

# How Important is Technology Capital for the United States?

Marek Kapička

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## Abstract

I construct measures of technology capital and country openness for the US economy and the rest of the world for 1982-2006. Technology capital is found to be about one fourth of tangible capital for both USA and the rest of the world. US economy is less open than the rest of the world, and the degree of openness increases over time.

Using the estimates I show that the neoclassical growth model with technology capital successfully explains movements in US foreign direct investment. While the welfare losses from totally closing US economy are only about 0.17% of consumption, the welfare gains from totally opening US economy are equal to 7.42% of consumption.

## 1. INTRODUCTION

Recently, [McGrattan and Prescott \(2007\)](#) have extended the neoclassical growth model by introducing the concept of technology 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 ag-

gregate production function exhibits constant returns to scale in relevant inputs and a standard general competitive analysis applies. Depending on country openness, technology capital can be also replicated abroad through foreign direct investment. The model thus offers a promising new mechanism through which (more or less open) economies interact.

However, in order to develop sensible quantitative implications of the model, one needs to have estimates of two of the main ingredients of the model: the stock of technology capital, and the degree of openness of an economy. Neither of them are directly measured. In this paper I provide an estimation procedure that uncovers both from the data, and estimate them for the US economy and the rest of the world for the 1982-2006 period. I then use the estimates to evaluate the performance of a neoclassical growth model with the technology capital. I also estimate the welfare gains from totally closing US economy and from opening US economy further.

The estimation of the stock of technology capital and the degree of openness uses economic theory to obtain estimates of an unobserved quantity.<sup>1</sup> It relies on two main ingredients. First, it uses an identifying assumption that the net rates of return from investments to both technology capital and tangible capital are equalized *within each firm*. This condition is relatively weak, since it is necessary for the firms to maximize profits. The second ingredient in the estimation follows from the assumption that both tangible capital and labor are used efficiently *within each country*. This assumption implies that both tangible capital inputs and labor inputs of all the firms within a given country are related to the country-wide inputs in the same proportion, which depends on the stock of technology capital of all countries, and on country openness.

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<sup>1</sup> Similar estimation procedures have been used frequently in a business cycle analysis, 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.

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 all models that incorporate international capital flow frictions or trade frictions. Similarly, the estimates are consistent with models involving imperfect consumption insurance within each country.

For the 1982-2006 time period, the estimated US technology capital is between 19%-25% of the US tangible capital. For the rest of the world, the ratio is about 1% lower than the US ratio. US economy is found to be less open than the rest of the world in the whole period. The openness of the US economy increases over the whole period with the exception of early 1990's and early 2000's. Since both cases occur during recessions, the openness appears to be procyclical. The openness of the rest of the world decreases until about 1985, and increases after that.

I find that the neoclassical growth model with technology capital successfully captures the movements in the foreign direct investment in the US and abroad. I compute the welfare gains from either totally closing or totally opening US economy. While the welfare losses from totally closing US economy are found to be very small (0.17% of consumption, in consumption equivalents), the welfare gains from totally opening US economy are large (7.42% of consumption, in consumption equivalents). This indicates that, despite the increase in openness after 1982, the US economy is still closer to being totally closed, rather than totally open.

The importance of foreign direct investment and openness for welfare has long been recognized by the economic literature.<sup>2</sup> However, their quantitative importance has been addressed only recently. Most notably, [Ramondo \(2007\)](#) analyzes and estimates an [Eaton and Kortum \(2002\)](#) type model with technology diffusion across countries.<sup>3</sup>

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<sup>2</sup>See e.g. [Horstmann and Markusen \(1989\)](#) for an early analysis.

<sup>3</sup>See also [Burstein and Monge-Naranjo \(2006\)](#) where the gains from openness are derived from

While the source of welfare gains in her model is similar to this model, both approaches differ along several dimensions. First, the diffusion of technology in her model is exogenously given, rather than being endogenous like here. Thus, there is no interaction between the amount of technology diffusion in one country and openness of other countries. Second, her model is static, while this model is dynamic and one can analyze the transitional adjustment to a change in country openness. On the other hand, her model can be easily integrated with modern theories of international trade and one can jointly analyze gains from openness and gains from trade, as in [Rodriguez-Clare \(2008\)](#) and [Ramondo and Rodriguez-Clare \(2008\)](#). However, the main advantage of the approach in this paper is, in my view, 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.

The paper is organized as follows. Next section sets up the model, develops the estimation procedure, and presents the main estimates. Section 3 evaluates the ability of the neoclassical growth model in explaining movements in foreign direct investment, and computes the welfare costs and benefits from closing or opening the US economy or the rest of the world further. Section 4 concludes. Alternative estimates of the country openness and of the stock of technology capital are presented in the Appendix.

## 2. HOW LARGE IS THE U.S. TECHNOLOGY CAPITAL STOCK?

There are  $I$  countries in the world. Country  $i$  has a population  $N_{it}$  in period  $t$ . In each country 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  $N_{it}$ . In each location, at most one firm from each country can operate. Firms can set 

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reallocation of managerial talent across countries, and quantitatively evaluated.

up plants at both domestic and foreign locations. The production of each plant in country  $i$  depends on country  $i$ 's total factor productivity  $A_i$ ,<sup>4</sup> labor  $l$ , tangible capital  $k$ , and is given by  $y = A_i(k^\alpha l^{1-\alpha})^{1-\phi}$ . Each plants 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  $M_t^i$  units of technology capital,  $K_{it}$  units of tangible capital and  $L_{it}$  units of labor efficiently spreads tangible capital and labor across all  $M_t^i N_{it}$  plants. Therefore, its total production in country  $i$  is

$$Y_{it}^i = F_i^i(N_{it}, M_t^i, K_{it}^i, L_{it}^i) = A_{it}(M_t^i N_{it})^\phi \left( K_{it}^j{}^\alpha L_{it}^j{}^{(1-\alpha)} \right)^{(1-\phi)}.$$

Production of multinationals from a foreign country is determined similarly but depends, in addition, on the openness of country  $i$ . The degree of openness in period  $t$  is measured by a parameter  $\omega_{it} \in [0, 1]$  that determines the fraction of foreign technology capital that is permitted to enter the domestic country. A firm from country  $j \neq i$  produces a total output in country  $i$  given by

$$Y_{it}^j = F_i^j(N_{it}, M_t^i, K_{it}^j, L_{it}^j) = A_{it}(\omega_{it} M_t^i N_{it})^\phi \left( K_{it}^j{}^\alpha L_{it}^j{}^{(1-\alpha)} \right)^{(1-\phi)}.$$

As in [McGrattan and Prescott \(2007\)](#), a country  $i$  is called *totally open* if  $\omega_{it} = 1$  and *totally closed* if  $\omega_{it} = 0$ .

A multinational from country  $i$  chooses its labor input, tangible capital stock, and

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<sup>4</sup>In what follows, a subscript on a variable indicates the country where production takes place, while superscript indicates country of origin.

a technology capital stock to maximize the present discounted value of dividends,

$$\max_{\{L_{tj}^i, K_{tj}^i, M_t^i\}_{j,t}} \sum_{t=0}^{\infty} \sum_{j=1}^I p_{jt} D_{jt}^i, \quad (1)$$

where  $p_{jt}$  is the intertemporal price of consumption in country  $j$  (not necessarily equal across countries), and  $D_{jt}^i$  are dividends from multinational's production in country  $j$ . They are equal to the after tax profits minus reinvested earnings:

$$\begin{aligned} D_{it}^i &= (1 - \tau_{it}^K)(Y_{it}^i - W_{it}L_{it}^i - \delta_K K_{it}^i - X_{M,t}^i) - (K_{i,t+1}^i - K_{it}^i) \\ D_{jt}^i &= (1 - \tau_{jt}^K)(Y_{jt}^i - W_{jt}L_{jt}^i - \delta_K K_{jt}^i - (K_{j,t+1}^i - K_{jt}^i)), \quad j \neq i, \end{aligned}$$

where  $\tau_{jt}^K$  is the tax on profits in country  $j$ ,  $X_{M,t}^i = M_{t+1}^i - (1 - \delta_M)M_t^i$  is investment in technology capital in period  $t$ , and  $\delta_K$ , and  $\delta_M$  are the depreciation rates. Note that while the investment in the technology capital is expensed, the investment in tangible capital is not.

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

$$R_{i,t+1}^K = (1 - \tau_{i,t+1}^p) \left( \alpha(1 - \phi) \frac{Y_{i,t+1}}{K_{i,t+1}} - \delta_K \right) \quad (2)$$

$$R_{i,t+1}^M = \frac{1 - \tau_{i,t+1}^K}{1 - \tau_{it}^K} \left( \phi \frac{Y_{i,t+1}^i}{M_{t+1}^i} + 1 - \delta_M \right) + \sum_{j \neq i} \frac{1 - \tau_{j,t+1}^K}{1 - \tau_{it}^K} \frac{p_{j,t+1}}{p_{it}} \phi \frac{Y_{j,t+1}^i}{M_{t+1}^i} - 1. \quad (3)$$

If the multinationals allocate the resources efficiently, i.e. their choices solve problem (1), 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:

$$R_{i,t+1}^K = R_{i,t+1}^M = r_{i,t+1}, \quad (4)$$

where  $r_{i,t+1} = \frac{p_{it}}{p_{i,t+1}} - 1$ . The equality (4) 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*  $v_{it}^j$  to be the ratio of country  $j$ 's effective technology capital in country  $i$  and of country  $i$ 's total effective technology capital:

$$v_{it}^i = \frac{M_t^i}{M_t^i + \omega_{it} \sum_{j \neq i} M_t^j} \quad (5)$$

$$v_{it}^j = \frac{\omega_{it} M_t^j}{M_t^i + \omega_{it} \sum_{j \neq i} M_t^j}, \quad j \neq i. \quad (6)$$

The proportion factor  $v_{it}^j$  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.<sup>5</sup> In particular, the solution to the firm's problem (1) implies that tangible capital and labor inputs, as well as the production of all firms, are related to the countrywide aggregates  $K_{it}, L_{it}$  and  $Y_{it}$  in the same proportions:

$$Y_{it}^j = v_{it}^j Y_{it}, \quad (7)$$

$$K_{it}^j = v_{it}^j K_{it}, \quad (8)$$

$$L_{it}^j = v_{it}^j L_{it}, \quad (9)$$

The production of country  $i$  can then be characterized by an aggregate production function depending only on population  $N_{it}$ , aggregate capital and labor inputs  $K_{it}$

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<sup>5</sup>Equation (8) can be related to a similar equation (18) in [Ramondo \(2007\)](#). In her model, the fixed costs  $t_{ij}$  play a role similar to the role of country openness here, and the variable  $\Gamma_{ij}$  plays a role similar to the stock of technology capital here.

and  $L_{it}$ , and the technology capital in all countries  $M_t = (M_t^1, \dots, M_t^I)$ :

$$\begin{aligned} F_i(N_{it}, M_t, K_{it}, L_{it}) &= \sum_j F_i^j(N_{it}, M_t^j, K_{it}^j, L_{it}^j) \\ &= A_{it} N_{it}^\phi (M_t^i + \omega_{it} \sum_{j \neq i} M_t^j)^\phi K_{it}^{\alpha(1-\phi)} L_{it}^{(1-\alpha)(1-\phi)}. \end{aligned} \quad (10)$$

Note that the aggregate production function exhibits constant returns to scale in  $M_t$ ,  $K_{it}$  and  $L_{it}$ . The aggregate implications of the firm's problem in each country are the second main ingredient to be used in the estimation of the technology capital.

## 2.2. The Estimation Procedure

This section develops a procedure that estimates the stock of technology capital, and the degree of openness. For simplicity, it will be assumed that there are only two countries in the world,  $I = 2$ . For any country  $i$ , the other country is denoted by  $-i$ .

The equation (4) and definition of  $R_{it}^M$  (3) imply that the stock of technology capital in country  $i$  can be expressed as

$$M_t^i = \phi \frac{\frac{1-\tau_{i,t+1}^K}{1-\tau_{it}^K} v_{it} Y_{it} + \frac{1-\tau_{-i,t+1}^K}{1-\tau_{it}^K} \frac{p_{-i,t+1}}{p_{it}} (1 - v_{-i,t}) Y_{-i,t}}{R_{it}^K - \frac{1-\tau_{i,t+1}^K}{1-\tau_{it}^K} (1 - \delta_M)}, \quad (11)$$

where  $Y_{it}^i$  and  $Y_{-i,t}^i$  have been eliminated using equation (7).<sup>6</sup> If country  $i$ 's production  $Y_{it}$  is observed, expression (11) can be immediately used to compute the implied stock

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<sup>6</sup>For the case of two countries the notation is simplified by writing  $v_{it} = v_{it}^i$  and  $v_{-i,t} = v_{-i,t}^{-i}$ . One then obtains  $v_{it}^{-i} = 1 - v_{it}$  and  $v_{-i,t}^i = 1 - v_{-i,t}$ .

of technology capital in country  $i$ , jointly with

$$R_{it}^K = (1 - \tau_{i,t+1}^p) \left( \alpha(1 - \phi) \frac{Y_{i,t+1}}{K_{i,t+1}} - \delta_K \right) \quad (12)$$

$$p_{it} = \prod_{\tau=1}^t R_{i\tau}^K. \quad (13)$$

However, since the investment in technology capital is expensed, country's production  $Y_{it}$  is not equal to its Gross Domestic Product  $\hat{Y}_{it}$ . The difference between them is the investment in technology capital:

$$\hat{Y}_{it} = Y_{it} - X_{M,t}^i \quad (14)$$

Investment in technology capital is not measured explicitly in the national accounts, and so  $Y_{it}$  is not directly observed as well. Substituting (14) for  $Y_{it}$  into (3), one can express the implied stock of technology capital as

$$M_t^i = \phi \frac{\frac{1-\tau_{i,t+1}^K}{1-\tau_{it}^K} v_{it} (\hat{Y}_{it} + X_{M,t}^i) + \frac{1-\tau_{i,t+1}^K}{1-\tau_{it}^K} \frac{p_{-i,t+1}}{p_{it}} (1 - v_{-i,t}) (\hat{Y}_{-i,t} X_{M,t}^{-i})}{R_{it}^K - \frac{1-\tau_{i,t+1}^K}{1-\tau_{it}^K} (1 - \delta_M)}. \quad (15)$$

The investment in technology capital  $X_{M,t}^i$  needs to be recovered simultaneously from its law of motion:

$$M_{t+1}^i = X_{M,t}^i + (1 - \delta_M) M_t^i. \quad (16)$$

The proportion factor  $v_{it}$  can be computed using any of the equations (7)-(9). Equations (15) and (16), together with  $R_{it}^K$  and  $p_{it}$  given by (12) and (13) then form a system of first order difference equations in the technology capital  $M_t^i$  and  $M_t^{-i}$ . Given some initial or terminal condition on technology capital, one can solve these difference equations for the time series of technology capital in both countries. After

the stock of technology capital is computed, equation (5) can be inverted to compute the openness parameters:

$$\omega_{it} = \frac{1 - v_{it}}{v_{it}} \frac{M_t^i}{M_t^{-i}}.$$

### 2.3. The Estimates

The two countries considered in the computations are United States, *US*, and an aggregate for the rest of the world, *RW*. In the benchmark estimates, the rest of the world includes most OECD countries.<sup>7</sup> On one hand, one would like to take the rest of the world as large as possible. The cost of doing so is that by aggregating foreign countries into one, it is implicitly assumed that all the foreign countries included in the definition are totally open toward each other and that they have the same degree of openness toward USA. Since foreign direct investment is mostly concentrated among OECD countries, those countries seem to be a natural benchmark. Nevertheless, alternative estimates using an extensive definition of the rest of the world are presented in the Appendix.

The time period considered is 1982-2006, for which all the required data are available. The data for real US tangible capital stock  $K_{US}$  are taken from the National Economic Accounts Fixed Assets Table.  $K_{RW}$  is constructed as a sum of real capital stock for the rest of the world countries. The data are taken from the AMECO database, and converted into 1990 US dollars using Geary-Khamis purchasing power parities, which are taken from the Penn World Tables.

The tangible capital stock of US firms abroad,  $K_{RW}^{US}$ , is measured by the amount

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<sup>7</sup>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.

of US-owned private assets owned in the rest of the world countries. Similarly, the tangible capital stock of foreign firms in the US,  $K_{US}^{RW}$ , is measured by foreign-owned private assets owned in the US. The data are taken from the Bureau of Economic Analysis Direct Investment Position data. Current cost valuation is used for both assets. The proportion factors are computed using equation (8), 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. Estimates for alternative proportion factor computations are presented in the Appendix.

The real US Gross Domestic Product  $\hat{Y}_{US}$  is taken from the National Income and Product Accounts. The real Gross Domestic Product for the rest of the world  $\hat{Y}_{RW}$  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.<sup>8</sup>

The values of profit tax rate  $\tau_{US}^p$  is taken to be equal to the ratio of total taxes on corporate income to corporate profits, and is taken from the National Income and Product Accounts. The value of  $\tau_{RW}^p$  is assumed to be the same as the US tax rate.

**Benchmark Estimates** I set the tangible capital share in GDP  $\alpha$  to be equal to 0.326, and the depreciation rate of tangible capital  $\delta_K$  to be equal to 5.6% annually. Both numbers are computed as the US average over the 1982-2006 period. I follow [McGrattan and Prescott \(2008\)](#) by setting the depreciation rate of technology capital to be 8% annually.<sup>9</sup> The remaining parameter to be chosen is the degree of decreasing returns in each location  $\phi$ . I set  $\phi$  in such a way that the average ratio of investment in technology capital to the production of US economy is 7%, which is somewhat higher than the ratio of US expenditures on R&D and advertisement to GDP. The

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<sup>8</sup>The data are already converted into 1990 US dollars using Geary-Khamis purchasing power parities.

<sup>9</sup>The argument 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 rate 15% annually.

resulting value of  $\phi$  is 0.075. The terminal condition I use in solving the difference equations (15) and (16) is that the investment in technology capital in 2006 in both countries is the same as the investment in technology capital in 2005. Since the last two assumptions are highly arbitrary, the Appendix again shows the estimates for alternative assumptions.

*INSERT FIGURE 1*

Figure 1 plots the ratio of technology capital and tangible capital for both countries. The ratio of US technology capital and US tangible capital fluctuates between 0.19 and 0.25. In the rest of the world, the ratio is about 1% lower in all periods, and has the same pattern. US investment in technology capital is also found to be highly procyclical (at annual frequency), and less volatile than investment in tangible capital.

*INSERT FIGURE 2*

Figure 2 plots the openness parameters  $\omega_{US}$  and  $\omega_{RW}$ . Overall, the magnitude of the openness parameters shows that both the US economy and the rest of the world are very closed. The fraction of foreign technology capital permitted in any of the two countries never exceeds 5%. The rest of the world is more open than USA throughout the whole period, and the difference in openness between both economies has even slightly increased after 2000. The increase in country openness has been fairly monotone for both countries, with the exception of the rest of the world before 1985 and US economy around the recessions in early 1990's and early 2000's when the openness decreased. The degree of openness of the US economy is positively correlated with US GDP.

US production has been growing on average at 3.31% per year which is slightly higher than the growth rate of US GDP, which has been 3.14%. The total factor

productivity has been growing at a rate of 1.13% per year. In contrast, the average growth rate of the total factor productivity one would incorrectly measure by ignoring technology capital has been growing at a rate of 1.16% per year. Thus, the contribution of the total factor productivity, why still of first order importance, is somewhat diminished if one properly accounts for the technology capital.

The Appendix of this paper presents several alternative estimates where i) the proportion factor was computed from (7) or from (9) rather than from (8), ii) a more extensive definition of the rest of the world is used, iii) the average ratio of investment to technology capital to production is higher or lower than the benchmark one, and iv) where an alternative terminal condition for the difference equations (15) and (16) is used. In all cases, the benchmark estimates roughly confirm the findings of the benchmark estimates. The most significant departure from the benchmark estimates is found when the proportion factor is computed using alternative methods. In that case, the openness of the rest of the world decreases over time rather than increases. However, the openness of the US economy follows similar pattern to the one found in the benchmark estimates even in this case.

### 3. 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 US economy or the rest of the world in 1982.

The agents in country  $i \in \{US, RW\}$  evaluate sequences of consumption according

to the following utility function:

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

where  $\rho$  is the discount rate,  $N_{it}$  is the population in country  $i$  and  $\frac{C_{it}}{N_{it}}$  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  $i$  citizens own 100% of country  $i$  multinationals, and none of country  $-i$  multinationals. The budget constraint then becomes

$$C_{it} + B_{i,t+1} = W_{it}N_{it} + D_{it}^i + D_{-i,t}^i + (1+r_t)B_{it} + T_{it}, \quad (18)$$

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

$$T_{it} = \tau_{it}^K ((\phi + \alpha(1-\phi))Y_{it} - \delta_K K_{it}) - (1 - \tau_{it}^K)X_{M,t}^i.$$

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

Each agent supplies one unit of labor inelastically. The production of country  $i$  is thus given by (10) with  $L_{it} = N_{it}$ , i.e. by

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

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.

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

**Properties of Equilibrium** It is assumed that the total factor productivity  $A_{it}$  and population  $N_{it}$  converge over time to a constant growth rate  $\gamma$  and  $\eta$ . Similarly, the tax rate on profits  $\tau_{it}^K$  and the openness parameter  $w_{it}$  converge over time to a constant. The economy then converges to a balanced growth path where consumption per person  $\frac{C_{it}}{N_{it}}$ , output per person  $\frac{Y_{it}}{N_{it}}$ , technology capital per person  $\frac{M_t^i}{N_{it}}$ , and tangible capital per person  $\frac{K_{it}}{N_{it}}$  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:

$$R_{it}^M = R_{it}^K = r_t = R_{-it}^K = R_{-it}^M.$$

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  $-i$ :

$$R_{it}^M = R_{it}^K = r_t = R_{-it}^K > R_{-it}^M.$$

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

$$R_{it}^M < R_{it}^K = r_t = R_{-it}^K > R_{-it}^M.$$

### 3.1. The Results

In the benchmark scenario, the openness parameters are assumed to be equal to the estimated values in the first twenty five periods (corresponding to years 1982-2006) and constant after that. The tax rates on profits are equal to their values used in the estimation for the first twenty five and are constant after that as well. The US population in the first twenty five 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 a modest increase of 3.5% of the rest of the world population. After the first twenty five years both populations grow at a common growth rate  $\eta$ , equal to the average growth rate in 1982-2006, which is 0.93%. The model total factor productivity in both countries equals the Solow Residuals in the first twenty five periods. The common long run growth rate of total factor productivity  $\gamma$  is taken to be the average growth rate of US and rest of the world total factor productivity in the 1982-2006 time period, which is 1.29%.

The discount rate  $\rho$  is chosen in such a way that the steady state capital output ratio equals 2.58, which is the average US capital output ratio in 1982-2006. The implied value of  $\rho$  is 0.0376. The coefficient of relative risk aversion  $\theta$  is set equal

to one. The remaining parameters  $\phi, \alpha, \delta^M, \delta^K$  are the same as the ones used in the benchmark estimation.

Figure 3 plots the (detrended) US production per person in the data and in the model. It shows that the model is able to replicate the fluctuations in US output. Figure 4 shows that the same can be said about fluctuations in both US investments abroad and foreign investments in the US. For instance, the model successfully captures the decline in US investments abroad until about 1985, and the surge of foreign direct investment in the US between 1995-2000.<sup>10</sup>

*INSERT FIGURE 3*

*INSERT FIGURE 4*

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 inability to explain higher frequency movements in net exports is not surprising since the model assumes that there are no trade frictions between both countries.

**Gains from Current US Openness** The welfare loss from forever totally closing US economy in 1982 turns out to be very small: they are equal to 0.17% of consumption (in consumption equivalents). When both US economy and the rest of the world are totally closed in 1976, the welfare losses are larger, but still small: they are equal

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<sup>10</sup>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 condition 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.

to 0.36% of consumption.

**Gains from Opening US Economy Further** If the US economy opens totally, it is no longer efficient to invest in technology capital in the US. Rather, the US economy imports all its technology capital from abroad. The steady state gain in terms of output is 12.3%. The gain in measured productivity is even larger: it is about 15.2% in all periods. The welfare gain from totally opening US economy turns out to be large as well: It is equal to 7.42% of consumption.<sup>11</sup>

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 US economy increases the rate of return on investment in technology capital in the rest of the world. In response, rest of the world increases its investment in technology capital. Increases in foreign technology capital is more significant than decreases in US technology capital and so consumption grows faster over the transition.

#### 4. CONCLUSIONS

This paper has two goals. First, it estimates the stock of technology capital, country openness in the US and in the rest of the world. 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 technology capital is about one fourth of the stock of tangible capital stock for both the US economy and for the rest of the world. The openness of

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<sup>11</sup>The magnitudes of both welfare losses from totally closing and welfare gains of US economy from totally opening are similar to the ones reported by Ramondo (2007) where the welfare losses from closing US economy are 0.00% and the welfare gains from opening are 8%. See her Table 9, case II.

US economy has been increasing over time, but is smaller than the openness in the rest of the world. These estimates are found to be robust to alternative assumptions about the definition of the rest of the world, the way proportion factors are computed, average size of the investment in technology capital and the terminal condition on investment in technology capital.

The neoclassical growth model with technology capital performs well in explaining the movements in output and foreign direct investment between 1982 and 2006. I also find that the losses from totally closing both economies are small. On the other hand, the gains from opening US economy totally are much larger.

Several assumptions are likely critical in the estimation of country openness, technology capital stock, and the welfare gains from opening an economy. First, the estimation procedure relies on an assumption that the rest of the world countries are mutually totally open. While this assumption seems to be the only alternative if one wants to restrict attention to a tractable two country model, it may result in estimating an implausibly large stock of the world technology capital. If this is the case, the actual welfare gain from totally opening US economy may be smaller than the one computed in this paper.

But how sensitive are the estimates and the welfare calculations to this assumption? This question is not easy to answer in the current two country framework, because a relaxation of this assumption will simultaneously change the estimates of the technology capital stock, country openness, as well as the theoretical predictions of the model. Clearly, a multicountry model is needed to find out how important this assumption is.

Another 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 like physical distance (see the evidence in Ramondo (2007)). 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 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 much larger role in domestic production than in the case of US economy. In this sense, studying US economy versus rest of the world probably gives us a lower bound on potential gains from openness across the world.

## APPENDIX: ALTERNATIVE ESTIMATES

To examine the robustness of the results, I consider alternative assumptions about i) the way proportion factors  $v_{US}$  and  $v_{RW}$  were computed, ii) the definition of the rest of the world, iii) the average ratio of investment to technology capital and production, and iv) the terminal condition that was used in solving the difference equations (15) and (16).

**Computation of Proportion Factors** The theory predicts that the proportion factors  $v_{it}$  can be alternatively computed using production data, labor input data and data on employee compensation:

$$v_{it} = \frac{Y_{it}^i}{Y_{it}} = \frac{L_{it}^i}{L_{it}} = \frac{w_{it}L_{it}^i}{w_{it}L_{it}}.$$

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 provide those alternative measures of the proportion factor. The values of  $Y_{US,t}^{RW}$ ,  $L_{US,t}^{RW}$ ,  $w_{US,t}L_{US,t}^{RW}$  are measured using gross product, number of employees and employee compensation of all US affiliates of foreign multinationals. Similarly,  $Y_{RW,t}^{US}$ ,  $L_{RW,t}^{US}$  and  $w_{RW,t}L_{RW,t}^{US}$  are measured by gross product, number of employees and employee compensation of majority-owned foreign affiliates of US multinationals<sup>12</sup> The data are scaled by the ownership shares of foreign multinationals in all US affiliates, and by the ownership shares of US multinationals in majority owned foreign affiliates. The ownership shares are obtained as a fraction of equity that is owned by the multinationals.

While using the financial and operating data to compute the proportion factors is theoretically equivalent to using the capital stock data, there are reasons why it may be inferior in practice. First, the financial and operating data cover only nonbank affiliates. This leaves a significant fraction of affiliates out. Even more importantly, the economywide data  $Y_{it}$ ,  $L_{it}$  and  $w_{it}L_{it}$  need to cover 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 gross product of a nonbank sector to GDP is the same in the United States and in the rest of the world. Similarly, the ratio of the number of employees in the nonbank sector to the total number of employees is the same in both countries, and that the ratio of the employee compensation in the nonbank sector to GDP is the same in both countries. Second, 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.

Using capital stock data to compute the proportion factors is therefore a better

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<sup>12</sup>Majority owned foreign affiliates are used because not all the required data are available for all foreign affiliates. At the same time, not all of the required data are available for majority owned US affiliates either, and so the definition of an affiliate is not symmetric.

alternative. Nevertheless, it is interesting to obtain the alternative estimates to see how they differ from the benchmark ones. Figure 5 shows that the estimates. Technology capital to tangible capital ratio are now about 2% higher than the benchmark estimates for both the US economy and for the rest of the world. The estimates of US openness based on production and employee compensation are somewhat higher than the benchmark estimates, while the estimates based on labor input are about the same. However, all the alternative estimates paint essentially the same picture: the openness of the US economy is low and has been increasing over the years. The estimates for the rest of the world differ more substantially: while they are in the same range as the benchmark estimates, all three alternative estimates indicate that the rest of the world is now more closed than it was in 1982. Overall, with the exception of the rest of the world openness, the alternative estimates confirm the results that were obtained in the benchmark estimation.

*INSERT FIGURE 5*

**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.<sup>13</sup> I use the World Bank estimates of [Nehru and Dhareshwar \(1995\)](#) for capital stock data<sup>14</sup>, and the GGDC Total Economy database for GDP data.

*INSERT FIGURE 6*

Figure 6 shows that the alternative estimates. The technology capital to tangible

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<sup>13</sup>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.

<sup>14</sup>Since the World Bank time series end in 1990, I extend the series by assuming that capital-output ratio in 1991-2005 is the same as capital-output ratio in 1990.

capital stock ratios are almost identical to the benchmark estimates.<sup>15</sup> 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. Thus, the effect of the definition of the rest of the world is small.

**Ratio of Investment to Technology Capital and Production** I have experimented with the average ratio of investment in technology capital and production being 9% and 5% rather than 7%. As shown in Figure 6, as a result, the ratio of technology capital and tangible capital has increased by about 7% for both US economy and for the rest of the world in the first case, and decreased by about the same amount in the second case. The change in country openness is negligible.

**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 2006 is equal to its long run average of 7%. Second, I have assumed that the investment in technology capital in 2006 is 20% higher (lower) than the investment in 2005. In all cases, the effects on the aggregate estimates of capital stock and openness parameters were negligible.

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<sup>15</sup>Naturally, since the stock of tangible capital in the rest of the world is now higher (by about 25% on average), the stock of technology capital in the rest of the world is also higher.

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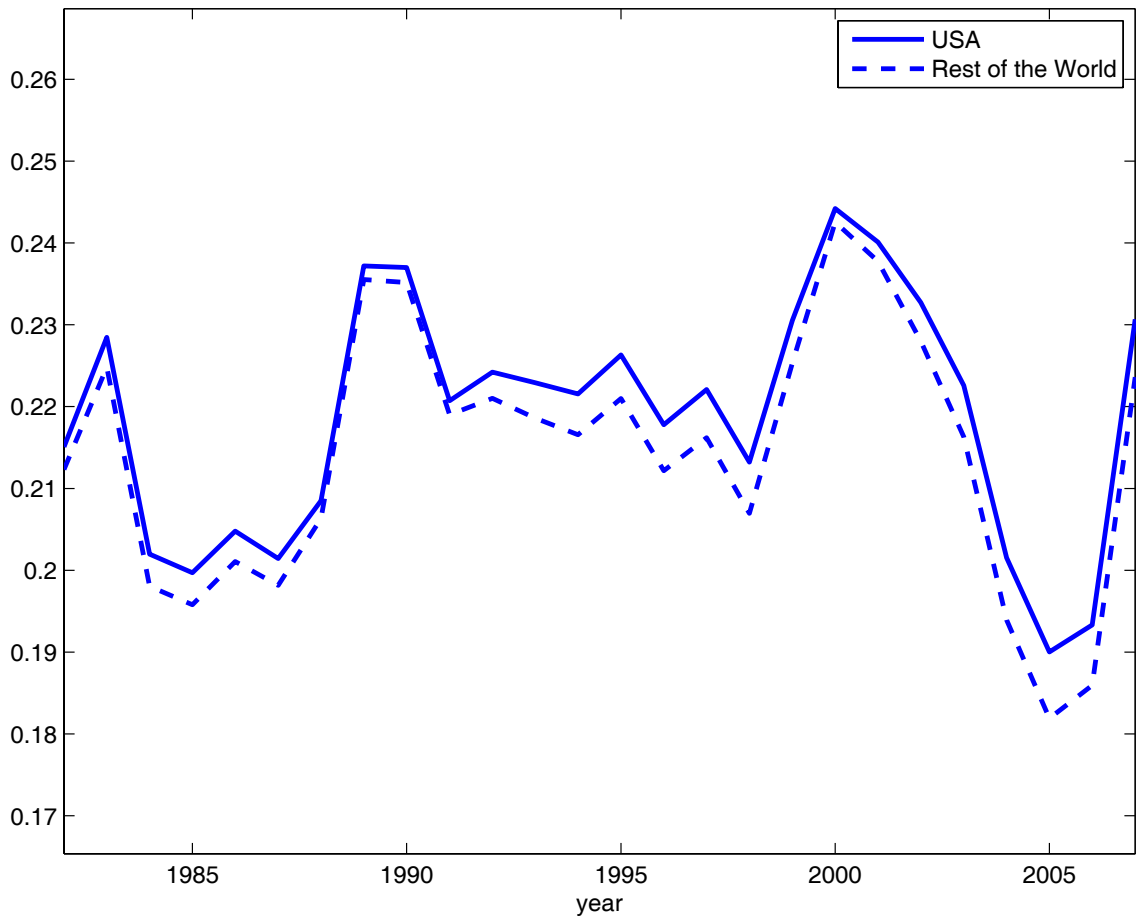


FIG. 1. Technology Capital to Tangible Capital Ratio

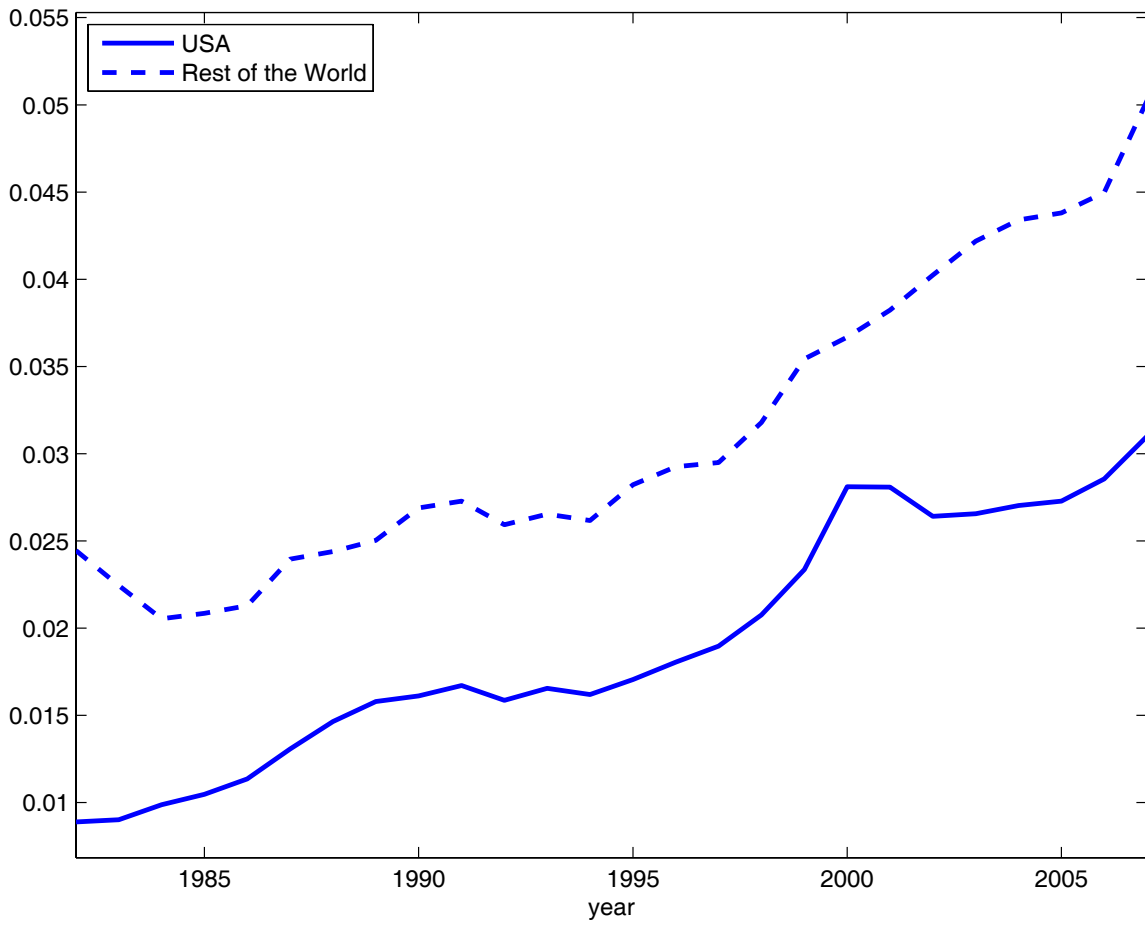


FIG. 2. Openness Parameters

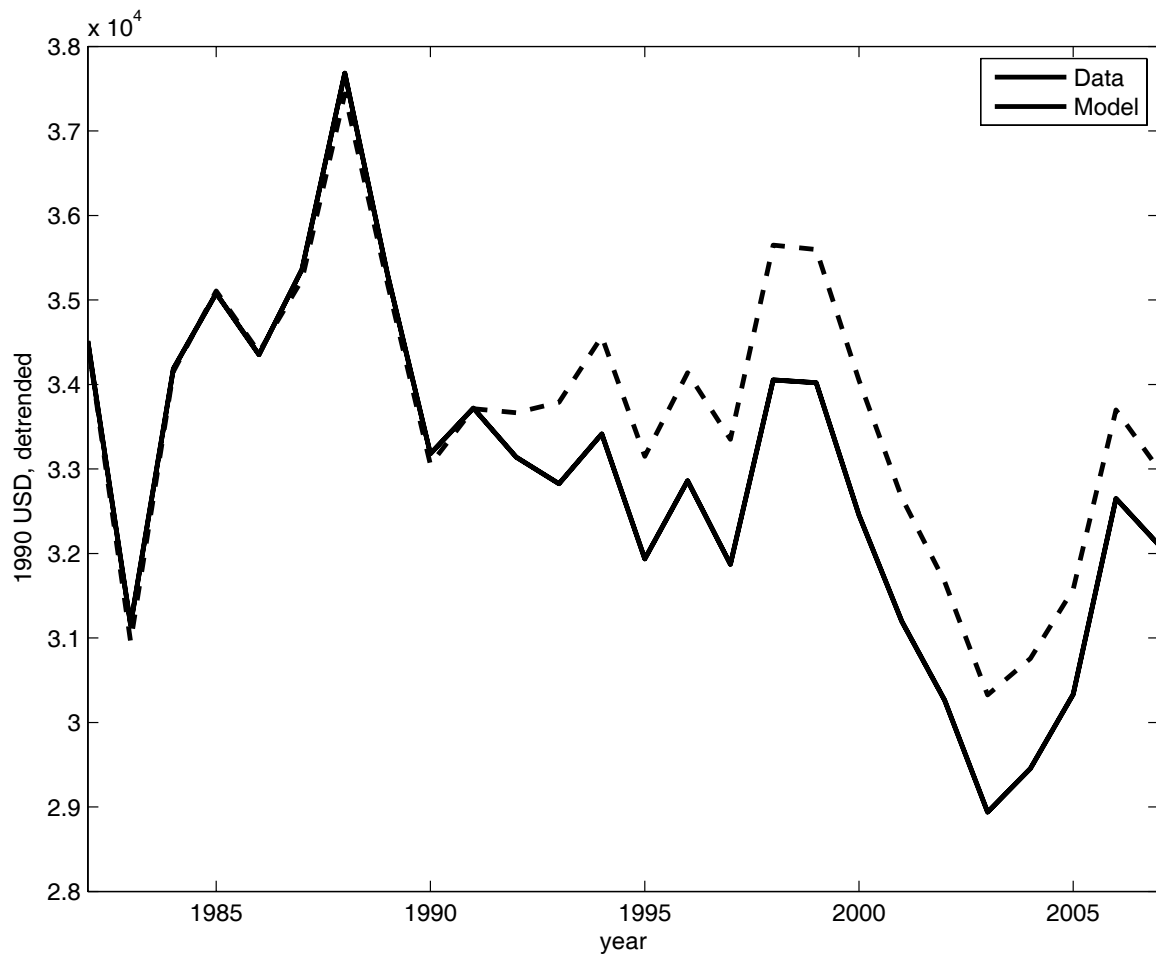


FIG. 3. US Output

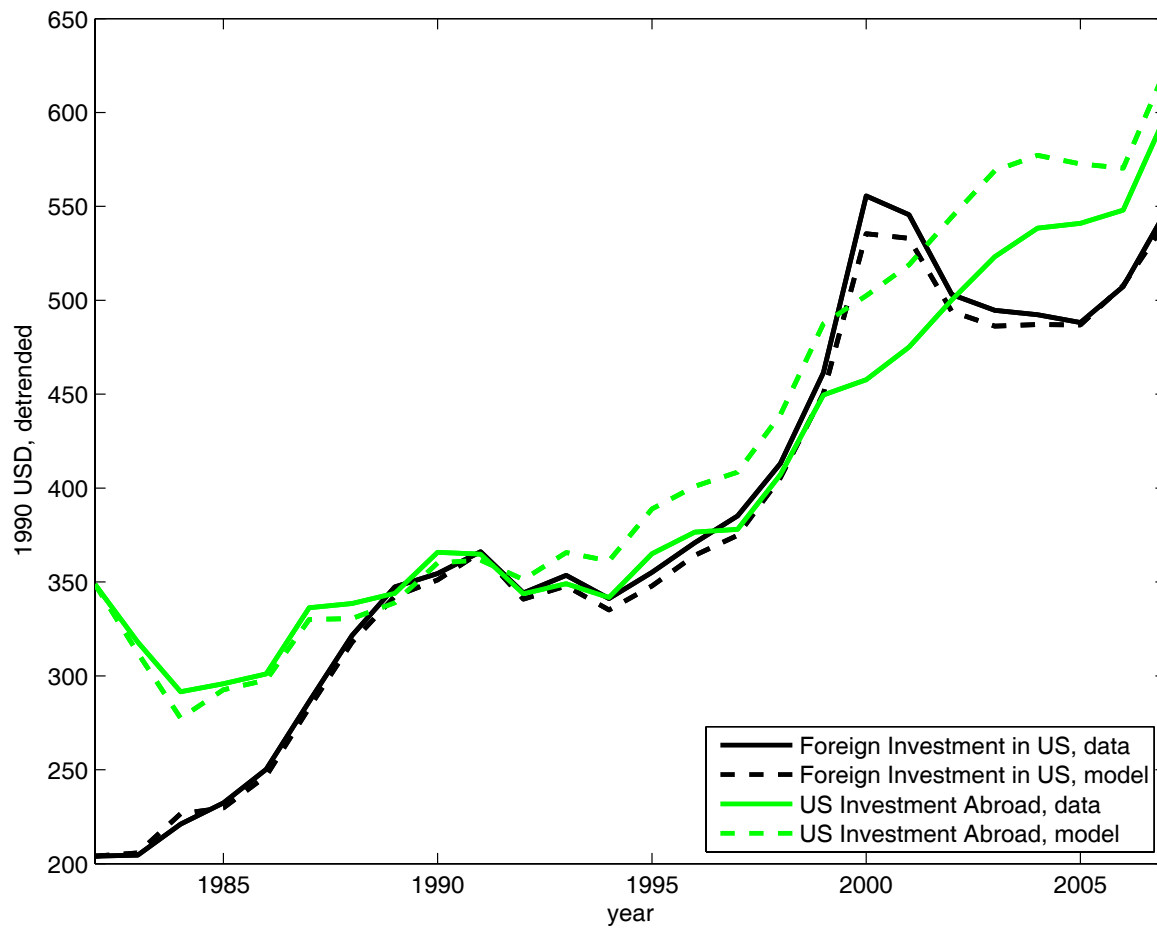


FIG. 4. Foreign Direct Investment

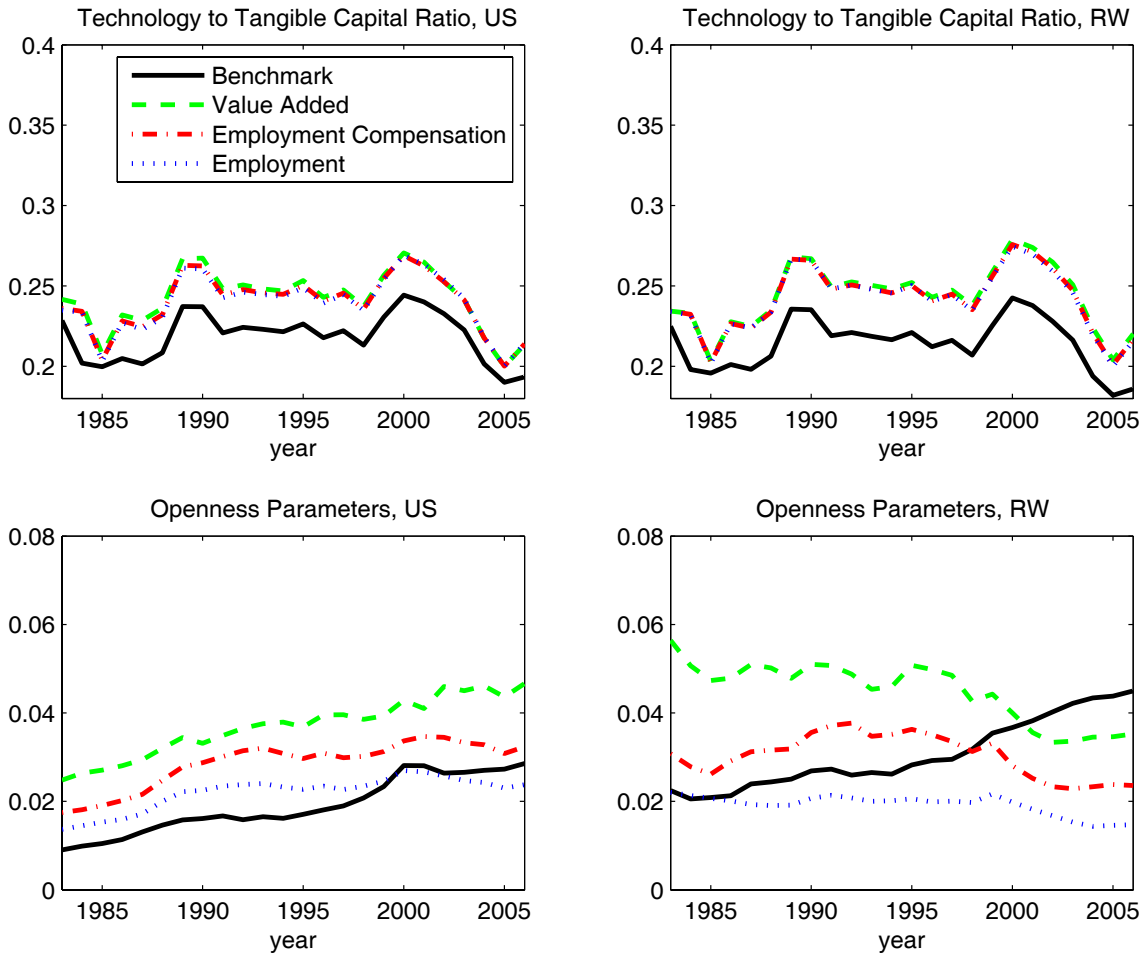


FIG. 5. Alternative Proportion Factors

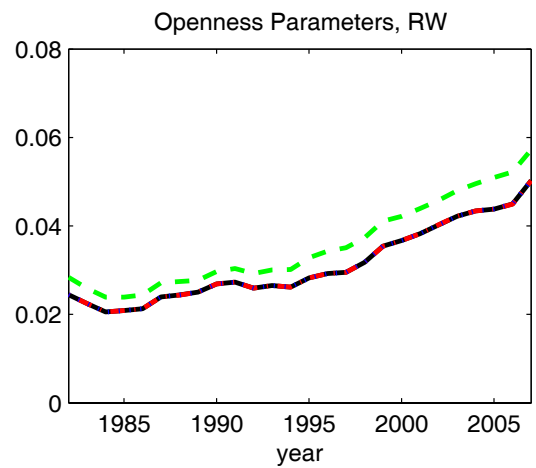
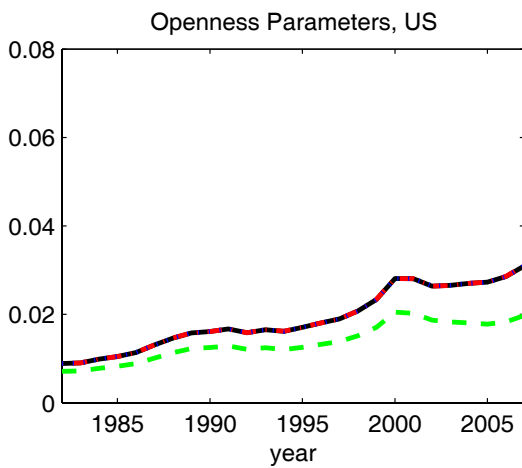
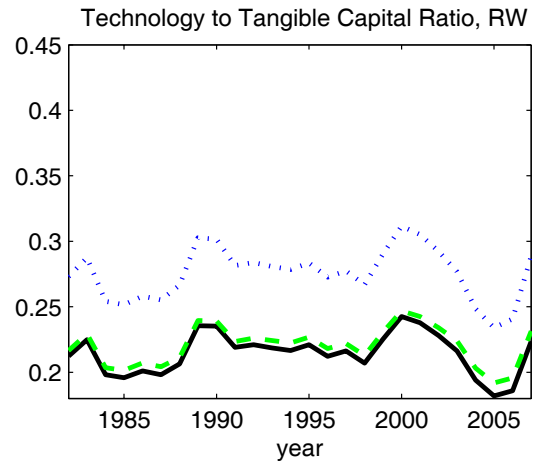
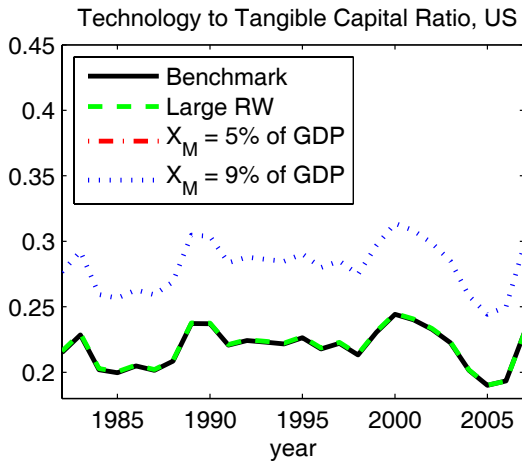


FIG. 6. Alternative Assumptions