American Economic Journal: Macroeconomics 2012, 4(2): 218–248
http://dx.doi.org/10.1257/mac.4.2.218

How Important is Technology Capital for the United States?†

By Marek Kapička*

I construct measures of technology capital and country openness for the US economy and the rest of the world for 1982–2007. The key identifying assumption is that firms equalize returns on tangible and technology capital. For the US economy, technology capital is about one-third of tangible capital, and the degree of openness is between 0.61 and 0.70. I provide both a two-country estimation and a multicountry estimation, and find that the US estimates are almost identical in both cases. The welfare loss from totally closing the US economy is small, but the welfare gain from totally opening the US economy is large. (*JEL* E22, F41, O30)

Recently, McGrattan and Prescott (2009) have extended the neoclassical growth model by introducing the concept of technology capital. Technology capital measures the stock of firm's unique know-how from investing in research and development, brands, and organization capital. The theoretical framework incorporates two seemingly incompatible features: technology capital is costlessly replicated at all locations at which a firm operates, but at the same time the aggregate production function exhibits constant returns to scale in relevant inputs and a standard general competitive analysis applies. Technology capital also can be replicated abroad through foreign direct investment. The extent to which countries are receptive to foreign direct investment is measured by the degree of openness. More precisely, country openness measures the total factor productivity of foreign multinationals relative to the total factor productivity of domestic firms. Barriers to foreign direct investment are seen as restrictions that lower the total factor productivity of foreign multinationals.

The model offers a promising new mechanism through which (more or less open) economies interact. However, neither technology capital nor country openness are directly measured in the data. Investments in technology capital are expensed in national accounts and are not considered as investment. The existing measures of restrictions on foreign direct investment are largely unrelated to economic theory (e.g., Golub 2003). For the model to have useful quantitative implications, one needs to find a way to estimate the unobserved quantities from the existing data.

* Department of Economics, University of California, 2127 North Hall, Santa Barbara CA 93106 (e-mail: mkapicka@econ.ucsb.edu). I would like to thank Natalia Ramondo and seminar participants at the University of California,Santa Barbara, Federal Reserve Bank of Atlanta, and Penn State for their helpful comments and suggestions.

† To comment on this article in the online discussion forum, or to view additional materials, visit the article page at http://dx.doi.org/10.1257/mac.4.2.218.

In this paper, I provide such an estimation procedure that uses economic theory to obtain estimates of an unobserved quantity.[1]

The estimation procedure depends on two key assumptions. First, the net rates of return from investments to both technology capital and tangible capital must be equalized *within each firm*. This condition is relatively weak, since it is necessary for the firms to maximize profits. Second, both tangible capital and labor must be used efficiently *within each country*. If all firms use identical technologies, this assumption implies that both tangible capital inputs and labor inputs of all the firms within a given country are related to country-wide inputs in the same proportion. Both assumptions, and hence the estimates, are compatible with a large set of models. For instance, since it is not required that the net rates of return on tangible capital are equalized across countries, the estimates are consistent with models that incorporate international capital flow frictions or trade frictions. Similarly, the estimates are consistent with models involving imperfect consumption insurance within each country.

The estimation method can be used to provide estimates for an arbitrary number of countries. However, for practical reasons, it is often needed to aggregate some countries into one foreign country (for instance, the requisite data are not available for each country separately). The aggregation may potentially bias the estimates. I show that if all countries have identical capital output ratio and tax rates on profits, then the estimation procedure will not bias the estimates of the technology capital stock, and of country openness of the country that is not aggregated. On the other hand, I show that the openness of the aggregated foreign country is likely to be biased upward, and provide a simple approximation of the bias.

I estimate the openness parameters and the stock of technology capital in two environments. In a two-country analysis, I aggregate all the rest of the world countries together and provide estimates for the US economy and the rest of the world from 1982 to 2007. I then perform a multi-country analysis for the period 1993–2007, using a smaller set of countries for which data are available. The two-country analysis shows that the estimated US technology capital is between 29 percent and 38 percent of the US tangible capital, and is increasing after 1990. The openness of the US economy increases from 0.61 in 1982 to 0.70 in 2007, implying that the total factor productivity of foreign multinationals has been 61 percent of the total factor productivity of domestic firms in 1982 and 70 percent in 2007. The increase in US openness is relatively monotone, except for the early 1990s and 2000s. Since both cases coincide with recessions, US openness is procyclical.

The multi-country estimation shows that the openness of the US economy is almost identical to its estimate in the two-country analysis. Thus, if one is only interested in the openness of the US economy, the two-country analysis is a reasonably good approximation. On the other hand, the aggregated procedure overestimates the rest of the world openness, as suggested by the theory: in contrast to

[1] Similar estimation procedures have been used frequently in the business cycle literature, starting with the estimation of Solow residuals in the aggregate production function (Prescott 1986). Other examples include Ambler and Paquet (1994), who estimate the stock of physical capital and stochastic depreciation shocks; Burnside, Eichenbaum, and Rebelo (1993), who estimate the work effort; and Ingram, Kocherlakota, and Savin (1997), who estimate nonmarket hours worked.

the two-country analysis, all the rest of the world countries are now less open than the US economy. Among the rest of the world countries, Netherlands and Great Britain are among the most open ones, while Norway, Finland and Denmark are among the most closed ones.

I also investigate a statistical relationship between a country's openness to technology and a country's openness to trade (measured by import to GDP ratios), GDP, and corporate income tax rates. I find that country openness is positively correlated with all those variables, although the correlation with taxes is relatively small and has decreased after 2000.

Relative to McGrattan and Prescott (2010), the estimation procedure has the advantage in that it does not rely on any exogenous functional forms for country openness and can therefore estimate the whole time series of technology capital and country openness, rather than just its trends. Also, the estimation procedure in this paper is simple enough to be extended for a large number of countries. The estimates in McGrattan and Prescott (2010) are higher by about 12 percentage points. I show that 89 percent of the gap can be attributed to differences in parameters and data used. The remaining part of the gap can then be attributed to differences in methodology.

I find that the neoclassical growth model with technology capital successfully captures the movements in the foreign direct investment in the United States and abroad. While welfare losses from totally closing the US economy are found to be very small (0.20 percent of consumption, in consumption equivalents), welfare gains from totally opening the US economy are large (8.17 percent of consumption, in consumption equivalents). This indicates that, the effects of country openness are highly nonlinear. Increasing the total factor productivity of foreign multinationals from 0 to 70 percent of the productivity of domestic firms creates only a tiny welfare gain relative to the increase from 70 to 100 percent.

The importance of foreign direct investment and openness for welfare has long been recognized by the economic literature.[2] However, its quantitative importance has been addressed only recently. Most notably, Ramondo (2010) analyzes and estimates an Eaton and Kortum (2002) type model with technology diffusion across countries.[3] The source of welfare gains in Ramondo (2010) is similar to this model. However, there are differences in the economic environment. On one hand, her model is static and the diffusion of technology is exogenous, with no interaction between technology diffusion and openness of other countries. On the other hand, her model can jointly analyze gains from openness and gains from trade, as in Rodriguez-Clare (2007) and Ramondo and Rodriguez-Clare (2010). The main advantage of the approach in this paper is that it is fully integrated with the neoclassical growth model. Therefore, all the available knowledge about the neoclassical growth model and its ability to match the data can be put to a new use.

[2] See e.g., Horstmann and Markusen (1989) for an early analysis.

[3] See also Burstein and Monge-Naranjo (2009), where the gains from openness are derived from reallocation of managerial talent across countries, and quantitatively evaluated. Unlike technology capital, managerial talent is a rivalrous good within a firm.

I. Theory

There are I countries in the world. Country i has a population $N_{i,t}$[4] and a total factor productivity $A_{i,t}$ in period t. All firms producing in country i share the same total factor productivity.

There is a large number of locations where production can take place. The measure of locations is, without loss of generality, taken to be equal to $N_{i,t}$. In each location, one representative firm from each country can set up a plant and operate. Thus, in each location, one domestic firm and $I - 1$ foreign multinationals operate.

The production of a plant in a given location in country i depends on country i's total factor productivity $A_{i,t}$, labor l_t, tangible capital k_t, and is given by

$$y_t = A_{i,t}\left(k_t^{\alpha} l_t^{1-\alpha}\right)^{1-\phi}.$$

Each plant therefore operates a decreasing returns to scale technology with $\phi \in [0, 1)$ being the degree of decreasing returns.

While tangible capital and labor are both specific to each firm and plant, technology capital is only specific to each firm. Technology capital affects production in *all* locations, both domestic and foreign, at which the firm operates by effectively multiplying the number of plants that can be operated at each location. A domestic firm with M_t units of technology capital, K_t units of tangible capital, and L_t units of labor efficiently spreads tangible capital and labor across all $M_t N_{i,t}$ plants. Therefore, its total production in country i is

$$Y_{i,t}^{i} = A_{i,t}(M_t N_{i,t})^{\phi}\left(K_t^{\alpha} L_t^{1-\alpha}\right)^{1-\phi}. \tag{1}$$

Production of a foreign multinational from a country $j \neq i$ is determined similarly but depends, in addition, on the openness of country i. The degree of openness in period t is given by a parameter $\omega_{i,t}^{j} \in [0, 1]$ that determines the total factor productivity of a foreign multinational $j \neq i$ relative to the domestic firm in country i. Aggregating across plants again, the production of a foreign multinational in country i is given by

$$Y_{i,t}^{j} = \omega_{i,t}^{j} A_{i,t}(M_t N_{i,t})^{\phi}\left(K_t^{\alpha} L_t^{1-\alpha}\right)^{1-\phi}. \tag{2}$$

As in McGrattan and Prescott (2009), a country i is called *totally open* if $\omega_{i,t}^{j} = 1$, foreign multinationals are treated equally to the domestic firms, and have the same productivity. It is called *totally closed* if $\omega_{i,t}^{j} = 0$. The stocks of tangible and technology capital follow their laws of motions:

$$K_{t+1} = (1 - \delta_K)K_t + X_{K,t}$$

$$M_{t+1} = (1 - \delta_M)M_t + X_{M,t},$$

[4] In what follows, a subscript on a variable indicates the country where production takes place, while superscript indicates country of origin.

where $X_{K,t}$ is investment in tangible capital in period t, $X_{M,t}$ is investment in technology capital in period t, and δ_K and δ_M are their depreciation rates.

Multinational's Problem.—Let $p_{j,t}$ be the intertemporal price of consumption in country j, not necessarily equal across countries. A multinational from country i chooses sequences of a technology capital stock M_t^i, of labor inputs $L_{j,t}^i$, and of tangible capital stocks $K_{j,t}^i$ to maximize the present discounted value of dividends,

$$\max_{\{L_{j,t}^i, K_{j,t}^i, M_t^i\}_{j,t}} \sum_{t=0}^{\infty} \sum_{j=1}^{I} p_{j,t} D_{j,t}^i, \tag{3}$$

where $D_{j,t}^i$ are dividends from multinational's production in country j. They are equal to the after tax profits minus reinvested earnings:

$$D_{i,t}^i = \left(1 - \tau_{i,t}^K\right)\left(Y_{i,t}^i - W_{i,t} L_{i,t}^i - \delta_K K_{i,t}^i - X_{M,t}^i\right) - \left(K_{i,t+1}^i - K_{i,t}^i\right)$$

$$D_{j,t}^i = \left(1 - \tau_{j,t}^K\right)\left(Y_{j,t}^i - W_{j,t} L_{j,t}^i - \delta_K K_{j,t}^i\right) - \left(K_{j,t+1}^i - K_{j,t}^i\right), \quad j \neq i,$$

where $\tau_{j,t}^K$ is the tax on profits in country j. Note that the investment in the technology capital is expensed, but the investment in tangible capital is not.

Denote the rate of return on tangible and technology capital in country i by $R_{i,t}^K$ and $R_{i,t}^M$. They are given by

$$R_{i,t+1}^K = (1 - \tau_{i,t+1}^K)\left(\alpha(1 - \phi)\frac{Y_{i,t+1}}{K_{i,t+1}} - \delta_K\right) \tag{4}$$

$$R_{i,t+1}^M = \frac{1 - \tau_{i,t+1}^K}{1 - \tau_{i,t}^K}\left(\phi\frac{Y_{i,t+1}^i}{M_{t+1}^i} + 1 - \delta_M\right) + \sum_{j \neq i} \frac{1 - \tau_{j,t+1}^K}{1 - \tau_{i,t}^K} \frac{p_{j,t+1}}{p_{i,t+1}} \phi \frac{Y_{j,t+1}^i}{M_{t+1}^i} - 1. \tag{5}$$

If the multinationals allocate the resources efficiently, i.e., their choices solve problem (3), then they equalize the net rate of return from investment in technology and tangible capital to each other and to country i's interest rates:

$$R_{i,t+1}^K = R_{i,t+1}^M = \frac{p_{i,t}}{p_{i,t+1}} - 1. \tag{6}$$

The equality (6) will serve as one of the two main assumption that will be used in the estimation of the technology capital and of country openness.

Aggregation.—Define a *proportion factor* $v_{i,t}^{j}$ to be the ratio of country j's effective technology capital in country i and of country i's total effective technology capital:

$$v_{i,t}^{i} = \frac{M_t^i}{M_t^i + \sum_{k \neq i} (\omega_{i,t}^k)^{\frac{1}{\phi}} M_t^k} \tag{7a}$$

$$v_{i,t}^{j} = \frac{(\omega_{i,t}^j)^{\frac{1}{\phi}} M_t^j}{M_t^i + \sum_{k \neq i} (\omega_{i,t}^k)^{\frac{1}{\phi}} M_t^k}, \quad j \neq i. \tag{7b}$$

The proportion factor $v_{i,t}^{j}$ plays a key role in determining the amount of foreign direct investment from country j to country i, as well as the production and labor input of the foreign subsidiaries.[5] In particular, the solution to the firm's problem (3) implies that tangible capital and labor inputs, as well as the production of all firms, are related to the countrywide aggregates $K_{i,t}$, $L_{i,t}$, and $Y_{i,t}$ in the same proportions:

$$Y_{i,t}^j = v_{i,t}^j Y_{i,t}, \tag{8a}$$

$$K_{i,t}^j = v_{i,t}^j K_{i,t}, \tag{8b}$$

$$L_{i,t}^j = v_{i,t}^j L_{i,t}. \tag{8c}$$

A. *The Estimation Procedure*

The estimation procedure uses the theory in two ways. First, it uses the equality of the rates of returns (6) to find out the required rate of return on technology capital, and, together with the estimates of the proportion factors (any equation (8a)–(8c)), to obtain the stock of technology capital that is compatible with such rate of return. Second, it uses the proportion factors (7a)–(7b) to obtain the openness parameters.

Equation (6) and the definition of $R_{i,t}^M$ (5) imply that the stock of technology capital in country i can be expressed as

$$M_t^i = \phi \frac{\frac{1-\tau_{i,t}^K}{1-\tau_{i,t-1}^K} v_{i,t}^i Y_{i,t} + \sum_{j \neq i} \frac{1-\tau_{j,t}^K}{1-\tau_{i,t-1}^K} \frac{p_{j,t}}{p_{i,t}} v_{j,t}^i Y_{j,t}}{1 + R_{i,t}^K - \frac{1-\tau_{i,t-1}^K}{1-\tau_{i,t}^K}(1 - \delta_M)}, \tag{9}$$

[5] Equation (8b) can be related to a similar equation, (18), in Ramondo (2010). In her model, the fixed costs t_{ij} play a role similar to the role of country openness here, and the variable Γ_{ij} plays a role similar to the stock of technology capital here.

where $Y^i_{j,t}$ and $Y^i_{i,t}$ have been eliminated using equation (8a). The proportion factors $v^i_{j,t}$ and $v^i_{i,t}$ can be computed using any of the equations (8a)–(8c).

If country i's production $Y_{i,t}$ is observed, expression (9) can be immediately used to compute the implied stock of technology capital in country i, jointly with the implied intertemporal prices given by

$$R^K_{i,t} = (1 - \tau^p_{i,t+1})\left(\alpha(1 - \phi)\frac{Y_{i,t}}{K_{i,t}} - \delta_K\right) \tag{10}$$

$$p_{i,t} = \prod_{\tau=1}^{t} (1 + R^K_{i,\tau})^{-1}. \tag{11}$$

However, since the investment in technology capital is expensed, country's production $Y_{i,t}$ is not equal to its Gross Domestic Product $GDP_{i,t}$. The difference between them is the investment in technology capital:

$$GDP_{i,t} = Y_{i,t} - X^i_{M,t}. \tag{12}$$

Investment in technology capital is not measured explicitly in the national accounts, and so $Y_{i,t}$ is not directly observed as well. Substituting (12) for $Y_{i,t}$ into (5), one can express the implied stock of technology capital as

$$M^i_t = \phi\,\frac{\frac{1-\tau^K_{i,t}}{1-\tau^K_{i,t-1}}\, v^i_{i,t}(GDP_{i,t} + X^i_{M,t}) + \sum_{j\neq i} \frac{1-\tau^K_{j,t}}{1-\tau^K_{i,t-1}}\,\frac{p_{j,t}}{p_{i,t}}\, v^i_{j,t}(GDP_{i,t} + X^j_{M,t})}{1 + R^K_{i,t} - \frac{1-\tau^K_{i,t}}{1-\tau^K_{i,t-1}}(1 - \delta_M)}. \tag{13}$$

The investment $X^i_{M,t}$ is recovered simultaneously from its law of motion:

$$M^i_{t+1} = X^i_{M,t} + (1 - \delta_M)M^i_t. \tag{14}$$

Equations (13) and (14), together with $R^K_{i,t}$ and $p_{i,t}$ given by (10), and (11), form a system of first order difference equations in the technology capital $\{M^i_t\}^I_{j=1}$. Given some initial or terminal condition on technology capital, one can solve these difference equations for the time series of technology capital in all countries.

After the stock of technology capital is computed, equations (7a)–(7b) can be inverted to compute the openness parameters:

$$\omega^j_{i,t} = \left(\frac{v^j_{i,t}}{v^i_{i,t}}\,\frac{M^i_t}{M^j_t}\right)^{\phi}. \tag{15}$$

B. *Aggregation*

It is often useful to aggregate a subset of countries into one. What happens to the estimates if one performs such an aggregation? This section studies such an aggregation from a theoretical perspective. Suppose that one estimates the technology capital and country openness on a disaggregated data, treating all I countries separately. Then one aggregates the last $I - 1$ countries in one ("foreign") country by defining $Y_{f,t} = \sum_{j=2}^{I} Y_{j,t}$, $K_{f,t} = \sum_{j=2}^{I} K_{j,t}$, $K_{f,t}^{1} = \sum_{j=2}^{I} K_{j,t}^{1}$ and $K_{1,t}^{f} = \sum_{j=2}^{I} K_{1,t}^{j}$. Denote the estimates from the disaggregated procedure by $\{M_t^i\}_{i=1}^{I}$ and $\{\omega_{i,t}^{j}\}_{i,j=1}^{I}$, and the estimates from the aggregated procedure by $(\hat{M}_t^1, \hat{M}_t^f)$ and $(\hat{\omega}_{t,f}^{1}, \hat{\omega}_{t,1}^{f})$. The next proposition relates the estimates in the aggregated and disaggregated procedure.

PROPOSITION 1: *Suppose that $Y_{i,t}/K_{i,t}$ and $\tau_{i,t}^K = \tau_t^K$ are independent of i for all t. Then,*

$$(i) \qquad \hat{M}_t^1 = M_t^1, \text{ and } \hat{M}_t^f = \sum\nolimits_{j=1}^{I} M_t^j,$$

$$(ii) \qquad \hat{\omega}_{1,t}^{f} = \left(\sum\nolimits_{j=2}^{I} (\omega_{1,t}^{j})^{\frac{1}{\phi}} \frac{M_t^j}{\sum\nolimits_{k=2}^{I} M_t^k} \right)^{\phi}.$$

PROOF:

Given the assumptions, R_t^K and p_t are identical across countries. In addition,

$$K_{f,t}^{f} = K_{f,t} - K_{f,t}^{1} = \sum_{j=2}^{I} (K_{j,t} - K_{j,t}^{1}) = \sum_{j=2}^{I} \left(K_{j,t}^{j} + \sum_{k \neq 1,j} K_j^k \right).$$

Let

$$\lambda_t = \phi \kappa_t \frac{1 - \tau_t^K}{1 - \tau_{t-1}^K} \left[1 + R_t^K - \frac{1 - \tau_t^K}{1 - \tau_{t-1}^K} (1 - \delta_M) \right]^{-1},$$

where $\kappa_t = Y_{i,t}/K_{i,t}$ is the common output-capital ratio. The estimates of the technology capital in country 1 and in the foreign country satisfy

$$\hat{M}_t^1 = \lambda_t (K_{1,t}^1 + K_{f,t}^1) = \lambda_t \left(K_{1,t}^1 + \sum_{j=2}^{I} K_{j,t}^1 \right) = M_t^1$$

$$\hat{M}_t^f = \lambda_t (K_{f,t}^f + K_{1,t}^f) = \lambda_t \left[\sum_{j=2}^{I} \left(K_{j,t}^j + \sum_{k \neq 1,j} K_j^k \right) + \sum_{j=2}^{I} K_{1,t}^j \right]$$

$$= \sum_{j=2}^{I} \lambda_t \left(K_{j,t}^j + \sum_{k \neq j} K_{k,t}^j \right) = \sum_{j=2}^{I} M_t^j.$$

The openness parameter $\hat{\omega}^f_{1,t}$ satisfies

$$(\hat{\omega}^f_{1,t})^{\frac{1}{\phi}} = \frac{\hat{v}^f_{1,t}}{\hat{v}^1_{1,t}} \frac{\hat{M}^1_t}{\hat{M}^f_t} = \frac{\sum_{i=2}^I v^i_{1,t}}{v^1_{1,t}} \frac{M^1_t}{\sum_{i=2}^I M^i_t} = \sum_{i=2}^I \frac{v^i_{1,t}}{v^1_{1,t}} \frac{M^1_t}{M^i_t} \frac{M^i_t}{\sum_{i=2}^I M^i_t}$$

$$= \sum_{i=2}^I (\omega^i_{1,t})^{\frac{1}{\phi}} \frac{M^i_t}{\sum_{i=2}^I M^i_t}.$$

Thus, if tangible capital-output ratios and taxes are identical across all countries, then the estimates of the technology capital will not be biased, and the estimate of the openness of country 1 toward the foreign country will be a weighted average of the openness of country 1 toward countries 2, $\dots, I$, with the weights determined by the stock of technology capital. On the other hand, there is no simple formula to relate the rest of the world openness in the aggregated procedure to the openness of all the foreign countries in the disaggregated procedure. In fact, the aggregated procedure will likely overstate the rest of the world openness. To see this, consider a simple example where the $I - 1$ rest of the world countries are all identical. Then one can show that $\hat{\omega}^1_{f,t} = \omega^1_{i,t}$ (where $\omega^1_{i,t}$ is independent of i because all the rest of the world countries are identical) only if all the rest of the world countries are mutually completely open toward each other, i.e., if $\omega^k_{j,t} = 1$ for all $j, k \neq 1$. On the other hand, if all the rest of the world countries are mutually completely closed toward each other, then one obtains $\hat{\omega}^1_{f,t} = (I - 1)^{\phi} \omega^1_{i,t}$, and the rest of the world openness is biased upward in the aggregated procedure.

C. *Generalizations*

This section shows that the estimates remain valid even if some of the assumptions of the theory are relaxed.

Heterogeneity across Locations.—The model assumes that the total factor productivity is the same across all locations. This assumption has no consequences for the estimation. To see this, denote a location by $n \in [0, N_{i,t}]$ and suppose that the production in a location n is given by

$$y_t(n) = \hat{A}_{i,t}\, \varepsilon_{i,t}(n) (k^{\alpha}_t l^{1-\alpha}_t)^{1-\phi}, \qquad n \in [0, N_{i,t}]$$

for some function $\varepsilon_{i,t} \geq 0$, where the "true" total factor productivity is now denoted by $\hat{A}_{i,t}$. Aggregating across all locations yields a production of a domestic firm in country i and a foreign multinational still given by (1) and (2), but with productivity parameter $A_{i,t}$ given by

$$A_{i,t} = \hat{A}_{i,t} \left(\frac{1}{N_{i,t}} \int_0^{N_{i,t}} \varepsilon_{i,t}(n)^{\frac{1}{\phi}}\, dn \right)^{\phi}.$$

Thus, the estimation procedure mismeasures the total factor productivity by incorporating the gains from uneven distribution of the factors of production across locations into the Solow residual. The estimation procedure leaves the estimates of the openness parameter and of the technology capital unchanged.

Inside Openness.—One of the seemingly crucial assumptions is that all countries are totally open inside. To see that this assumption can be relaxed, assume that there are B_i identical regions within a country i. Each region has a population $N_{i,t}/B_i$, and the regions are mutually open toward each other with a degree of openness $\hat{\varphi}_{i,t}$. All the regions in country i have the same total factor productivity $\hat{A}_{i,t}$. The openness toward foreign country j is given by $\hat{\omega}^j_{i,t}$ for all the regions. The production of a plant of a domestic firm from region s in a region r in a given location is thus

$$y^{i,r}_{i,r} = \hat{A}_{i,t}(k^{\alpha}_t l^{1-\alpha}_t)^{1-\phi}$$

$$y^{i,s}_{i,r} = \hat{A}_{i,t}\hat{\varphi}_{i,t}(k^{\alpha}_t l^{1-\alpha}_t)^{1-\phi} \qquad s \neq r.$$

Aggregating across all plants and regions in country i, for domestic firms, and similarly for foreign multinationals from country j, one obtains that their production is given by

$$Y^i_{i,t} = \hat{A}_{i,t}B^{\phi}_i \varphi_{i,t}(M_t N_{i,t})^{\phi}\, K^{\alpha(1-\phi)}_t L^{(1-\alpha)(1-\phi)}_t$$

$$Y^j_{i,t} = \hat{A}_{i,t}B^{\phi}_i \hat{\omega}^j_{i,t}(M_t N_{i,t})^{\phi}\, K^{\alpha(1-\phi)}_t L^{(1-\alpha)(1-\phi)}_t \qquad j \neq i,$$

where $\varphi_{i,t} = \left(\frac{1 + (B_i - 1)\hat{\varphi}_{i,t}}{B_i}\right)^{\phi}$ is the "effective" internal openness of country i. The production functions show that the parameters $\hat{A}_{i,t}B^{\phi}_i$, $\varphi_{i,t}$, and $\hat{\omega}^j_{i,t}$ enter the production functions symmetrically. One of those variables can always be normalized without loss of generality. The default is to normalize internal openness to one. Equivalently, if one denotes $A_{i,t} = \hat{A}_{i,t}\varphi_{i,t}B^{\phi}_i$ and $\omega^j_{i,t} = \hat{\omega}^j_{i,t}/\varphi_{i,t}$, then the estimation procedure will uncover a *relative openness* of foreign countries $\omega^j_{i,t}$, relative to the internal openness of country i. It will also mismeasure productivity by equating Solow residual with $A_{i,t}$ rather than $\hat{A}_{i,t}$. Given the definition of $A_{i,t}$ and $\omega^j_{i,t}$, the production functions are formally equivalent to (1) and (2). The estimation results are unchanged. In particular, the estimation procedure will correctly measure the stock of technology capital.

II. The Estimates: A Two-country Analysis

This section provides the estimates of the technology capital and the openness parameters for the 1982–2007 time period, using a two-country framework.

A. *Calibration*

The two countries considered are the United States, *US*, and an aggregate for the rest of the world, *RW*. The rest of the world includes most OECD countries.[6] Since foreign direct investment is mostly concentrated among OECD countries, those countries are a natural benchmark. Nevertheless, alternative estimates using an extensive definition of the rest of the world are presented later as well.

Data.—The time period considered is 1982–2007, for which all the required data are available. The data for real US tangible capital stock $\mathbf{K_{US}}$ are taken from the National Economic Accounts Fixed Assets Table. $\mathbf{K_{RW}}$ is taken to be the sum of real capital stock for the rest of the world countries. The data are based on the AMECO database and converted into 1990 US dollars using Geary-Khamis purchasing power parities, which are taken from the Penn World Tables.[7]

The benchmark analysis computes the proportion factors using equation (8b), i.e., using the capital stock data. The main advantage of computing the proportion factor this way is that the data on capital stock are readily available for most countries.

The tangible capital stock of US firms abroad, $\mathbf{K_{RW}^{US}}$, is measured by the US direct investment position in the countries included in the rest of the world definition. Similarly, the tangible capital stock of foreign firms in the US, $\mathbf{K_{US}^{RW}}$, is measured by the foreign direct investment position of the rest of the world countries in the United States. The data are taken from the Bureau of Economic Analysis Direct Investment Position data by country.

The real US Gross Domestic Product, $\mathbf{GDP_{US}}$, is taken from the National Income and Product Accounts. The real Gross Domestic Product for the rest of the world, $\mathbf{GDP_{RW}}$, is constructed as a sum of real GDP for all the countries that are included in the definition of the rest of the world capital stock. The data are taken from the Groningen Growth and Development Center (GGDC) Total Economy database.[8]

The values of tax rate $\tau_{\mathbf{US}}^{\mathbf{K}}$ are equated with the effective marginal corporate tax rate estimated by Hassett and Mathur (2006). The same source is used to obtain the effective marginal corporate tax rate for each country included in the rest of the world definition, and the values are averaged to obtained $\tau_{\mathbf{RW}}^{\mathbf{K}}$. The average is weighted by each country's physical capital stock. All data inputs required for the estimation are in the Data Appendix, in Table (B1).

Parameters.—I follow McGrattan and Prescott (2010) by setting the depreciation rate of technology capital to be 8 percent annually.[9] I set ϕ to match a target ratio of investment in technology capital to US GDP. The target ratio is constructed from the data as follows. Three types of investments are considered to be investment

[6] The rest of the world includes Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Republic of Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom Japan, Finland, Australia, New Zealand, Mexico, South Korea. Czech Republic, Hungary, Slovak Republic, and Poland are excluded because of limited data availability.

[7] See the Data Appendix for details.

[8] The data are already converted into 1990 US dollars using Geary-Khamis purchasing power parities.

[9] The argument as to why technology capital depreciates faster than the tangible capital is that it includes R&D investment, and BEA estimates that R&D investment depreciates at a rate of 15 percent annually.

Table 1—Benchmark Calibration

Parameter	Value	Target
ϕ	0.1041	Investment in technology capital to GDP ratio of 8 percent
$\alpha(1 - \phi)$	0.334	Average capital share, NIPA
δ_K	0.045	Average depreciation rate, NIPA
δ_M	0.08	McGrattan and Prescott (2010)

in technology capital: R&D expenditures, expenditures on brand equity (which consists mostly of advertising expenditures), and expenditures on organizational capital. Corrado, Hulten and Sichel (2005) provide estimates of the aggregate expenditures on each of those categories for three time periods: 1988–1990, 1993–1995, and 1998–2000. Averaging over those three periods, one obtains that R&D expenditures are 4.0 percent of GDP, expenditures on brand equity are 2.4 percent of GDP, and expenditures on organizational capital are 2.6 percent of GDP. To be consistent with McGrattan and Prescott (2010), expenditures on organizational capital are lowered by 1 percent to reflect the fact that a part of the expenditures might be plant specific. All together, the target ratio of investment in technology capital is taken to be 8 percent of GDP.[10] The resulting value of ϕ is 0.1041. I set the tangible capital share in GDP $\alpha(1 - \phi)$ to be equal to 0.334, and the depreciation rate of tangible capital δ_K to be equal to 4.5 percent annually. Both numbers are computed as the US average over the 1982–2007 period. The terminal condition I use in solving the difference equations (13) and (14) is that the investment in technology capital in 2007 in both countries is the same as the investment in technology capital in 2006. Table 1 summarizes the calibrated parameters of the model.

B. *Benchmark Estimates*

The left panel of Figure 1 plots the openness parameters for the US economy, ω_{US}. Overall, the magnitude of the openness parameters shows that foreign multinationals have significantly lower productivity. The total factor productivity of foreign multinationals never exceeds three-fourths of the total factor productivity of domestic firms.[11] The openness overall has been increasing over time, although there are periods of temporary decrease. The rest of the world openness (not shown) appears to be larger than US openness throughout the whole period, although, as we shall see in the multi-country analysis of Section IV, there is a significant bias in the estimates of foreign openness.

[10] The estimates in McGrattan and Prescott (2010) are only 5–6 percent because their estimates of R&D expenditures and expenditures on brand equity are averages over a much longer period (1960–2006).

[11] Note, however, that if one measured the total factor productivity of foreign multinationals using the traditional Solow residual method, i.e., by dividing $Y^j_{i,t}$ by $(K^j_{i,t})^{\alpha}(L^j_{i,t})^{1-\alpha}$, then one would find out that the total factor productivity of foreign multinationals is the same as the total factor productivity of domestic firms. This is so because foreign multinationals produce less, and there are decreasing returns to scale at the plant level.

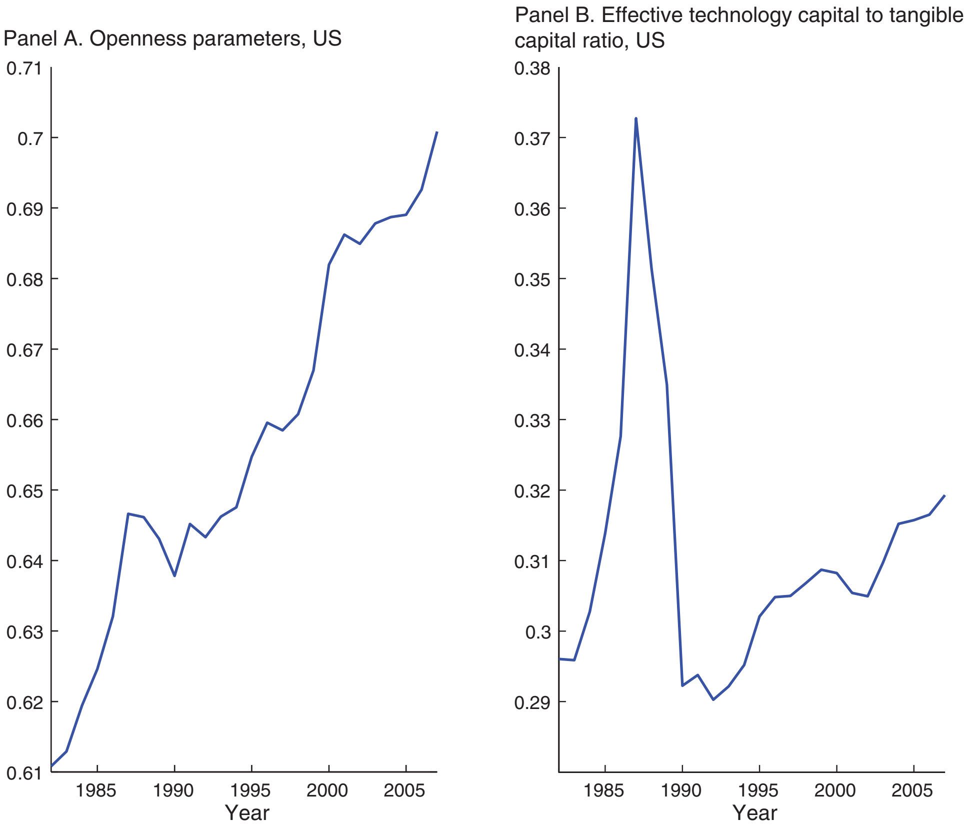

Figure 1. Benchmark Estimates, US

The right panel of Figure 2 plots the ratio of effective technology capital $M_{i,t} \equiv M_t^i + (\omega_{i,t}^{-i})^{\frac{1}{\phi}} M_t^{-i}$ and tangible capital $K_{i,t}$ for the United States. The ratio of US technology capital and US tangible capital fluctuates between 0.30 and 0.36. The ratio of technology to tangible capital has been increasing after 1990, following a temporary spike between 1985 and 1990 caused by a rapid decrease in taxes τ^K. US investment in technology capital is also found to be highly procyclical (at annual frequency) and less volatile than investment in tangible capital.

The degree of openness of the US economy is positively correlated with US GDP. The total factor productivity has been growing at a rate of 1.08 percent per year. In contrast, the average growth rate of the total factor productivity one would incorrectly measure by ignoring technology capital (i.e., by computing $\hat{A}_{i,t} = Y_{i,t}/(K_{i,t}^{\alpha} L_{it}^{1-\alpha})$ has been growing at a rate of 1.31 percent per year. Thus, the contribution of the total factor productivity, while still of first order importance, is somewhat reduced if one properly accounts for the effects of technology capital. Figure 2 compares the correctly measured total factor productivity with the mismeasured one. The difference in growth rates is especially visible after 1990. Large variations in the stock of technology capital before 1990 without corresponding variations in output imply large volatility of the correctly measured total factor productivity.

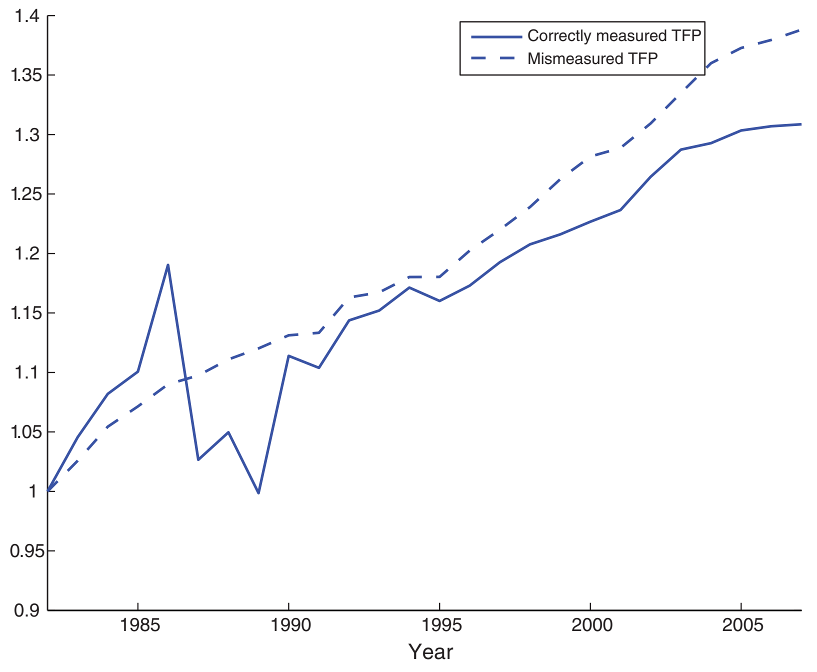

Figure 2. Total Factor Productivity

Decomposing the Estimates.—The degree of openness and the stock of technology capital are determined by three factors: tax rates on profits, capital-output ratios, and the stock of foreign direct investment. Figure 3 shows the implied openness parameters if one sets the tax rates to zero. The taxes increase the openness of the US economy by about 10 percentage points, and are responsible for large variations in the stock of technology capital before 1990. This is intuitive, since taxes decrease investment both home and abroad, and so to rationalize the observed levels of capital stocks with positive tax rates, the openness must be higher than if the taxes are zero. Taxes do not significantly alter the time profile of openness. They do, however, affect the effective technology capital to tangible capital ratio. The ratio is now less volatile, although it is still increasing after 1990.

The second factor is differences in tangible capital-output ratios across countries. They affect the estimates because they determine the rates of return $R^K_{i,t}$ and intertemporal prices $p_{i,t}$. Figure 3 plots the estimates for a hypothetical case when, in addition to zero taxes, the rest of the world GDP is altered to keep the same tangible capital-output ratio as the US economy. Varying capital output ratios have a relatively small effect on US openness, and they change the estimate of the ratio of both capitals by at most 1.5 percentage points.

In the absence of taxes, and with the tangible capital-output ratio equal in both the US economy and the rest of the world to a common quantity κ_t, the estimates have simple analytical expressions. The stock of technology capital is given by

$$M^i_t = \lambda_t(K^i_{i,t} + K^i_{-i,t}),$$

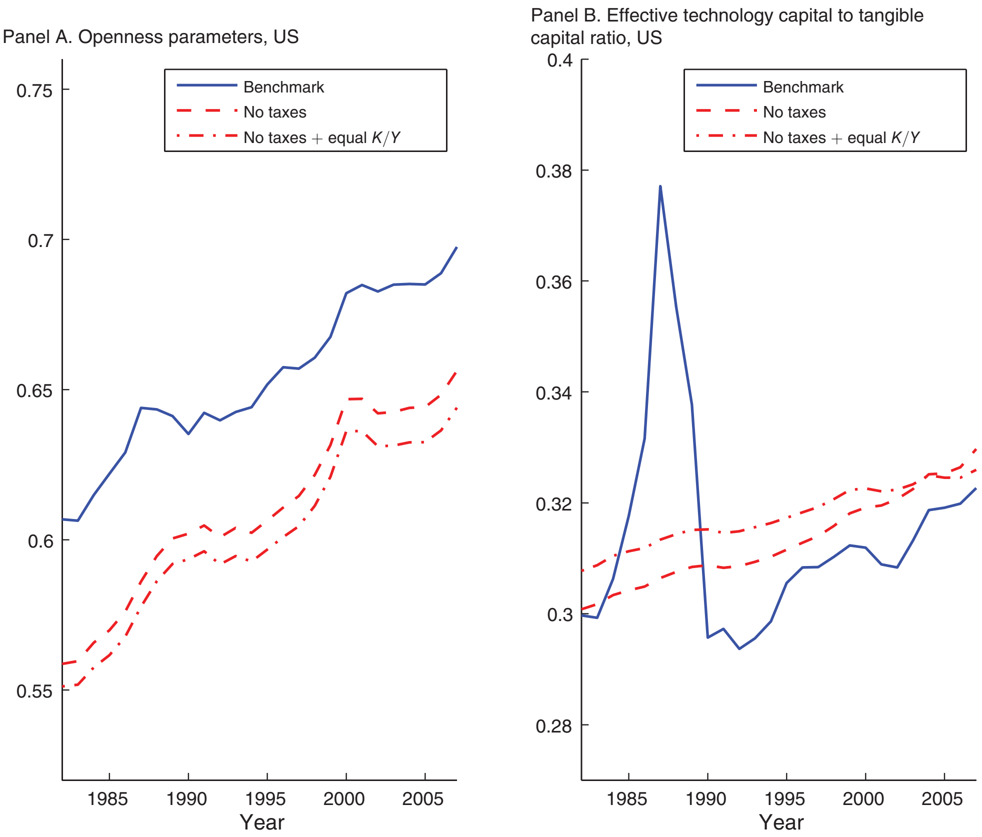

Figure 3. Benchmark Estimates: A Decomposition

where $i \in \{US, RW\}$, $-i$ is the other country, and $\lambda_t = \phi\kappa_t/\left(R_t^K + \delta_M\right)$. Thus, the implied technology capital stock of a multinational is higher whenever one observes that a multinational has a higher capital stock, either at home or in the foreign country. The country openness is, as follows from (15), a product of two factors. First, it is determined by the ratio of proportion factors that is equal to the ratio of domestic capital stocks $v_{i,t}^{-i}/v_{i,t}^{i} = K_{i,t}^{-i}/K_{i,t}^{i}$ and, second, it is determined by the ratio of technology capital M_t^i/M_t^{-i}. Thus, changes in the observed levels of tangible capital stock affect the openness either directly through the proportion factors, or indirectly, through the implied stock of technology capital. One can show that the openness parameter can be written as

$$\omega_{i,t}^{-i} = \left(\frac{1 + \mu_{-i,t}^{i}}{1 + \dfrac{1}{\mu_{i,t}^{-i}}} \right)^{\phi}, \tag{16}$$

where $\mu_{-i,t}^{i} = K_{-i,t}^{i}/K_{i,t}^{i}$. The equation shows that country openness is fully determined by the ratio of capital stock of multinationals abroad to the capital stock of multinationals at home. The openness of country i depends positively both on the relative capital stock of domestic multinationals $\mu^{i}_{-i,t}$ and of foreign multinationals $\mu^{-i}_{i,t}$. The ratio of the effective technology capital stock to the domestic tangible capital stock can be shown to be equal to

$$\frac{M_{i,t}}{K_{i,t}} = \lambda_t(1 + \mu^{i}_{-i,t}),$$

and depends therefore only on the relative capital stock of domestic multinationals $\mu^{i}_{-i,t}$. Figure 3 implies that the variations in $\mu^{-i}_{i,t}$ and $\mu^{i}_{-i,t}$ account for most of the variations in the openness parameters.

C. *Comparison with McGrattan and Prescott*

Relative to McGrattan and Prescott (2010), there are several important differences in the estimation procedure and estimation results. First, McGrattan and Prescott (2010) estimate the openness parameters so as to mimic the trend path of the ratio of US direct investment abroad to US GNP, and of the ratio of US foreign direct investment to US GNP. Their estimates are exogenously restricted to satisfy $\omega_{US,t} = a_u\big(1 + b_u \tanh(c_u + d_u t)\big)$ and $\omega_{RW,t} = a_t + b_r t$. In contrast, the estimates in this paper use a simple identifying assumption that the rates of return are equal on both types of capital, and are not required to fit any functional forms. They can thus be used to study fluctuations in country openness. Moreover, equation (16) shows that the openness parameter is naturally related to the relative stock of tangible capital rather than the ratios of direct investment to GNP ratios. Finally, restricting attention to long-run trends may make the estimates less transparent because they depend on the whole structure of the model, including preferences. Estimates in this paper depend only on the stock of tangible capital home and abroad for all countries, GDP for all countries, and tax rates for all countries. They are therefore relatively easy to compute without knowing the rest of the model.

Qualitatively, the estimates of the openness parameters show a similar picture. US openness is smaller than the rest of the world openness, and the gap is decreasing over time. Quantitatively, however, the estimates differ. For instance, McGrattan and Prescott (2010) estimate that the openness of the US economy and the rest of the world was 0.806 and 0.877 in 2005. The respective estimates in this paper are 0.685 and 0.738. One source of differences is that McGrattan and Prescott (2010) calibrate the data to an average investment in technology capital to GDP ratio of only 5.3 percent, reflecting a focus on a longer time period. Re-estimating the openness parameter with their average investment in technology capital to GDP ratio yields the US and rest of the world openness parameters of 0.777 and 0.817 in 2005. That can explain about three-fourths of the gap for the US economy, and a little more than half of the gap for the rest of the world. A second source of differences is that McGrattan and Prescott (2010) estimate the taxes on capital to be equal to the average tax liability of corporations. Further re-estimating the openness parameters using the average investment in technology capital to GDP ratio of 5.3 percent and their tax rates on profits yields US and rest of the world openness of 0.791 and 0.823 in 2005. Taken together, those two differences explain 89 percent of the gap for the

US economy, and 61 percent of the gap for the rest of the world. The remaining gap is most likely due to the differences in the estimation method, McGrattan and Prescott (2010) parametric restrictions, and the fact that their model also includes a plant specific intangible capital stock.

D. *Robustness Analysis*

The estimation rests on a number of assumptions. In this section, I examine the role of various assumptions in the estimation.

Treatment of Investment in Technology Capital.—The estimation procedure assumes that investment in the technology capital is expensed, while investment in the tangible capital is not. This assumption reflects the fact that national accounting systems typically do not recognize technology capital as an asset. In the estimations the investment in technology capital will be equated with R&D expenditures, expenditures on brand equity, and expenditures on organizational capital. As noted by Corrado, Hulten, and Sichel (2005), virtually none of those expenditures is recognized as investment.

The estimation procedure also assumes that all the investment in technology capital is assumed to be made by the domestic firm. While this is not literally true in the data, it is a reasonable approximation. According to the OECD's Main Science and Technology Indicators, the R&D expenditures of majority-owned US affiliates abroad are only 14 percent of total R&D expenditures of US multinationals in 2006. For the rest of the world, this number is available only for a subset of countries. It varies significantly, ranging from 5.4 percent for Japan to 70.3 percent for Ireland. On average, the R&D expenditures of majority-owned rest of the world affiliates are only 21.4 percent of total R&D expenditures of US multinationals in 2006.[12]

Computation of Proportion Factors.—The theory predicts that the proportion factors $v^j_{i,t}$ can be as well computed using production data, labor input data, and data on employee compensation:

$$v^j_{i,t} = \frac{Y^j_{i,t}}{Y_{i,t}} = \frac{L^j_{i,t}}{L_{i,t}} = \frac{w_{i,t}L^j_{i,t}}{w_{i,t}L_{i,t}}.$$

The financial and operating data of US affiliates and of foreign affiliates, available from the Bureau of Economic Analysis, provide a data source that can be used to compute the alternative measures of the proportion factor. The values of $Y^{RW}_{US,t}$, $L^{RW}_{US,t}$, and $w_{US,t}L^{RW}_{US,t}$ are measured using gross product, number of employees, and employee compensation of all US affiliates of foreign multinationals. Similarly, $Y^{US}_{RW,t}$, $L^{US}_{RW,t}$, and $w_{RW,t}L^{US}_{RW,t}$ are measured by gross product, number of employees, and employee compensation of majority-owned foreign affiliates of US multinationals. The Data Appendix contains additional details.

[12] See OECD's Main Science and Technology Indicators (2010, table 64).

While using the financial and operating data to compute the proportion factors is theoretically equivalent to using the capital stock data, it is likely to be inferior in practice. First, the financial and operating data cover only nonbank affiliates, leaving a significant fraction of affiliates out. In addition, to compute the economy-wide value added $Y_{i,t}$, employment $L_{i,t}$, and employment compensation $w_{i,t}L_{i,t}$, one needs to include the nonbank sector as well. While for the US economy those data are available from the NIPA accounts, for the rest of the world, those measures are not readily available. It is therefore assumed that the ratio of the value added of a nonbank sector to GDP is the same in the United States and in the rest of the world, and similarly for the other two measures.

Figure 4 shows the resulting estimates for the US economy. All three alternative estimates are similar to the benchmark estimates in magnitude, although they tend to increase overtime less rapidly. The effective technology capital to tangible capital ratio estimates are now about 2 percent higher than the benchmark estimates. After 1990, they, again, tend to increase less rapidly than the benchmark estimates.

Technology of Domestic Firms and Foreign Affiliates.—The technology of foreign affiliates is assumed to be identical to the technology of domestic firms. To check accuracy of this assumption, I have computed the capital share of foreign affiliates in the US using the financial and operating data of foreign affiliates, available from the Bureau of Economic Analysis for the 1982–2007 time period.[13] The average capital share is 0.362. This is very similar to the average capital share for the US economy overall, which is 0.334. The average capital share of the rest of the world countries, computed from the OECD data is found to be 0.344, which is, again, very similar. On the other hand, US affiliates abroad operate a technology that is more capital intensive. The capital share of US affiliates abroad is 0.552 on average.

The assumption of equal capital shares affects the estimation in two ways. First, it is essential for capital, labor, and production of foreign multinationals to be in the same proportion to their respective economywide quantities (equations 8a–8c). The first problem disappears if $Y_{i,t}^{j}$ is observed directly or, equivalently, the proportion factor is computed by $v_{i,t} = Y_{i,t}^{i}/Y_{i,t}$ as shown in Figure 4 using the value added.

Second, the equality of capital shares in all firms allows the rate of return on capital to be computed from the economy-wide tangible capital to output ratio (equation 4). To assess the importance of this effect, I have computed the rate of return on capital in the rest of the world by using the tangible capital to output ratio of only the domestic firms in the rest of the world:

$$R_{RW,t+1}^{K} = (1 - \tau_{RW,t+1}^{K})\left(\alpha(1 - \phi)\,\frac{Y_{RW,t+1}^{RW}}{K_{RW,t+1}^{RW}} - \delta_K\right).$$

[13] The capital share is computed by one minus the ratio of employee compensation and the gross product of foreign affiliates. Due to the lack of data, all foreign affiliates are considered for the 1982–1996 period, and majority owned foreign affiliates are used for the 1997–2007 period.

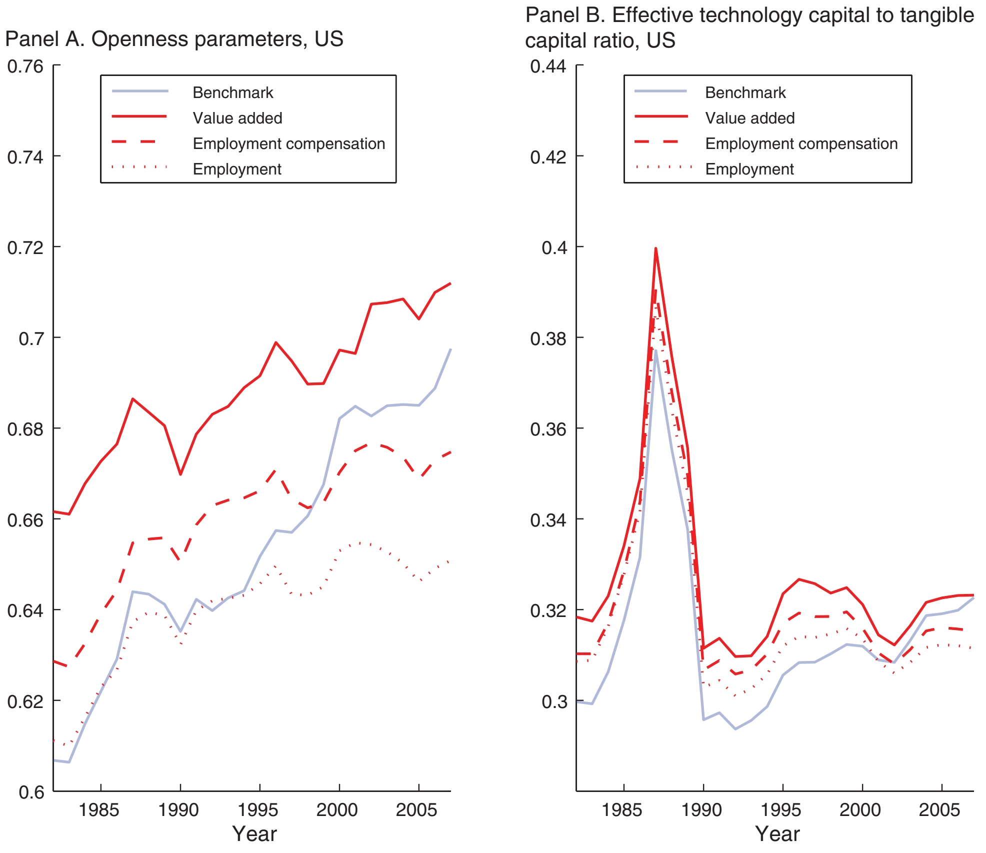

Figure 4. Alternative Proportion Factors, US

As a result, the openness of both the US economy and the rest of the world decreases by about 5 percentage points. There is virtually no change in the ratio of effective technology capital and tangible capital.

Definition of the Rest of the World.—I have redefined the rest of the world to include a larger number of foreign countries for which all data were available.[14] The alternative estimates of the openness parameters are slightly lower for the US economy, and slightly higher for the rest of the world. In both cases, however, the time profile is practically the same as before. The technology capital to tangible capital stock ratios are almost identical to the benchmark estimates. Thus, the effect of the definition of the rest of the world is small.

[14] The following countries were added: Argentina, Bolivia, Brazil, Chile, China, Colombia, Costa Rica, Cyprus, Dominican Republic, Ecuador, Guatemala, Jamaica, Malta, Peru, Singapore, Taiwan, Uruguay, and Venezuela. I use the World Bank estimates of Nehru and Dhareshwar (1995) for capital stock data, and the GGDC Total Economy database for GDP data. Since the World Bank time series end in 1990, I extend the series by assuming that the capital-output ratio in 1991–2005 is the same as the capital-output ratio in 1990.

Table 2—Alternative Parameter Values, 1982–2007 average

	ω_{US}	ω_{RW}	$\frac{M_{US}}{K_{US}}$	$\frac{M_{US}}{K_{US}}$
Benchmark	0.654	0.712	0.314	0.310
$\delta_M = 0.10$	0.669	0.722	0.265	0.255
$\delta_M = 0.06$	0.631	0.697	0.387	0.395
$\frac{X_M}{GDP} = 0.10$	0.589	0.655	0.393	0.389
$\frac{X_M}{GDP} = 0.06$	0.726	0.774	0.236	0.232

Ratio of Investment to Technology Capital and Production.—I have experimented with the average ratio of investment in technology capital and production being 10 percent and 6 percent rather than 8 percent. The results are shown in Table 2. The estimates of country openness are sensitive to this ratio. They decrease by 6.50 percentage points for the US economy in the first case, and increases by 7.20 percentage points in the second case. The ratio of both capital stocks is affected as well, and it increases in the first case and decreases in the second case. The effects are similar for the rest of the world.

Depreciation of Technology Capital.—If one increases the depreciation rate of technology capital to 10 percent, then, predictably, the ratio of effective technology capital and tangible capital decreases. It decreases from 0.314 to 0.265. The results are fairly symmetric if one decreases the depreciation rate of technology capital to 6 percent. Country openness decreases by 4.67 percentage points and the ratio of both capital stocks increases to 0.395. In both cases, the impact on the openness parameters is negligible, and the effects are similar for the rest of the world. The results are again shown in Table 2.

Terminal Condition.—I have also experimented with several sensible alternatives. First, I have assumed that the ratio of investment in technology capital to output in 2007 is equal to its long-run average of 8 percent. Second, I have assumed that the investment in technology capital in 2007 is 20 percent higher (lower) than the investment in 2006. In all cases, the effects on the aggregate estimates of capital stock and openness parameters were negligible.

III. The Estimates: A Multi-country Analysis

While Proposition 1 creates a useful benchmark, it is clear that its assumptions are usually not satisfied. An explicit multi-country analysis is needed to determine how important the bias in the aggregation is. In this section I, provide the estimates of country openness and of technology capital using a multi-country framework for a shorter time period, 1993–2007.

A. *Calibration*

I consider the following set of countries: Australia, Austria, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Sweden, Switzerland, Great Britain, and United States. The choice of countries is, to a large extent, dictated by the availability of data; one needs to know the bilateral stocks of foreign direct investment. For the same reason, the analysis focuses on the 1993–2007 time period.

Data.—The tangible capital stock of foreign multinationals, $\mathbf{K}_{\mathbf{i}}^{\mathbf{j}}$, is measured by the direct investment position of country i in country j. The data are taken from the OECD's Foreign Direct Investment position dataset. Ideally, each position should be recorded twice: once in the statistics for country i as an outward FDI stock, and once in the statistics for country j as an inward FDI stock. However, the data often disagree. The procedure used is to give priority to the data obtained from countries that have more consistent data reporting. In particular, the data are taken in the following order of precedence: United States, Canada, Great Britain, Germany, Netherlands, France, Italy, Austria, Switzerland, Sweden, Norway, Denmark, Finland, Japan, and Australia. That way, the resulting matrix $\mathbf{K}_{\mathbf{i}}^{\mathbf{j}}$ agrees with United States' inward and outward FDI position toward all the other countries. It agrees with Canada's inward and outward FDI position toward all the other countries, with the exception of United States, and so on.

The economy-wide capital stock $\mathbf{K}_{\mathbf{i}}$, gross domestic product $\mathbf{GDP}_{\mathbf{i}}$, and the tax rates $\tau_{\mathbf{i}}^{\mathbf{K}}$ are identical to the ones in Section II.

Parameters.—The estimation procedure yields $\phi = 0.1090$ to match the investment in technology capital to GDP ratio of 8 percent. The remaining parameters are identical to the ones given in Table 1.

B. *The Estimates*

Figure 5 shows the estimate of US openness obtained from the aggregated procedure, when all the countries other than the United States are aggregated into one foreign country; and the average US openness obtained in the disaggregated procedure, with the average being weighted by the technology capital stock, as suggested by Proposition 1. The estimates are nearly identical, the difference is less one half of a percentage point, on average. Thus, the bias obtained from the aggregation procedure is small.

When one compares the rest of the world openness in the aggregated procedure with the openness of the rest of the world countries in the disaggregated procedure, one finds evidence for the bias suggested in the discussion following Proposition 1. The rest of the world openness in the aggregated procedure is significantly higher than the openness of the rest of the world obtained from the disaggregated procedure. In fact, while the aggregated procedure shows that the rest of the world is more open than the US economy, the disaggregated procedure shows that the US economy is more open than each of the rest of the world countries! The most open

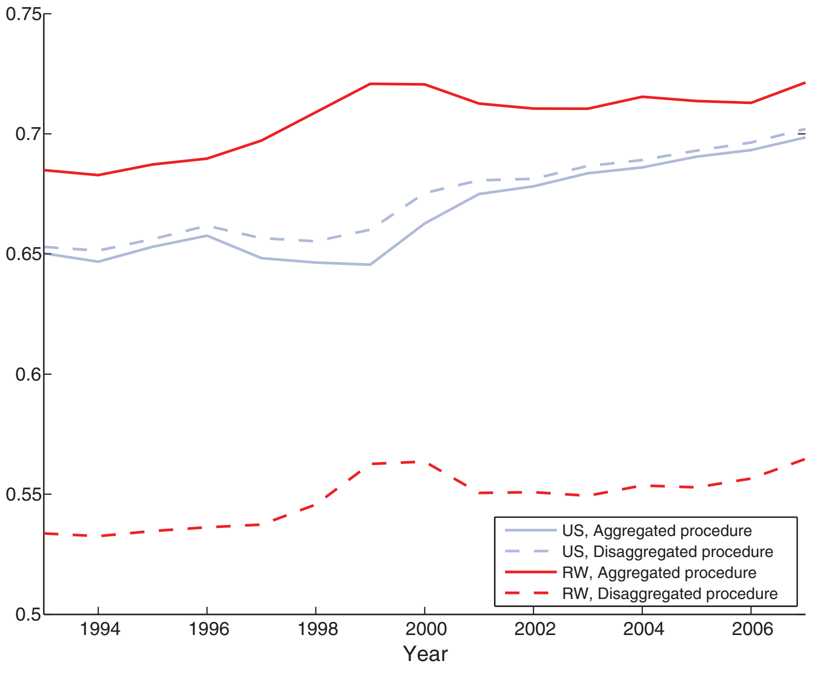

Figure 5. Openness Parameters, US Economy

rest of the world countries are the Netherlands (0.603, on average) and Great Britain (0.601, on average). The most closed rest of the world countries are Norway (0.441, on average), Finland (0.419, on average), and Denmark (0.447, on average).

The discussion after Proposition 1 also gives a rule of thumb for the magnitude of the bias. If all the rest of the world countries are identical and completely closed to each other, then the rest of the world openness is $(I - 1)^{\phi} = 1.333$ times the average rest of the world openness in the disaggregated procedure. The estimated ratio is equal to 1.287. Thus, the scaling factor $(I - 1)^{\phi}$ turns out to be a fairly accurate guess of the bias.

Table 3 shows the mutual openness for a selected subset of countries, averaged over the 1993–2007 time period. Rows denote the country whose openness is measured, and columns denote the partner country. For example, the average openness of the US economy toward Canada is 0.705, while the average openness of Canada toward the US economy is 0.590. The table shows that the US economy is open especially toward Switzerland, the Netherlands, and Great Britain. On the other hand, the openness of the US economy toward Norway, Japan, and especially Italy is relatively small. Looking in the other direction, the Netherlands, Great Britain, and Canada are the most open toward the US Economy. The rest of the world countries are mutually, relatively closed. Perhaps surprisingly, France, Italy, and Germany seem to be mutually, relatively closed toward each other, despite obvious physical proximities. The largest openness among those three countries is German openness toward France, which is 0.602.

Table 3—Average Openness 1993–2007, Selected Countries

	CAN	FRA	GER	ITA	JPN	NLD	GBR	USA
CAN	1.000	0.530	0.470	0.382	0.451	0.613	0.573	0.590
FRA	0.502	1.000	0.568	0.543	0.442	0.661	0.609	0.512
GER	0.501	0.602	1.000	0.505	0.475	0.779	0.583	0.535
ITA	0.439	0.566	0.547	1.000	0.401	0.595	0.533	0.483
JPN	0.502	0.495	0.492	0.423	1.000	0.497	0.497	0.532
NLD	0.530	0.554	0.627	0.427	0.468	1.000	0.735	0.594
GBR	0.613	0.612	0.583	0.475	0.489	0.745	1.000	0.616
USA	0.705	0.658	0.648	0.483	0.623	0.794	0.737	1.000

Other Measures of Openness.—Golub (2003) provides a measure of formal restrictions that countries impose on foreign direct investment. He considers the following restrictions: restrictions on foreign ownership (e.g., a requirement that foreigners hold less than 50 percent of equity), screening and approval procedures (e.g., a requirement that the investor must show "economic benefits" of FDI), and other formal restrictions (e.g., a requirement that nationals must form the majority of the board of directors). He provides a comprehensive index of FDI restrictions that weighs those restrictions in a somewhat arbitrary way.

It is reasonable to imagine that those restrictions would manifest themselves in a lower total factor productivity of foreign multinationals. Upper bounds on equity holdings or restrictions on the composition of the board of directors can create moral hazard problems within the firm. Extensive approval procedures may require the firm to divert its resources to unproductive uses. However, unlike the concept of openness in this paper, the index of FDI restrictions only includes formal restrictions and is thus narrower. The correlation between his index of FDI restrictions and country openness in 2000 is negative, as expected, and is equal to -0.242. Two outliers are United States and Canada, which are relatively open, but their index of FDI restrictions is relatively high. Perhaps, the informal restrictions on US FDI in Canada and Canadian FDI in the US are small, and they more than make up for the formal restrictions. If those two countries are removed from the sample, the negative correlation between the index of FDI restrictions and country openness becomes stronger, and is now equal to -0.511.

C. *Openness*, *Trade*, *Taxes*, *and GDP*

The concept of country openness is a completely different concept than is trade openness. It is nevertheless interesting to see if there is a statistical relationship between the two concepts. To investigate this, I have computed the ratio of goods imports to GDP for all the countries in the sample. The trade data are taken from the OECD's STAN bilateral trade database. Averaging across all countries and years, the correlation between country $i's$ openness toward country j and country $i's$ imports from country j is 0.449. Thus, countries that are more receptive toward foreign technology capital are also more receptive toward foreign imports. The correlation is stable over time. It varies over countries in magnitude, but is almost always positive.

The two exceptions are Japan and Australia. In those countries, country openness is slightly negatively correlated with imports.

I have also computed the correlations between the average country openness toward the other countries and country's tax rates and real GDP. Country openness is highly correlated with its GDP, with the average correlation being 0.649. On the other hand, the correlation between country's openness and its effective marginal corporate tax rates is only 0.159 overall, and is in fact only 0.060 after 2000.

IV. What are the Gains from Openness?

I will now use the estimates of technology capital and country openness to evaluate the performance of a neoclassical growth model with technology capital. I will also compute welfare gains/losses from either closing or opening the US economy or the rest of the world in 1982. The welfare calculations are done using a two-country framework, and the two-country estimates of Section II.

The agents in country $i \in \{US, RW\}$ evaluate sequences of consumption according to the following utility function:

$$(17) \qquad \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho}\right)^t N_{i,t} \frac{\left(\frac{C_{i,t}}{N_{i,t}}\right)^{1-\theta}}{1-\theta}, \qquad \theta > 0,$$

where ρ is the discount rate; $N_{i,t}$ is the population in country i; and $C_{i,t}/N_{i,t}$ is consumption per person in country i.

The agents have three ways of transferring wealth over time. They can buy shares of US multinationals, shares of foreign multinationals, or they can buy bonds. All three choices are perfect substitutes to each other, and the equilibrium composition of the portfolio is indeterminate. Therefore, the problem can be simplified by assuming that country *i's* citizens own 100 percent of country i multinationals, and none of country $-i$ multinationals. The budget constraint then becomes

$$(18) \qquad C_{i,t} + B_{i,t+1} = W_{i,t} N_{i,t} + D^i_{i,t} + D^i_{-i,t} + (1 + r_t) B_{i,t} + T_{i,t},$$

where $B_{i,t}$ are the bond holdings at the beginning of period t, and $T_{i,t}$ are government lump sum transfers which, in equilibrium, must satisfy

$$T_{i,t} = \tau^K_{i,t}\big((\phi + \alpha(1-\phi))Y_{i,t} - \delta_K K_{i,t}\big) - (1 - \tau^K_{i,t}) X^i_{M,t}.$$

Note that the interest rate r_t is now common in both countries.

The production of country i is thus given by the aggregate production function, which can be written as[15]

$$Y_{i,t} = A_{i,t} N_{i,t}^{\phi}(M_t^i + \omega_{i,t} M_t^{-i})^{\phi} K_{i,t}^{\alpha(1-\phi)} L_{i,t}^{(1-\alpha)(1-\phi)}.$$

Each agent is assumed to supply one unit of labor inelastically, and so $L_{i,t} = N_{i,t}$. Consumption, tangible capital, and technology capital are all required to be nonnegative. Moreover, it is not possible to convert technology capital back to consumption goods, and so the investment in technology capital is required to be nonnegative as well. Net exports are given by $NX_{i,t} = Y_{i,t} - X_{i,t}^K - X_{i,t}^M - C_{i,t}$, and foreign direct investment is given by $FDI_{i,t} = K_{-i,t+1}^i - K_{-i,t}^i$, where $K_{-i,t}^i$ can be computed using the proportion factors from the capital stock $K_{-i,t}$

The *competitive equilibrium* consists of allocations $\{C_{i,t}, Y_{i,t}, K_{i,t+1}, M_{t+1}^i, B_{i,t}\}$, and prices $\{W_{i,t}, r_t\}$ such that, given the initial capital stocks of tangible capital K_{i0} and of technology capital M_0^i and exogenous sequences $\{N_{i,t}, A_{i,t}, \omega_{i,t}, \tau_{i,t}^K\}$, households in each country maximize (17) subject to (18), taking prices, taxes, and dividends as given; firms solve problem (3) taking prices as given; the government budget is balanced each period; and markets clear.

Properties of Equilibrium.—It is assumed that the total factor productivity $A_{i,t}$ and population $N_{i,t}$ converge over time to a constant growth rate γ and η. Similarly, the tax rate on profits $\tau_{i,t}^K$ and the openness parameter $w_{i,t}$ converge over time to a constant. The economy then converges to a balanced growth path, where consumption per person $C_{i,t}/N_{i,t}$, output per person $Y_{i,t}/N_{i,t}$, technology capital per person $M_t^i/N_{i,t}$, and tangible capital per person $K_{i,t}/N_{i,t}$ all grow at a common rate g, given by $g = [(1 + \gamma)(1 + \eta)^{\phi}]^{\frac{1}{(1-\alpha)(1-\phi)}} - 1$.

Depending on whether the nonnegativity constraints on investment in technology capital bind, three possibilities can arise in any given period. In the first case, investment in technology capital is strictly positive in both countries. The net rates of return from all investments are then equalized:

$$R_{i,t}^M = R_{i,t}^K = r_t = R_{-i,t}^K = R_{-i,t}^M.$$

In the second case, investment in technology capital is zero in country i but strictly positive in country $-i$. Then the net rates of return from investments in tangible capital and from investment in technology capital in country i are still equalized, and they are greater than the net rate of return from investment in technology capital in country $-i$:

$$R_{i,t}^M = R_{i,t}^K = r_t = R_{-i,t}^K > R_{-i,t}^M.$$

[15] See McGrattan and Prescott (2009).

In the third case, both investments in technology capital are zero. Then the net rates of return from investment in technology capital are smaller in both countries:

$$R^M_{i,t} < R^K_{i,t} = r_t = R^K_{-i,t} > R^M_{-i,t}.$$

Calibration.—In the benchmark scenario, the openness parameters are assumed to be equal to the estimated values in the first 25 periods (corresponding to years 1982–2007), and constant after that. The tax rates on profits are equal to their values used in the estimation for the first 25, and are constant after that as well. The US population in the first 25 years is equal to its values used in the estimation. The rest of the world population is in addition rescaled to match the ratio of US net exports to US GDP in the first period. That requires an increase of 32.9 percent of the rest of the world population. After the first 25 years, both populations grow at a common growth rate η, equal to the average growth rate in 1982–2007, which is 0.99 percent. The model total factor productivity for 1982–2007 for both countries equals the Solow residuals $A_{i,t}$. The common long-run growth rate of total factor productivity γ is taken to be the average growth rate of the US and rest of the world total factor productivity in the 1982–2007 time period, which is 1.02 percent.

The discount rate ρ is chosen in such a way that the steady state capital output ratio equals 2.28, which is the average US capital-output ratio in 1982–2007. The implied value of ρ is 0.0582. The coefficient of relative risk aversion θ is set equal to one. The remaining parameters ϕ, α, δ^M and δ^K are the same as the ones used in the benchmark estimation.

A. *The Results*

Figure 6 plots the fluctuations in both US investments abroad and foreign investments in the United States, as a fraction of the country's GDP. The model overstates the increase in foreign direct investment in the United States in the late 1980's, but is able to replicate the decrease in the growth rate in the early 1990's, and a more rapid increase in late 1990's. The model also succesfully captures the fluctuations in US direct investment abroad.[16]

Although the model is successful in explaining movements in foreign direct investment, it is not very successful in explaining higher frequency movements in US net exports. US net exports in the model are much more volatile than US net exports in the data. The standard deviation of export to GDP ratio is 0.092, which is six times larger than in the data. The inability to explain higher frequency movements in net exports without any adjustment costs is not surprising and has been found in the literature previously.[17]

[16] It is worth noting that, to some extent, the success of the model is to be expected because the openness parameters and technology capital stocks were estimated using one of the equilibrium conditions of the model, namely the equality of the net rates of return within country. Naturally, the model provides more restrictions which determine its success in explaining the data.

[17] See e.g., (Chen, İmrohoroğlu, and İmrohoroğlu 2009).

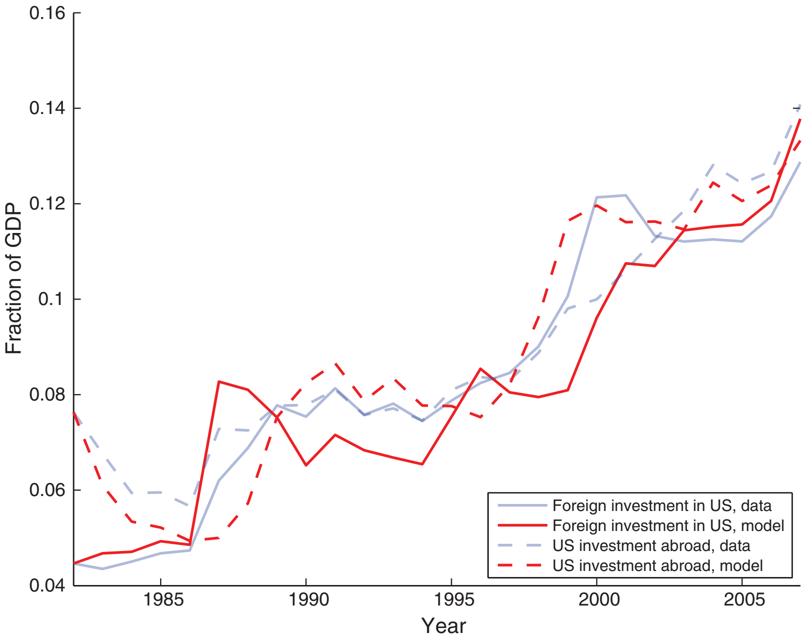

Figure 6. Foreign Direct Investment

Gains from Current US Openness.—The welfare loss from forever totally closing the US economy in 1982 (i.e., setting $\omega_{US}^{RW} = 0$ in all future periods starting in 1982) turns out to be very small. They are equal to 0.195 percent of consumption (in consumption equivalents). When both US economy and the rest of the world are totally closed in 1982, the welfare losses are larger, but still small. They are equal to 0.412 percent of consumption. The welfare gains and losses are in Table 4.

Gains from Opening US Economy Further.—If the US economy opens totally,[18] it is no longer efficient to invest in technology capital in the United States. Since a lot of technology capital is permitted from abroad, the rate of return from investing in technology capital is low. The US economy imports all its technology capital from abroad. The gain in measured productivity is about 21.5 percent in all periods. The welfare gain from totally opening the US economy turns out to be large as well. It is equal to 8.171 percent of consumption.[19]

The fact that there is no investment in US technology capital allows for an immediate increase in consumption in both countries. At the same time, total openness of the US economy increases the rate of return on investment in technology capital in the rest of the world. In response, the rest of the world increases its investment in technology capital. Increases in foreign technology capital are more significant than decreases in US technology capital, and so consumption grows faster over the transition.

[18] For computational reasons, total openness is equivalent to setting $\omega = 0.99$ rather than 1.

[19] The magnitude of both welfare losses from totally closing and welfare gains of US economy from totally opening are similar to the ones reported by Ramondo (2010), where the welfare losses from closing the US economy are close to zero, and the welfare gains from opening are 8 percent. See Ramondo (2010, table 9, case II).

TABLE 4—GAINS FROM OPENNESS, IN PERCENT CONS. EQUIV.

	Welfare gain
US totally closed	−0.195
US and RW totally closed	−0.412
US totally open	8.171
RW totally open	7.910
US and RW totally open	9.283

The gains from the rest of the world opening totally are slightly smaller than the gains from the US economy opening totally. When both the US economy and the rest of the world open totally, the welfare gain is larger by an additional 1.112 percent.

V. Conclusions

This paper has two goals. First, it estimates the stock of technology capital, and country openness in the United States and in other countries. Second, using the estimates, it evaluates the performance of a neoclassical growth model with technology capital, and quantifies the gains from country openness.

I identify the time series of technology capital and country openness by assuming that the net rates of return on both types of capital are equalized within each firm. I estimate that the effective technology capital is about one-third of the stock of tangible capital stock for both the US economy and for the rest of the world. The openness of the US economy has been increasing over time, from about 0.61 in 1982 to about 0.70 in 2007. The interpretation is that the total factor productivity of foreign multinationals in the United States is 61 percent of domestic firms in 1982, and it increases to 70 percent in 2007.

The estimates of US openness are found to be robust to alternative assumptions about the definition of the rest of the world, the way proportion factors are computed, the depreciation rate on technology capital and the terminal condition on investment in technology capital. They are somewhat sensitive to the average investment in technology capital to GDP ratio. A multicountry analysis shows that the estimates are almost the same when the rest of the world countries are disaggregated.

On the other hand, the openness of the rest of the world is sensitive to whether countries are aggregated. An aggregated procedure biases the estimates upward. As a rule of thumb, the size of the bias is $(I - 1)^{\phi}$, where I is the number of countries, and ϕ is the degree of decreasing returns. The rest of the world estimates are also somewhat sensitive to the average investment in technology capital to GDP ratio and the way proportion factors are computed.

The neoclassical growth model with technology capital performs well in explaining the movements in output and foreign direct investment between 1982 and 2007. I also find that the losses from totally closing both economies are small. On the other hand, the gains from opening the US economy totally are much larger.

One reason why the estimates of welfare gains from opening the economy further might be too large is that total openness may be impossible to achieve. The implicit assumption in the welfare calculation is that the degree of openness is related to government policies, and one thus computes the welfare gains from moving toward the best government policy. But maybe no government policy can achieve total openness because there are other limitations on the flow of foreign direct investment, such as physical distance (see the evidence in Ramondo 2010). If that is the case, one should really compare the current degree of openness with a degree of openness that is achievable by the best government policy. Estimation of the upper bound on country openness is left for future research.

On the other hand, the welfare gains from opening less developed countries or countries with a smaller population are likely to be much larger than the welfare gains from opening US economy. In both cases foreign technology capital will, at least potentially play a larger role in domestic production than in the case of the US economy. In this sense, studying the US economy versus the rest of the world probably gives us a lower bound on potential gains from openness across the world.

Data Appendix

A. *Data Sources*

- US tangible fixed capital stock (K_{US}): NIPA Fixed Asset Table 1.2, line 3. Converted to 1990 US dollars using NIPA Fixed Asset Table 1.1, line 3.
- US real GDP (GDP_{US}): NIPA table 1.1.5 line 1. Converted to 1990 US dollars by using NIPA table 1.1.9 line 1.
- Rest of the world tangible fixed capital stock ($K_j, j \in RW$): AMECO Total economy net capital stock at 2000 prices, national currency (OKND series). Deflated by the United Nations Estimates of GDP Price Deflator in National Currency (http://unstats.un.org/unsd/snaama/selbasicFast.asp) to convert it to 1990 prices in national currency. Converted into 1990 US dollars (Geary-Khamis purchasing power parity) by using Penn World Table variables XRAT and PPP.
- Rest of the world real GDP ($GDP_j, j \in RW$): Groningen Total Economy database, Total GDP, in millions of 1990 US dollars table (http://www.conference-board.org/retrievefile.cfm?filename=TEDI-Jan20121.x1s&type=subsite).
- Tangible capital stock of US firms abroad, ($K_j^{US}, j \in RW$): BEA US Direct Investment Abroad, US Direct Investment Position Abroad on a Historical-Cost Basis, by country (http://www.bea.gov/international/di1usdbal.htm). Converted to current costs by multiplying by BEA International Investment Position of the United States at Yearend, 1976–2007, line 18 (http://www.bea.gov/international/xls/intinv09_t2.xls) and dividing by the US Direct Investment Position Abroad on a Historical-Cost Basis, all countries.
- Tangible capital stock of foreign firms in the US, ($K^j_{US}, j \in RW$): BEA, Foreign Direct Investment in the US, Foreign Direct Investment Position in the United States on a Historical-Cost Basis, by country (http://www.bea.gov/international/di1fdibal.htm). Converted to current costs by multiplying by BEA International Investment Position of the United States at Yearend, 1976–2007, line 35 (http://www.bea.gov/international/xls/intinv09_t2.xls) and dividing by the Foreign Direct Investment Position in the United States on a Historical-Cost Basis, all countries.

- Effective marginal corporate tax rates $(\tau_j^K, j \in US, RW)$: Hassett and Mathur (2006), data provided by the authors.
- Gross product, number of employees and employee compensation of all US affiliates of foreign multinationals $(Y_{RW,t}^{US}, L_{RW,t}^{US}$ and $w_{RW,t}\, L_{RW,t}^{US})$: BEA, Foreign Direct Investment in the US: Financial and Operating Data for US Affiliates of Foreign Multinational Companies (http://www.bea.gov/international/di1usdop.htm). The data are scaled by the ownership shares of foreign multinationals in all US affiliates. The ownership shares are obtained as a fraction of equity that is owned by the multinationals. The ownership shares as well as the data on gross product are not available by country for all the required years, and so aggregate totals are used instead.
- Gross product, number of employees and employee compensation of majority-owned foreign affiliates of US multinationals $(Y_{RW,t}^{US}, L_{RW,t}^{US}$ and $w_{RW,t}\, L_{RW,t}^{US})$: BEA, US Direct Investment Abroad: Financial and Operating Data for US Multinational Companies (http://www.bea.gov/international/di1usdop.htm). Majority owned foreign affiliates are used because not all the required data are available for all foreign affiliates. The data are again scaled by the ownership shares of US multinationals in majority owned foreign affiliates.
- Tangible capital stock abroad, multicountry analysis $(K_i^j, i, j \in US, RW)$: OECD FDI positions by partner country (http://stats.oecd.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=FDI_POSITION_PARTNER&ShowOnWeb=true&Lang=en).

B. *Data Inputs*

Table B1—Data Inputs

year	K_{US}	K_{RW}	K_{RW}^{US}	K_{US}^{RW}	GDP_{US}	GDP_{RW}	τ_{US}^K	τ_{RW}^K
1982	11,500	23,577	349	204	4,234	8,013	0.285	0.363
1983	11,742	24,217	329	212	4,425	8,160	0.286	0.366
1984	12,067	24,864	313	237	4,743	8,431	0.287	0.368
1985	12,409	25,553	328	258	4,939	8,707	0.284	0.370
1986	12,754	26,264	346	289	5,110	8,951	0.279	0.372
1987	13,086	27,043	400	341	5,283	9,273	0.257	0.371
1988	13,429	27,959	417	396	5,501	9,707	0.240	0.365
1989	13,773	28,972	443	443	5,696	10,076	0.225	0.352
1990	14,092	30,053	483	468	5,803	10,428	0.227	0.339
1991	14,341	31,037	499	500	5,793	10,630	0.227	0.331
1992	14,613	31,987	487	487	5,986	10,802	0.229	0.326
1993	14,935	32,827	512	518	6,146	10,885	0.232	0.320
1994	15,294	33,597	518	518	6,393	11,174	0.234	0.316
1995	15,687	34,454	573	558	6,553	11,450	0.234	0.315
1996	16,137	35,323	612	603	6,796	11,754	0.233	0.317
1997	16,640	36,226	637	649	7,101	12,113	0.233	0.313
1998	17,209	36,950	710	720	7,398	12,307	0.232	0.304
1999	17,834	37,855	812	833	7,727	12,623	0.232	0.290
2000	18,493	38,902	855	1,038	8,010	13,147	0.232	0.275
2001	19,057	39,680	919	1,056	8,070	13,323	0.233	0.267
2002	19,559	40,595	1,002	1,008	8,199	13,541	0.235	0.262
2003	20,087	41,417	1,085	1,026	8,405	13,759	0.237	0.260
2004	20,669	42,348	1,203	1,057	8,710	14,167	0.237	0.257
2005	21,268	43,315	1,203	1,085	8,966	14,496	0.237	0.253
2006	21,950	44,405	1,262	1,168	9,215	14,948	0.236	0.249
2007	22,570	45,520	1,428	1,305	9,402	15,376	0.236	0.246

Note: All variables (except τ_{US}^K an τ_{RW}^K) are in billions of 1990 US dollars.

REFERENCES

Ambler, Steve, and Alain Paquet. 1994. "Stochastic Depreciation and the Business Cycle." *International Economic Review* 35 (1): 101–16.

Burnside, Craig, Martin Eichenbaum, and Sergio Rebelo. 1993. "Labor Hoarding and the Business Cycle." *Journal of Political Economy* 101 (2): 245–73.

Burstein, Ariel T., and Alexander Monge-Naranjo. 2009. "Foreign Know-How, Firm Control, and the Income of Developing Countries." *Quarterly Journal of Economics* 124 (1): 149–95.

Chen, Kaiji, Ayse Imrohoroglu, and Selahattin Imrohoroglu. 2009. "A Quantitative Assessment of the Decline in the U.S. Current Account." *Journal of Monetary Economics* 56 (8): 1135–47.

Corrado, Carol, Charles Hulten, and Daniel Sichel. 2005. "Measuring Capital and Technology: An Expanded Framework." In *Measuring Capital in the New Economy*, edited by Carol Corrado, John Haltiwanger, and Daniel Sichel, 11–41. Chicago: University of Chicago Press.

Eaton, Jonathan, and Samuel Kortum. 2002. "Technology, Geography, and Trade." *Econometrica* 70 (5): 1741–79.

Golub, Stephen S. 2003. "Measures of Restrictions on Inward Foreign Direct Investment for OECD Countries." *OECD Economic Studies* (36): 85–116.

Hassett, Kevin, and Aparna Mathur. 2006. "Taxes and Wages." American Enterprise Institute for Public Policy Research Working Paper 128.

Horstmann, Ignatius J., and James R. Markusen. 1989. "Firm-Specific Assets and the Gains from Direct Foreign Investment." *Economica* 56 (221): 41–48.

Ingram, Beth F., Narayana R. Kocherlakota, and N. E. Savin. 1997. "Using Theory for Measurement: An Analysis of the Cyclical Behavior of Home Production." *Journal of Monetary Economics* 40 (3): 435–56.

Kapička, Marek. 2012. "How Important is Technology Capital for the United States: Dataset." *American Economic Journal: Macroeconomics*. http://dx.doi.org/10.1257/mac.4.2.218.

McGrattan, Ellen R., and Edward C. Prescott. 2009. "Openness, Technology Capital, and Development." *Journal of Economic Theory* 144 (6): 2454–76.

McGrattan, Ellen R., and Edward C. Prescott. 2010. "Technology Capital and the US Current Account." *American Economic Review* 100 (4): 1493–1522.

Nehru, Vikhram, and Ashok Dhareshwar. 1995. "A New Database on Physical Capital Stock: Sources, Methodology, and Results." *Rivista de Análisis Económico* 8 (1): 37–59.

Prescott, Edward C. 1986. "Theory Ahead of Business-Cycle Measurement." *Carnegie-Rochester Conference Series on Public Policy*, 25: 11–44.

Ramondo, Natalia. 2010. "A Quantitative Approach to Multinational Production." Unpublished. https://sites.google.com/site/nataliaramondo/July252011.pdf?attredirects=0.

Ramondo, Natalia, and Andrés Rodríguez-Clare. 2010. "Trade, Multinational Production, and the Gains from Openness." Unpublished. https://sites.google.com/site/nataliaramondo/July252011.pdf?attredirects=0.

Rodríguez-Clare, Andrés. 2007. "Trade, Diffusion, and the Gains from Openness." National Bureau of Economic Research Working Paper 13662.