ WHEN $\omega = 0$)

Country	Fraction of FDI Permitted		Gain (%)
	$\omega = 0$	$\omega = 1$	
Big, $N_1 = 10$	101.3	102.6	1.3
Small, $N_2 = 1$	79.1	99.8	26.1

TABLE III. PER CAPITA OUTPUT (WITH $y=1$ WHEN $I=1, \omega=0$)

Number of Countries, I	Fraction of FDI Permitted			
	$\omega = 0$	$\omega = 1/3$	$\omega = 2/3$	$\omega = 1$
1	1	1.000	1.000	1.000
20	1	1.239	1.325	1.380
21	1	1.245	1.332	1.387