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International Capital Market Integration: Implications for Convergence, Growth, and Welfare

by

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Abstract
This paper studies the effects of international capital market integration on welfare and the speed of adjustment in a two-region endogenous growth model. Monopolistic firms undertake research and development (R&D) to improve their productivity level. National and international knowledge spillovers affect the returns to R&D. The two countries differ with respect to the initial productivity level and R&D capability (which is a proxy for human capital and structural policies). Long-run productivity gaps are determined by the difference in R&D capability. Over time, there is conditional convergence in productivity levels. The speed of convergence is larger with integrated international capital markets than without. Long-run gaps in consumption levels are larger in the former situation than in the latter. Capital market integration harms (benefits) the leading (lagging) region if domestic spillovers are more important than international spillovers and differences in R&D capabilities are small.

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Key words: rate of convergence, knowledge spillovers, endogenous growth, capital mobility.

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1. Introduction

One of the central questions in debates about international economic relations and policies is what allows countries with relatively low income to grow at a relatively high rate of growth so that they can catch up with the richer countries. Europe had been successfully catching up with the US during the decades following the second world-war, but since the late 1990s European policy makers have been concerned about the fact that the convergence process came to a halt and that European income levels failed to fully converge to those in the US. Within Europe, similar questions arise. The single market program was intended to spur growth and convergence within Europe. Yet, structural differences weaknesses of lagging regions have been considered as obstacles in the convergence process. The extension of the European Union to Eastern Europe has been expected to speed up convergence of income and productivity levels between "Old" and "New" Europe, but debates continue about how far convergence will go and who will gain most from the integration process. On world level, liberalization of capital markets since the 1980s has increased world capital flows, supposedly financing investment in capital-scarce regions and thus stimulating convergence. However, it has also raised concerns about globalization and its effects on welfare.

In this paper, I present a two-region endogenous growth model to study the following type of questions. Under what conditions do income levels in rich and poor countries converge, and how fast? How is regional growth affected by capital market integration? What are the welfare effects from faster convergence and international integration? I study how rates of convergence are affected by the presence of international capital markets, by international goods market conditions, and by structural differences between regions. In particular, I contrast two regions that start with different productivity levels and that differ in their structural innovation capability. The latter can be the result of differences in human capital levels and schooling policies, innovation policies or infrastructure, or, as it has been coined (cf. Furman et al 2002), differences in the quality of national innovation systems.

The model in this paper is a two-region model of endogenous growth based on in-house R&D. There is a given number of firms. By spending on R&D, each of them invests in firm-specific knowledge, which determines their productivity level. The cost of R&D depends on the firm-specific knowledge stock, as well as on national and international knowledge average knowledge stocks. The latter two determinants capture intertemporal knowledge spillovers and result in the familiar research externality, which makes firms invest too little in R&D.

The main results are as follows. Long-run productivity gaps are determined by the difference in R&D capability. Over time, there is conditional convergence in productivity levels. The speed of convergence is larger with integrated international capital markets than without. Long-run gaps in consumption levels are larger in the former situation than in the latter. Capital market integration harms (benefits) the leading (lagging) region if domestic spillovers are more important than international spillovers and if differences in R&D capabilities are small.

The topic of convergence has received a lot of attention in the theoretical growth literature. Two strands stand out in this literature. The first strand focusses on growth driven by (human) capital accumulation with one final good produced only and perfect competition. A distinction should be made between closed and open economies. Closed economy models predict convergence between rich and poor countries as long as there are diminishing returns with respect to reproducible capital. Poor countries have low levels of capital and realize high rate of return to investment so that they grow relatively fast (Barro and Sala-i-Martin 1995). If there are constant returns to capital, growth differentials are persistent and there is no convergence (the AK-model, see Rebelo 1991). In the open economy setting, capital is assumed to be mobile. In the simplest version, convergence in productivity levels is immediate since capital flows to the poor country that has accumulated less capital and realizes a high (ex-ante) rate of return. However, this is at odds with empirical research that finds a limited rate of convergence, of about two per cent only (Temple, 1999). The introduction of adjustment costs or borrowing constraints makes the rate of convergence limited again (see Turnovsky and Sen, 1995; Barro, Mankiw and Sala-i-Martin 1995). While *financial* capital is internationally mobile, physical (and human) capital have to be accumulated in the country where they are used. Investment in the domestic capital stock takes time and is costly in terms of foregone consumption, even though borrowing from abroad is possible. In the present paper, productive capital stocks (firm specific knowledge) is home-grown, too, which explains why convergence takes time.

The second strand of literature focuses on growth driven by R&D with monopolistic competition and differentiated goods in the spirit of Dixit and Stiglitz (1977). It is found that spillovers of knowledge between countries are important for convergence. If there are no such spillovers and if no inputs in production are traded, countries that start at different productivity levels diverge (Grossman and Helpman, 1991 chapter 8; Feenstra, 1996). With international spillovers, most analyses find that international growth rates converge in the long run (Wälde, 1996; Aghion and Howitt, 1998). In this literature both goods trade and international capital mobility are considered. However, so far it has not been explored how, in the presence of monopolistic competition and R&D-based growth, convergence is affected by international capital mobility and by structural differences between the regions. The welfare effects of differences in convergence rates is also ignored, not only in the monopolistic competition literature (see, however, Diehl and Gundlach 1999). The present paper aims at filling these gaps.

The paper is organised as follows. The model is presented in Section 2. Section 3 discusses structural (long-run) results. Sections 4 and 5 discuss the dynamics of productivity and consumption, respectively. Section 6 analyses welfare and Section 7 concludes. The appendix contains derivations of equations and proofs of claims in the main text.

2. A slightly asymmetric two-country endogenous growth model

2.1. Structure of the model

There are two countries (or regions consisting of several countries) that are characterized by identical preferences and primary factor endowments, and similar – but not identical – technological opportunities. One country, indexed by superscript A, starts at a more *A*dvanced productivity level than country B (also referred to as the *B*ackward country). We also allow one country to have a higher productivity in research activity than the other, to reflect structural differences. The central question is whether the two countries, when starting from this initial asymmetry, converge in terms of productivity levels, how fast they converge, and how welfare in the two countries evolves over time. We answer this question for two equilibria (or regimes). First, in the balanced trade (BT) regime, capital markets are not integrated and the goods trade is balanced. Second, in the capital mobility (CM) regime, international capital markets are perfectly integrated, interest rates are equalized, and changes in net foreign asset holdings allow countries to smooth consumption. Comparing these two regimes of capital market integration allows us to assess the role of capital market integration in the convergence process.

Each country has one primary factor of production in fixed supply (labour), which is allocated over two activities, production and research. Produced goods are differentiated and each variety is produced by a single monopolistic firm. These firms control and accumulate firm-specific knowledge (as in Smulders and Van de Klundert, 1995). Within each country, there is a continuum of symmetric firms on the unit interval. This allows us to save on notation by formulating the model for a single representative firm. All goods are traded in international markets at zero transport costs.

Table A presents the structural relationships. Countries are denoted by superscript i = A, B (and if necessary also by superscript j for the other country). Each line in the table represents two equations, one for each country. To simplify notation, I have not only omitted the time argument (t), but also the regime index (k = BT, CM, for balanced trade and capital mobility, respectively), which apply to each variable (roman letters). For example, h^i should be read as $h^i_k(t)$.

Labour productivity in production is denoted by h as appears from eqs. (A.1), relating output of final goods X to labour input L. Firms have an opportunity to increase labour productivity h by performing R&D according to eqs. (A.2). Productivity can be increased by allocating labour (R) to R&D. Productivity in R&D depends on a country specific fixed coefficient ξ^i and three sources of knowledge (h^i, $\bar{h}^i$ and $\bar{h}^j$). First, firms build upon specific knowledge accumulated in the past. Second, all firms benefit from knowledge spillovers emanating from other firms in their country. Third, there are knowledge spillovers from abroad. Knowledge spillovers relate to the *average* level of knowledge in the different economies (denoted by $\bar{h}$), rather than the *total* knowledge stock. This captures the fact that not all knowledge developed in an economy is relevant for a particular firm because of technological differences (Peretto and Smulders, 2002, provide a micro-foundation and explain why this avoids the so called scale problem; see also Bretschger and Steger, 2004). Parameters α_h and α_f measure the productivity of spillovers, from domestic and foreign firms respectively, in the firm's innovation process.

Table A Structural relationships

Technology	$X^i = h^i L^i$	(A.1)
	$\dot{h}^i = (h^i)^{1-\alpha_h-\alpha_f} (\bar{h}^i)^{\alpha_h} (\bar{h}^j)^{\alpha_f} \xi^i R^i$	(A.2)
Preferences	$U_0^i = \frac{\sigma}{\sigma-1} \int_0^{\infty} (C_t^i)^{(\sigma-1)/\sigma} e^{-\vartheta t} dt$	(A.3)
	$C^i = \left[(D^i)^{(\varepsilon-1)/\varepsilon} + (M^i)^{(\varepsilon-1)/\varepsilon} \right]^{\varepsilon/(\varepsilon-1)}, \qquad \varepsilon \geq 1$	(A.4)
	$D^i = \left(\int_0^1 (D_z^i)^{(\eta-1)/\eta} dz \right)^{\eta/(\eta-1)}; M^i = \left(\int_0^1 (M_z^i)^{(\eta-1)/\eta} dz \right)^{\eta/(\eta-1)}; \eta > 1$	(A.5)
Market clearing	$X^i = D^i + M^j$	(A.6)
	$L^i + R^i = 1$	(A.7)

Endogenous variables:		*Parameters:*	
X	output	α_f	foreign spillover parameter
h	labour productivity	α_h	domestic spillover parameter
L	labour in production	ξ	research productivity parameter
R	labour in research	ϑ	utility discount rate
D	consumption domestically produced goods	σ	elast. intertemporal substitution
		ε	elast. of substitution between home and imported goods
M	imports		
C	aggregate consumption index	η	elast. of substitution among product varieties

All equations apply to i, j = A, B and $j \neq i$. Time argument (t) and regime index (k) omitted.

Productivity levels differ across countries, but are identical across firms within a country. For this reason average knowledge levels are equal to the knowledge levels of firms in each country ($\bar{h}^i = h^i$). The scale parameter ξ reflects the capability of firms in country i to use knowledge and labour effort to produce innovations; it reflects the country's skill level (human capital), innovation policies, infrastructure and institutions conducive to innovation.

Intertemporal preferences in the consumption index C are given in eqs. (A.3). Infinitely-lived households apply a constant utility discount rate ϑ. The elasticity of intertemporal substitution equals the constant σ. The consumption index (C) combines consumption of domestically produced varieties (D) and imported varieties (M) by way of a CES sub-utility function, with an elasticity of substitution denoted by ε, eqs. (A.4). Unless stated otherwise, we assume $\varepsilon > 1$, which seems most realistic. There is a continuum (with mass 1) of domestically produced and imported goods, they are imperfect substitutes and the elasticity of substitution among them equals $\eta > 1$, eqs (A.5).

Goods markets clear, see eqs. (A.6). The supply of labour is normalized at one and equals total demand for labour, see eqs. (A.7).

2.2. Consumer and firm behaviour

The behavioural equations of the model are summarized in Table B. Consumers maximize intertemporal utility over an infinite horizon. The decision problem consists of three stages subject to the usual budget constraints. In the first stage, each consumer decides on the path of aggregate consumption over time. This gives rise to the familiar Ramsey rule, shown in eqs. (B.1). The growth rate of consumption equals the difference between the real consumption rate of interest and the pure rate of time preference, multiplied by the elasticity of intertemporal substitution. In the second stage consumers split total per period consumption spending over domestically produced varieties and foreign varieties, eqs. (B.2). The price elasticity of demand is equal to ε in all cases considered. Eqs. (B.4) define the price index of aggregate consumption. Since there are neither transport costs nor international differences in preferences, this index is the same in both countries. By choosing the composite consumption good as the numeraire, we can set the aggregate consumption price equal to one. In the third stage, consumers decide how to split expenditures on home and foreign goods over the different varieties, eqs. (B.3).

Producers maximize the value of firm over an infinite horizon (for details, see the appendix). Each firm faces a downward sloping demand function for its products as appears from eqs. (B.2) and (B.3). Profit maximization implies that firms set a mark-up over (marginal) cost equal to $\eta/(\eta-1)$, as in eqs. (B.6). Labour demand for R&D follows from setting marginal revenue ($\xi K p_h$) equal to marginal cost (w), eqs. (B.7). The shadow price of firm-specific knowledge p_h is introduced as a costate variable in the dynamic maximization procedure. Firms face a trade-off with respect to investing in specific knowledge as appears from the arbitrage conditions (B.8), which state that investing an amount of money equal to p_h in the capital market (the RHS of B.7) yields the same revenue as investing that same amount of money in knowledge creation. The latter raises labour productivity in the production sector and hence revenue in this sector (first term on the LHS of B.7), it raises also the knowledge base in R&D (second term) and it yields a capital gain (last term). We assume all firms within a country are symmetric, $h_z^i = h^i \;\; \forall i$, so that $p_z^i = p^i \;\; \forall i$. This is why we have omitted the firm index *z* in (B5)-(B.8).

Table B Behavioural relationships

Consumer behaviour	$\dot{C}^i / C^i = \sigma(r^i - \dot{p}_c / p_c - \vartheta)$	(B.1)
	$D^i = C^i (p^i / p_c)^{-\varepsilon};\;\; M^i = C^i (p^j / p_c)^{-\varepsilon}$	(B.2)
	$D_z^i = D^i (p_z^i / p^i)^{-\eta};\;\; M_z^i = M^i (p_z^j / p^j)^{-\eta}$	(B.3)
where	$p_c = [(p^i)^{1-\varepsilon} + (p^j)^{1-\varepsilon}]^{1/(1-\varepsilon)} = 1$	(B.4)
	$p^i = \left(\int_0^1 (p_z^i)^{1-\eta} dz \right)^{1/(1-\eta)}$	(B.5)
Producers behaviour	$p^i = \frac{\eta}{\eta - 1} \frac{w^i}{h^i}$	(B.6)
	$p_h^i = \frac{w^i}{\xi^i K^i}$	(B.7)
	$\left(\frac{\eta - 1}{\eta} \right) p^i L^i + (1 - \alpha_h - \alpha_f) \left(\frac{K^i}{h^i} \right) p_h^i \xi^i R^i + \dot{p}_h^i = r^i p_h^i$	(B.8)
where	$K^i = (h^i)^{1-\alpha_h-\alpha_f} (\bar{h}^i)^{\alpha_h} (\bar{h}^j)^{\alpha_f}$	
Goods market equilibrium	$X^A p^A + X^B p^B = (C^A + C^B) p_c$	(B.9)
Balance of payments	$X^i p^i - C^i p_c = 0$ BT regime	(B.10a)
	$X^i p^i - C^i p_c + r^i F^i = \dot{F}^i$ CM regime	(B.10b)

Symbols

F	net foreign assets	p_c	price index consumption
r	nominal interest rate	*p*	output price
w	wage rate	p_h	firm's shadow price of knowledge

All equations apply to *i, j* = A, B and *j* ≠ *i*. Time argument (*t*) and regime index (*k*) omitted.

Finally, eqs. (B.10) imply that domestic net savings are invested in net foreign assets (*F*).

Domestic savings are the sum of the trade balance and interest receipts on foreign assets. Under perfect capital mobility the rate of interest is uniform across countries ($r^A = r^B$). At the other extreme there is the case of balanced trade or zero mobility implying $F = 0$. Both regimes with respect to the balance of payments will be analysed.

Table C Key relationships

Ramsey rule	$r^i = \vartheta + g_c^i / \sigma$		(C.1)
Investment decision	$r^i = (h^i / h^j)^{-\alpha_f} \xi^i L^i + (1-\alpha_h) g^i - \alpha_f g^j + \hat{p}^i$		(C.2)
Labour market equilibrium	$g^i = (h^i / h^j)^{-\alpha_f} (1 - L^i) \xi^i$		(C.3)
Terms of trade	$\dfrac{p^i}{p^j} = \left(\dfrac{h^i L^i}{h^j L^j} \right)^{-1/\varepsilon}$		(C.4)
	$p^i = [(h^j L^j / h^i L^i)^{(\varepsilon-1)/\varepsilon} + 1]^{1/(\varepsilon-1)}$		(C.5)
Production value share	$\dfrac{p^i X^i}{p^i X^i + p^j X^j} \equiv s^i = [(h^j L^j / h^i L^i)^{(\varepsilon-1)/\varepsilon} + 1]^{-1}$		(C.6)
Goods market equilibrium	$p^A h^A L^A + p^B h^B L^B = C^A + C^B$		(C.7)
Balance of payments	$C^i = p^i h^i L^i$	BT regime	(C.8a)
	$NPV(C^i) = F^i + NPV(p^i h^i L^i)$	CM regime	(C.8b)

Notation: hats denote growth rates, $g_c \equiv \hat{C}$ consumption growth; $g \equiv \hat{h}$ productivity growth. In all equations *j* = A, B; *i* = A, B and $j \neq i$. Time argument (*t*) and regime index (*k*) omitted.

2.3. Semi-reduced model

Table C reduces the model to eight key equations. In deriving the equations, we take into account that all firms within a country have the same productivity level, $h^i = \bar{h}^i$. The growth rates of *h* and *C* are denotes by *g* and g_C respectively.

Equation (C.1), which is derived from (B.1) and (B.4), restates the Ramsey rule. It represents the relationship between consumption growth and the required rate of return on households' savings. Equation (C.2) combines (B.7) and (B.8). The equation represents the rate of return that firms can maximally pay to households. Equation (C.3) represents labour market equilibrium. It states that the amount of labour not allocated to production, results into productivity growth. The productivity in research depends on the knowledge gap h^i/h^j. A low stock of knowledge relative to the other country induces large spillovers and allows the country to grow faster at a given amount of labour allocated to research. The international terms of trade is given by (C.4), which combines (A.1), (A.6) and (B.2)-(B.3). Equation (C.5), which follows from (C.4) and (B.4), translates the terms of trade into the national price level. Equation (C.7) equates the value of world consumption to the value of world production and follows from (A.1), (B.4), (B.9). Equation (C.6), which is derived from (A.1) and (C.4), gives the value share of country *i*'s production in world production. Since preferences are homothetic and prices are the same in both countries, s^i is also the share of country *i*'s goods in each country's consumption basket. Balance of payments equilibrium is represented by equations (C.8), which follow from (A.1) and (the integral of) (B.10). With balanced trade, the value of consumption equals the value of production. With capital mobility, the intertemporal butget constraint implies that the net present value of future consumption, denoted by $NPV(C)$, equals the net present value of future production, $NPV(phL)$, and net foreign assets.

We now reduce the model to a set of equations in the key variables $h^R \equiv h^A / h^B$, L^A, and L^B. From the other equations in Table C we find the following system of differential equations (see appendix):

$$\hat{h}^R = g^A - g^B \tag{1}$$

$$(1+\Gamma_k)(\hat{L}^A - \hat{L}^B) = \varepsilon \frac{g^A L^A}{1-L^A} - \varepsilon \frac{g^B L^B}{1-L^B} + \left[\varepsilon(\alpha_f - \alpha_h) + \varepsilon - 1 - \Gamma_k\right](g^A - g^B) \tag{2}$$

$$\begin{aligned} &\frac{1}{\sigma}\left[s^A \hat{L}^A + s^B \hat{L}^B\right] = \\ &\quad s^A \frac{g^A L^A}{1-L^A} + s^B \frac{g^B L^B}{1-L^B} + (1-\sigma^{-1} - \alpha_h)[s^A g^A + s^B g^B] - \alpha_f [s^B g^A + s^A g^B] - \vartheta \end{aligned} \tag{3}$$

where hats denote growth rates. After substituting (C.3) and (C.6) to eliminate g^i and s^i, we find a system of three differential equations in the key variables $h^R \equiv h^A / h^B$, L^A, and L^B. To simplify notation, I have not only omitted the time argument (*t*), and also the regime index (*k* = BT, CM), which apply to each variable (roman letters). The regime of capital market integration affects the structure of the differential equations only through Γ_k, which takes the following values (I will use capital Greek letter to denote composites of parameters that are regime-specific):

$$\begin{aligned} \Gamma_{BT} &= (\varepsilon - 1)/\sigma \\ \Gamma_{CM} &= 0 \end{aligned} \tag{4}$$

In the equations above, equation (1) governs the dynamics of the productivity gap. Equation (2) governs the allocation of production over the two countries; it is basically the no-arbitrage equation that ensures that in both countries the capital market is in equilibrium. In contrast, equation (3) ensures that the world goods market is in equilibrium; it governs the allocation of aggregate world production over time.

3. The steady state: structural productivity gaps and growth

A balanced growth path, defined as a situation in which variables grow at a constant rate, can only arise if $h^R \equiv h^A / h^B$, L^A, and L^B are constant. From (1)-(3), we see that such a steady state is independent of Γ, so that the steady state is the same for both regimes of capital market integration. In the steady state, the following holds:

$$\frac{\dot{C}}{C} = \frac{\dot{h}}{h} = g = \frac{(\xi^A \xi^B)^{1/2} - \vartheta}{\alpha_h + \alpha_f + \sigma^{-1}} \tag{5}$$

$$h^A / h^B = (\xi^A / \xi^B)^{1/2\alpha_f} \tag{6}$$

where country superscripts have been omitted for variables that are the same in both countries in the steady state. To prevent corner solutions (with zero growth), we assume $\zeta \equiv (\xi^A \xi^B)^{1/2} > \vartheta$.

In the steady state consumption and productivity in both countries grows at the same rate g, see (5). As in most endogenous growth models, the growth rate falls with the discount rate and spillover parameters, but increases with the productivity of R&D and the elasticity of intertemporal substitution. In particular, higher research capability (ξ) in one of the countries results in faster long-run growth in both countries.

The long-run productivity gap is determined by differences in research capability ξ and the spillover parameter α_f, see (6). The larger the difference in research capability between the two countries, the larger the *structural productivity gap* between them. The country with the highest research capability has highest productivity on the balanced growth path. The larger international spillovers are, the smaller the impact of cross-country differences in research productivity are. The country with lower research productivity tends to grow at a slower pace for given allocation of labour to research, but receives relatively more spillovers from the other country, which boosts growth. In the balanced growth path, the relatively low level of research capability is exactly offset by relatively high spillovers from the other country, such that both countries grow equally fast.

Long-run differences in productivity result into an asymmetric distribution of GDP. The share of country *A*'s GDP in world GDP can be calculated from (C.6) and (6) as:

$$s^A = [1 + (\xi^A / \xi^B)^{-(\varepsilon-1)/2\alpha_f \varepsilon}]^{-1}, \tag{7}$$

whereas *B*'s share is the complement: $s^B = 1 - s^A$. If the countries do not accumulate foreign assets (in BT), s^i is also the share of *i*'s consumption in world consumption, and relative consumption is given by:

$$C^A / C^B = (\xi^A / \xi^B)^{(\varepsilon-1)/2\alpha_f \varepsilon} \tag{8}$$

Equations (7) and (8) reveal that income and consumption differences for given differences in research productivity increase with ε and decrease with α_f. The high productivity country produces more output, which results in more income the better the goods produced substitute for the goods produced in the other country (that is, the higher ε). A high degree of foreign spillovers (α_f) implies that a higher research productivity not only benefits own national income but also foreign income, which tends to reduce international income differences.

For future use, we note that $L^A = L^B$ in the steady state and that the following steady state relationships hold:

$$r = \vartheta + g / \sigma . \tag{9}$$

$$\frac{gL}{1-L} = \zeta L = \vartheta + (\alpha_h + \alpha_f + \sigma^{-1} - 1)g , \tag{10}$$

where $\zeta \equiv (\xi^A \xi^B)^{1/2}$. We asume $r > g$ to ensure bounded utility.

4. Productivity dynamics

We now turn to the question how productivity gaps change over time and how fast they converge to the structural levels discussed in the previous section. Although the model can be used to analyse several situations, we are interested in the particular situation in which the backward country adopts policies that suddenly improve research capability, such that the difference in research capability with the advanced country ($\xi^A - \xi^B$) narrows, but not completely vanishes. According to (6), this lowers the long-run productivity gap, h^A / h^B, but it takes time before cumulative investment has bridged the gap between initial and structural productivity levels.

4.1 Convergence versus divergence

To focus on convergence between the two countries, I solve the model in relative variables. Superscript R denotes ratios: $x^R \equiv x^A / x^B$ for any variable *x*, or, using unabreviated notation with time and regime indices, $x_k^R(t) \equiv x_k^A(t) / x_k^B(t)$. When comparing the two regimes of capital market integration, we refer to ratios of variables over the two regimes. The subscript D denotes regime differences: $x_D^i(t) \equiv x_{CM}^i(t) / x_{BT}^i(t)$.

To derive analytical solutions, we log-linearize our model around the steady state. Linearized variables are denoted by tildes, $\tilde{x} \equiv$ dln*x* = d*x*/*x*, and hence, $\tilde{x}^R \equiv \tilde{x}^A - \tilde{x}^B$ and $\tilde{x}_D^i = \tilde{x}_{CM}^i - \tilde{x}_{BT}^i$. Thus tilded variables measure the deviation from structural levels. Finally, a tilded variable with superscript W denotes the weighted sum a variable of the two countries, where the share in world GDP, s^i, is the weight: $\tilde{x}^W \equiv s^A \tilde{x}^A + s^B \tilde{x}^B$. Generally speaking, linearization provides a good approximation only for small deviations from the steady state (i.e. for $\tilde{h}^R(0)$ small). Numerical experiments with the non-linear model gave qualitatively similar results even for large deviations, so that the method seems justified.

Linearizing (1)-(3) after substituting (C.3) and (C.6), we find:

$$\begin{bmatrix} \dot{\tilde{h}}^R \\ \dot{\tilde{L}}^R \end{bmatrix} = \begin{bmatrix} -2\alpha_f g & -\zeta L \\ -2\alpha_f \Omega & \zeta L \Phi \end{bmatrix} \cdot \begin{bmatrix} \tilde{h}^R \\ \tilde{L}^R \end{bmatrix} \tag{11}$$

$$\begin{aligned} \sigma^{-1} \dot{\tilde{L}}^W &= -(2s^A - 1)\alpha_f (\vartheta + 2\alpha_f g)\tilde{h}^R - (2s^A - 1)\alpha_f (\zeta L)\tilde{L}^R \\ &\quad + (\sigma^{-1} + \alpha_h + \alpha_f)(\zeta L)\tilde{L}^W \end{aligned} \tag{12}$$

where

$$\Phi = 1 + \frac{(\alpha_h - \alpha_f)\varepsilon}{1 + \Gamma}; \quad \Omega = \frac{(\vartheta + 2\alpha_f g)\varepsilon + \varepsilon g / \sigma - (1 + \Gamma)g}{1 + \Gamma}$$

and where $\tilde{h}^R \equiv \tilde{h}^A - \tilde{h}^B, \tilde{L}^R \equiv \tilde{L}^A - \tilde{L}^B$ and $\tilde{L}^W \equiv s^A \tilde{L}^A + s^B \tilde{L}^B$. The key insight is that relative variables $\tilde{h}^R$ and $\tilde{L}^R$, the productivity gap and the ratio of employment in production, can be solved from (11), independently from (12). In particular, solving (11) using each of the two possible values of Γ, see (4), we find two sets of solutions for the time paths of $\tilde{h}_k^R(t)$ and $\tilde{L}_k^R(t)$, one the balanced trade regime (*k* = BT) and one the integrated capital markets regime (*k* = CM). The determinant of the matrix in (11) equals $-2\alpha_f \varepsilon \zeta^2 L / (1 + \Gamma)$. Under our assumption

$\varepsilon > 1$, the determinant is negative for both regimes of capital market integration so that the system of differential equations is saddle-point stable. The corresponding phase diagram is drawn in Figure 1. As appears from eqs. (11) the $\dot{\tilde{h}}^R = 0$ locus slopes downward. The figure depicts an upward sloping $\dot{\tilde{L}}^R = 0$ locus, which applies under realistic parameter assumptions (e.g. $\sigma < 1$ and $\alpha_h > \alpha_f$). The stable arm of the saddle path is indicated by the broken line. Its slope is unambiguously positive. When the productivity gap differs from its structural level, transitional dynamics arise: for any $\tilde{h}^R \neq 0$, the system moves along the stable arm and converges to structural levels in the long run ($\tilde{h}_k^R(\infty) = \tilde{L}_k^R(\infty) = 0$).

To interpret the results, suppose that, in the long run, country B structurally lags behind country A – that is, $\xi^A > \xi^B$, so that $h^R > 1$, see (6). Furthermore suppose that, at time zero, country B lags more behind A than justified by its structural differences – that is, $h^B(0)/h^A(0) < (\xi^B/\xi^A)^{1/2\alpha_f} < 1$ so that $\tilde{h}^R(0) > 0$. From time zero, the productivity gap between A and B will gradually narrow. During this process of convergence to structural levels, the leading economy employs more labour in production than the lagging country ($\tilde{L}^R > 0$, see the movement along the saddlepath to the South-West in the phase diagram). The lagging country allocates relatively more labour to R&D, so that it grows faster than the leading country. The catch-up process slows down over time and in the long run only structural productivity differences remain, as given by (6), while each country's productivity expands at the same rate, given by (5). It may seem unrealistic that the poor country undertakes more R&D than the rich country. Note, however, that R&D in the model should be given a broader interpretation than merely patent development. It encompasses all activities that firms undertake to improve productivity and quality, including for example imitation and reverse engineering.

Insert Figure 1

A different picture arises for the situation in which country B lags behind A, but less than justified by its structural differences, where country A is still the country with highest research productivity; that is, $(\xi^B/\xi^A)^{1/2\alpha_f} < h^B(0)/h^A(0) < 1$ so that $\tilde{h}^R(0) < 0$. In this situation the productivity levels in the two countries will diverge rather than converge over time (in the phase diagram, we start to the left of the point of intersection and move along the saddlepath to the right). The productivity gap becomes larger over time in favour of country A.

In the sequel of this paper we will focus on the convergence case. Unless stated otherwise, we make the following "catching-up situation" assumption:

$$\xi^A > \xi^B \text{ and } \tilde{h}^R(0) > 0 \text{ and } \vartheta < (\alpha_h + \alpha_f + \sigma^{-1})\sigma\zeta L \quad (13)$$

The assumption implies that the poor country B will catch up over time with A, but it will not fully converge because it has lower research productivity. We refer to the case as the "catching-up situation" – to distinguish it from the divergence situation with $\tilde{h}^R(0) < 0$. Catching-up arises if the productivity gap is larger than justified by its structural differences (that is, $\tilde{h}^R(0) > 0$), for example when policies have been implemented to improve national research capability, but when the effects have not yet fully materialized. The restriction on ϑ holds for reasonable parameters and allows us to rule out some ambiguities below.

4.2 Convergence at what speed?

Comparing the regime without international capital mobility with the regime of completely integrated capital markets, we find that international productivity differences converge more slowly in the former than in the latter (provided $\varepsilon > 1$).

The speed at which the steady state is (locally) approached can be determined by standard procedures. In particular, it equals the positive scalar Λ that solves the quaracteristic equation $|M + \Lambda I| = 0$, where M is the matrix in (11) and I is the identity matrix. I denote the speed of convergence by a capital Greek letter to indicate that this parameter depends on the capital markets regime. The analytical solutions for the linearized model in (11) read:

$$\tilde{L}_k^R(t) = \left(\frac{\Lambda_k - 2\alpha_f g}{\zeta L} \right) \tilde{h}_k^R(0) \exp(-\Lambda_k t) \tag{14}$$

$$\tilde{h}_k^R(t) = \tilde{h}_k^R(0) \exp(-\Lambda_k t) \tag{15}$$

where $\tilde{h}^R(0)$ is deviation of the initial productivity gap from the structural productivity gap. Thus Λ is the adjustment speed that governs the dynamics of the labor allocation and relative productivity. A closed-form solution of Λ is given in the appendix. For reasonable parameters, Λ can easily take a value close to 2%, which is usually considered as the empirically relevant number (Temple 1999). For example, for the parameters reported in Figure 3, Λ_{BT} and Λ_{CM} lie in the ranges 1.51-1.57 and 3.12-3.53 percent, respectively.

The speed of convergence is faster with capital market integration than without ($\Lambda_{BT} < \Lambda_{CM}$, see appendix for a formal proof). Consumers prefer to smooth consumption. Capital mobility allows a country to reduce the productivity gap at higher speed without restraining consumption a lot, by running current account deficits. The country of which the productivity gap is larger than the structural gap realizes (ex ante) a higher rate of return and can attract investment funds from the other country. By contrast, if capital is not mobile internationally, investments have to be financed fully by domestic savings, which is costly for domestic consumers who want to smooth consumption. In this case, the supply of savings is less elastic, which slows down the process of catching up relative to the case in which foreign supply of capital finances catching up.

To gain more insight into why capital market integration speeds up convergence, let us consider an extreme case. If $(\varepsilon-1)/\sigma = 0$, we have $\Gamma = 0$ irrespective of the capital market regime. Then, the dynamics are exactly the same in two regimes, see (1)-(3); the adjustment speeds are the same, $\Lambda_{BT} = \Lambda_{CM}$. This extreme case requires $\varepsilon = 1$, that is Cobb-Douglas preferences over domestic and imported goods, or $\sigma \to \infty$, that is utility is linear in consumption. In the latter case, consumption smoothing no longer plays a role; supply of savings is perfectly elastic, independent of whether capital mobility applies or not, so that international capital mobility cannot speed up convergence. In the Cobb-Douglas case, each country earns a fixed share of world income, independent of how large the productivity gap is, since terms of trade effects exactly offset productivity effects, see (C.6). Then, there is no possibility to borrow or lend internationally to smooth consumption over time (cf. Corsetti and Pesenti, 2001). In the realistic case with $\varepsilon > 1$, a country's share in world production increases with the narrowing of its productivity gap. Hence, the country that catches up can borrow against future productivity gains.

5. Consumption dynamics

5.1. Catching-up in consumption

We now investigate how much consumption, rather than productivity, in the lagging country deviates over time from that in the leading country. For the balanced trade regime, this is a relatively straightforward question, since the value of national consumption must equal the value of national production. Relative consumption thus equals $\tilde{C}^R = \tilde{p}^R + \tilde{h}^R + \tilde{L}^R$. From (C.4), (C.8a), (14) and (15) we find:

$$\tilde{C}^R_{BT}(t) = \left(\frac{\varepsilon-1}{\varepsilon}\right)\left(\frac{\Lambda_{BT} + \zeta L - 2\alpha_f g}{\zeta L}\right)\tilde{h}^R(0)[1-\exp(-\Lambda_{BT}t)] \qquad (16)$$

In the capital mobility regime, interest rates are the same in both countries so that consumption grows at the same rate and relative consumption, C^R, is time-invariant (see C.1). Its level follows from the intertemporal budget constraint (C.8b) and (14) and (15):

$$\tilde{C}^R_{CM}(t) = \left(\frac{\varepsilon-1}{\varepsilon}\right)\left(\frac{\Lambda_{CM} + \zeta L - 2\alpha_f g}{\zeta L}\right)\tilde{h}^R(0)\left(\frac{r-g}{r-g+\Lambda_{CM}}\right) \qquad (17)$$

Figure 2 depicts the evolution of consumption and productivity under the catching-up assumption (13). Without capital mobility, the advanced country (A) consumes more than the lagging one (B), but consumption levels gradually converge to structural levels. With capital mobility, again A consumes more than B, but now the gap in consumption levels does not narrow over time, despite the fact that productivity levels converge. The reason is that country A accumulates foreign assets. Country B uses growing export revenues to service its foreign debt. Capital mobility allows both countries to smooth consumption over time.

Insert Figure 2

5.2. Aggregate consumption

What are the effects of international capital market integration on the level and growth rate of aggregate production and consumption in the two-country world? To investigate this question, we need to solve for aggregate, rather than relative, variables. The value of aggregate world employment in production can be directly solved from (12) after plugging in (14) and (15) and taking into account that $\tilde{L}_k^W(\infty) = 0$:

$$\tilde{L}_k^W(t) = (2s^A - 1)\alpha_f \sigma \left(\frac{\Lambda_k + \vartheta}{\Lambda_k + [(\alpha_h + \alpha_f)\sigma + 1]\zeta L} \right) \tilde{h}_k^R(0) \exp(-\Lambda_k t) \tag{18}$$

The value of world production equals $p^A h^A L^A + p^B h^B L^B$, or, as logarithmic deviation from the steady state, $s^A(\tilde{p}^A + \tilde{h}^A + \tilde{L}^A) + s^B(\tilde{p}^B + \tilde{h}^B + \tilde{L}^B) = \tilde{h}^W + \tilde{L}^W$ (to establish the right hand side expression, I have used the fact that $s^A \tilde{p}^A + s^B \tilde{p}^B = 0$, because of the numeraire choice, and I have used the superscript W to denote weighted sums, $\tilde{x}^W \equiv s^A \tilde{x}^A + s^B \tilde{x}^B$). At time zero, productivity levels are the same for both regimes and world production can be different under the different regimes of capital market integration only in so far world employment differs. That is, we have $\tilde{h}_D^W(0) = 0$, so that $\tilde{L}_D^W(0) = \tilde{C}_D^W(0)$ holds, where the latter expression represents how much world production, and hence also world consumption, is higher with capital market integration than without (recall that subscript D denotes regime differences). From (18) and (13), we derive in the appendix that $\tilde{L}_D^W(0)/\tilde{h}^R(0) = \tilde{C}_D^W(0)/\tilde{h}^R(0) > 0$ holds. Hence, when the low productivity country is catching up, initial world consumption levels are higher with integrated capital markets than with balanced trade.

The deviation of the growth rate of world production from its steady state value, as given in (5), can be derived from (C.3) and expressed as:

$$g\tilde{g}_k^W + \dot{\tilde{L}}_k^W = -(2s^A - 1)(\alpha_f g)\tilde{h}_k^R - \zeta L\tilde{L}_k^W - \Lambda_k \tilde{L}_k^W \tag{19}$$

where we used the fact that $s^A \dot{\tilde{p}}^A + s^B \dot{\tilde{p}}^B = 0$, because of the numeraire choice, and $\dot{\tilde{L}}^W = -\Lambda \tilde{L}^W$, from (18). Comparing the different regimes at time zero, we find that initial aggregate growth is lower under capital mobility than under balanced trade if the low productivity country is catching up (since $\tilde{h}_{CM}^W(0) = \tilde{h}_{BT}^W(0)$ and $\tilde{L}_{CM}^W(0) - \tilde{L}_{BT}^W(0) \equiv \tilde{L}_D^W(0) > 0$).

6. Welfare

Intertemporal welfare of the representative consumer in a country depends on the entire path of consumption. The leading country has higher welfare than the lagging country. The interesting question is which country would benefit most from capital market integration, if at all. Let us start with exploring some numerical examples, which are depicted in figure 3 and calculated from the equations that follow below. The numbers in the figure approximate the percentage increase in balanced-growth equivalent consumption when switching from balanced trade to perfect capital mobility and when the actual productivity gap between A and B is twice the structural one (or $100\tilde{U}_D^i(0)/\tilde{h}^R(0)$ in our formal notation). Consequently, if the difference between the actual and structural productivity gap is 200% (or, more generally 100*x*%) of the structural gap, the numbers have to be multiplied by 2 (or *x*, respectively).

Both countries experience higher welfare with integrated capital markets than without, provided that the countries are sufficiently different in structural terms and provided domestic spillovers are sufficiently small. Capital market integration allows countries with catch-up potential to specialize in investment without hurting consumption. Hence, there are potential gains from specialization. With structurally very similar countries, the gains from specialization are small. In a second-best world, these gains may be so small, that they are offset by distortions. With large knowledge spillovers, private agents' investment decisions are distorted and result in underinvestment. Introducing international capital mobility shifts investment funds from the leading to the lagging country. Hence, the underinvestment distortion is aggrevated in the leading country. Indeed, for high spillovers (and small structural differences), the leading country is worse off in an integrated international capital market than in a world without international lending.

insert Figure 3

We now explore the question analytically. A change in welfare can be decomposed in a level effect – the change in initial consumption – and a growth effect – the change in the growth rate of consumption over time. Linearizing the intertemporal welfare function (A.3), we find the following expression (see Smulders, 1994, page 294):

$$\frac{\sigma}{\sigma-1}\frac{dU_k^i(0)}{U_k^i(0)} \equiv \tilde{U}_k^i(0) = \tilde{C}_k^i(0) + \frac{1}{r-g+\Lambda_k} g\tilde{g}_{Ck}^i(0) \tag{20}$$

where I have taken into account that the long-run rate of growth of consumption by construction equals the structural rate, so that $\tilde{g}_{Ck}^i(\infty) = 0$. The larger the adjustment speed, the smaller is the growth effect, since the economy converges faster to structural growth rates. The change in welfare in (20) is scaled in such a way that the expression can be interpreted as the *Balanced-growth-equivalent change in consumption*, that is the permanent increase in level of consumption on a balanced growth path that generates an equivalent change in welfare.

Taking country differences and substituting $g\tilde{g}_{Ck}^R(t) = \dot{\tilde{C}}_k^R(t) = \Lambda_k[\tilde{C}_k^R(\infty) - \tilde{C}_k^R(t)]$, we may write for the change in country A's welfare relative to country B's welfare:

$$\tilde{U}_k^R(0) = \frac{r-g}{r-g+\Lambda_k}\tilde{C}_k^R(0) + \frac{\Lambda_k}{r-g+\Lambda_k}\tilde{C}_k^R(\infty) \tag{21}$$

Substituting the solutions for C^R, from (16) and (17), and steady state relations, (9) and (10), we find for the two regimes:

$$\tilde{U}_k^R(0) = \left(\frac{\varepsilon-1}{\varepsilon}\right)\left(\frac{1+(\alpha_h-\alpha_f)g/(r-g+\Lambda_k)}{1+(\alpha_h+\alpha_f)g/(r-g)}\right)\tilde{h}_k^R(0) \tag{22}$$

Not surprisingly, a larger productivity gap results into a larger welfare differential, but large spillovers reduce the welfare gap.

Summing (20) over the two regions, we can derive the weighted change in world welfare:

$$\tilde{U}_k^W(0) = \tilde{L}_k^W(0) + \tilde{h}_k^W(0) + \left[(1-2s^A)(\alpha_f g)\tilde{h}_k^R(0) - (\zeta L + \Lambda_k)\tilde{L}_k^W(0)\right]\left(\frac{1}{r-g+\Lambda_k}\right) \tag{23}$$

where at the right hand side the first two terms together represent the initial change in the level of world consumption and the term in brackets is the initial change in the world growth rate of consumption from (19).

We can now use (21) and (22) to find expressions for regime differences (recall $\tilde{U}_D = \tilde{U}_{CM} - \tilde{U}_{BT}$):

$$\tilde{U}_D^W(0) = (\alpha_f + \alpha_h)g\left(\frac{\tilde{L}_{BT}^W(0)}{r - g + \Lambda_{BT}} - \frac{\tilde{L}_{CM}^W(0)}{r - g + \Lambda_{CM}}\right) \tag{24}$$

$$\tilde{U}_D^R(0) = \left(\frac{\varepsilon - 1}{\varepsilon}\right)\left(\frac{(\alpha_f - \alpha_h)g}{1 + (\alpha_h + \alpha_f)g/(r - g)}\right)\left(\frac{\Lambda_{CM} - \Lambda_{BT}}{(r - g + \Lambda_{CM})(r - g + \Lambda_{BT})}\right)\tilde{h}_k^R(0) \tag{25}$$

To derive welfare gains of capital mobility over balanced trade for an individual country, notice that by construction the following holds:

$$\tilde{U}_D^A = \tilde{U}_D^W + s^A \tilde{U}_D^R , \tag{26}$$

$$\tilde{U}_D^B = \tilde{U}_D^W - (1 - s^A)\tilde{U}_D^R . \tag{27}$$

These two expressions can be labelled the welfare premium of capital integration in the respective countries. We explore two special cases, one to show that a country may lose from capital market integration because of knowledge spillovers, and another to show that both countries gain from integrated capital markets if $\alpha_f = \alpha_h$.

First consider the case in which spillovers within the country are equally strong as spillovers between countries ($\alpha_f = \alpha_h$). Then $\tilde{U}_D^R = 0$ and $\tilde{U}_D^A = \tilde{U}_D^B = \tilde{U}_D^W$. In the catching-up situation the sign of the latter is positive, see appendix. Hence, both countries gain.

Now consider the case in which both countries are structurally symmetric, that is $\xi^A = \xi^B$ so that $s^A = s^B = 0.5$. From the above equations, we then find $\tilde{U}_D^W = 0$ and $\tilde{U}_D^A = -\tilde{U}_D^B = 0.5 \cdot \tilde{U}_D^R$. Hence, one country gains, and the other loses from capital market integration. Which one loses depends on whether international spillovers are larger or smaller than domestic spillovers. If domestic spillovers are larger than international ones ($\alpha_f > \alpha_h$), country A loses; if $\alpha_f < \alpha_h$, B loses.

Turning to the general case with $\alpha_f \neq \alpha_h$, $s^A \neq 0.5$, we claim the following: (i) the welfare gain of capital market integration increases in both countries with international differences in research capabilities, $\xi^A - \xi^B$; (ii) if firms receive knowledge spillovers more from firms in their own country than from firms in the other country, that is if $\alpha_h > \alpha_f$, the country that catches up gains from capital mobility but the other country may lose; (iii) if $\alpha_h < \alpha_f$, the leading country gains for sure, but the country that catches up may lose. These claims can be proved as follows. First note that when ξ^A / ξ^B increases such that ζ remains the same, $\tilde{U}_D^W$, which is positive, increases through an increase in s^A, while $\tilde{U}_D^R$ is unaffected (see 27c and 30 and the results in section 3). From (26)-(27) we see that this increases welfare $\tilde{U}_D$ in both countries. The second and third parts follows from the fact that $\alpha_f - \alpha_h$ determines the sign of $\tilde{U}_D^R$, see (25), which affects the welfare premium of capital mobility of countries A and B in opposite direction, see (26)-(27).

It might come as a surprise that the introduction of capital mobility does not necessarily improve welfare for both countries. In the standard neoclassical model with perfect competition, capital mobility improves welfare since no externalities are present and the market outcome is first best. Only in a second-best world the introduction of a missing market can deteriorate welfare (Lipsey and Lancaster, 1956). The international trade literature has studied static second-best situations where a tariff distorts goods supply; for example Brecher and Diaz-Alejandro (1977) show that capital mobility might hurt a small open economy that levies an import tariff on capital intensive goods. In our dynamic model, the investment decision is distorted because of knowledge spillovers. The market for public knowledge is missing, so that after introducing the market for international assets (that is, after capital market integration), markets are still not complete and we remain in a second-best world.

Domestic knowledge spillovers imply underinvestment from a welfare point of view. With capital mobility, productivity in the leading country grows more slowly than with balanced trade and in the lagging country it grows faster, since capital flows to the lagging country. Therefore, capital mobility mitigates the underinvestment effect in the lagging country, but aggravates it in leading country. Cross-country spillovers have an opposite effect. The returns to innovation undertaken by one country accrue partly to its trading partner, thereby deteriorating its competitive position. Hence, foreign spillovers result in overinvestment from the point of national welfare. Capital mobility aggravates overinvestment in the leading country. Our results show that if the national externality is more severe than the international externality, there is on balance underinvestment in each country. Since capital mobility speeds up investment in the lagging country, it is this country that gains from capital mobility.

7. Conclusions

In the two-region growth model in this paper, initial productivity differences between regions are ultimately eliminated only if the two regions have equal innovation capabilities; the region with a structurally weak national innovation system will ultimately grow at the same rate as the leading region, but at a lower level. In the short run, regional productivity levels converge or diverge depending on whether the actual productivity gap is larger or smaller than the structural one. International capital market integration increases the rate at which the difference between these two gaps is closed. It reduces short-run differences in consumption levels, but magnifies long-run differences, such that consumption is smoother over time than without capital market integration. Welfare does not necessarily increase with capital market integration. In particular, the low-income region that catches up with the high-income region is likely to gain, but the latter may lose if firms learn more from firms in their own country than from firms in the other country.

It remains to be seen how the results change when national governments subsidize R&D to correct the externalities, and how the results change in the case of coordinated R&D policies. We have focussed on the second-best situation without any government intervention. Apart from the decision to liberalize capital markets, other policies could have important effects on convergence and welfare. An important implication of the model is that convergence of income levels between regions is stimulated by structural policies that improve the national innovation system in low-income regions. However, we did not make explicit (the costs of) these policies. More specific innovation policies could be easily modeled. The first-best situation with maximal welfare in the aggregate (world) economy requires innovation policy. In particular, in the steady state the combination of a subsidy on the labour cost of innovation and a subsidy on the return to savings can fully correct intertemporal knowledge spillover (both subsidies should equal $(\alpha_f + \alpha_h)/(1 - \alpha_f - \alpha_h)$ and hence increase with the spillover parameters). In the resulting first-best situation, the introduction of capital mobility increases welfare. However, such a situation is not very realistic. For example, in the absence of international coordination, national policies may be set to maximize national rather than aggregate welfare. In the two-region setting of the model, each country has incentives to exploit technology policy to strategically induce spillovers from the other country or manipulate the terms of trade. These policy issues are left for future research.

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84.

Appendix

The firm's maximization problem (B.6)-(B.8)

The following Hamiltonian corresponds to the maximization problem of firm z in country i:

$$H^z = p^z(X^z;\bullet)\cdot X^z - (X^z/h^z + R^z)w^i + p_h^z\cdot(h^z)^{1-\alpha_h-\alpha_f}[(\bar{h}^i)^{\alpha_h}(\bar{h}^j)^{\alpha_f}\xi^i]R^z, \qquad (X.1)$$

where $p^z(\cdot)$ is the firm's demand function, see (B.2), $X^z/h^z = L^z$ is labour employed in production, see (A.1), and the last term multiplies the co-state variable p_h^z with firm-specific knowledge accumulation $\mathrm{d}h^z/\mathrm{d}t$, see (A.2). The firm's instruments are X^z and R^z and it controls state variable h^z. The first order conditions with respect to X^z, R^z, and h^z give (B.6)-(B.8).

Equations (1)-(3)

Equation (1) follows directly from the definitions $h^R \equiv h^A/h^B$ and $g^i \equiv \hat{h}^i$.

Equation (2) is derived as follows. Using (C.2) to find an expression for $r^A - r^B$, using (C.3) to eliminate terms with ξ, and using the time derivative of (C.4) to eliminate $\hat{p}^A - \hat{p}^B$, we find:

$$r^A - r^B = \frac{g^A L^A}{1-L^A} - \frac{g^B L^B}{1-L^B} + (1-\alpha_h+\alpha_f)(g^A - g^B) - \frac{1}{\varepsilon}(\hat{L}^A - \hat{L}^B + g^A - g^B) \qquad (X.2)$$

For integrated capital markets (k = CM), we have $r^A - r^B = 0$ and we directly find (2). Without capital market integration (k = BT), we have, from (C.1), $r^A - r^B = \hat{C}^R/\sigma$, and, from (C.4) and (C.8a), we have $C^R = h^R L^R p^R = (h^R L^R)^{(\varepsilon-1)/\varepsilon}$ (recall that superscript R denotes ratios, $x^R \equiv x^A/x^B$). Hence, we may write $r^A - r^B = (\hat{h}^R + \hat{L}^A - \hat{L}^B)(\varepsilon-1)/\varepsilon\sigma$. Substituting this into the above equation, we find (2) for k = BT.

Equation (3) follows from goods market equilibrium (C.7), which reads after differentiation with respect to time and substitution of (C.1) to eliminate the growth rate of consumption:

$$\sigma[s_c^A r^A + (1-s_c^A)r^B] - \sigma\vartheta = s^A(g^A + \hat{L}^A) + (1-s^A)(g^B + \hat{L}^B) \qquad (X.3)$$

where $s_c^A \equiv C^A/(C^A + C^B)$ is the share of country A in world consumption. With balanced trade, we have $s_c^A = s^A$. After substituting (C.2) to eliminate the interest rates, we find (3). With integrated capital markets, we have $r^A = r^B$, so that, from (C.2), we find:

$$\hat{p}^R = \frac{g^A L^A}{1-L^A} - \frac{g^B L^B}{1-L^B} + (1-\alpha_h + \alpha_f)(g^A - g^B) \tag{X.4}$$

This equation also solves for $\hat{p}^A$ since $\hat{p}^A = (1-s^A)\hat{p}^R$ from (C.5)-(C.6). Substituting the results into (C.2), we solve for the interest rate in the integrated capital market:

$$r^A = r^B = \sum_i [s^i g^i L^i/(1-L^i) + (1-\alpha_h + \alpha_f)s^i g^i - \alpha_f g^i] \tag{X.5}$$

Substituting this into (X.3), we find (3).

Steady state

By setting $\hat{h}^R = \hat{L}^A = \hat{L}^B = 0$, we find $g^A = g^B$ from (1) and $L^A = L^B$ from (2). Substituting this into (C.3), we find $h^A / h^B = (\xi^A/\xi^B)^{1/2\alpha_f}$, which is equation (6) in the text, and we find $gL/(1-L) = \zeta L = \zeta - g$, where $\zeta \equiv (\xi^A \xi^B)^{1/2}$. Substituting the latter result and $\hat{L}^A = \hat{L}^B = 0$ into (3), we find $0 = \zeta - g + (1-\sigma^{-1} - \alpha_h - \alpha_f)g - \vartheta$, which solves for *g* as in (5). From (C.2) we can now solve for *r*; substituting this solution into (C.1) gives $g_c = g$.

Speed of convergence

The adjustment speed Λ_k can be solved from the characteristic equation associated to (11) and can be written as

$$\Lambda_k = \frac{\sqrt{T_k^2 - 4D_k} - T_k}{2} = \frac{\sqrt{1 + 4D_k/T_k^2} - 1}{2/T_k} > 0, \tag{X.6}$$

where $T_k = \zeta L - 2\alpha_f g + (\alpha_h - \alpha_f)\zeta L\varepsilon/(1+\Gamma_k)$ and $D_k = -(2\alpha_f \zeta)\zeta L\varepsilon/(1+\Gamma_k)$ be the trace and determinant, respectively, of the system in (11). Total differentiation of this solution gives $d\Lambda_k = -[dD_k + \Lambda_k dT_k]/(2\Lambda_k + T_k)$, in which the denominator is positive by construction.

Proposition: $\Lambda_{CM} > \Lambda_{BT}$

Proof: Differentiating (X.6) with respect to Γ, we find

$$\frac{d\Lambda_k}{d\Gamma_k} = -\left(\frac{\zeta L\varepsilon}{2\Lambda_k + T_k}\right)\left(\frac{1}{1+\Gamma_k}\right)^2 \left[2\alpha_f \zeta + (\alpha_f - \alpha_h)\Lambda_k\right] \tag{X.7}$$

(i) If $\alpha_f \geq \alpha_h$, we have $d\Lambda_k / d\Gamma_k < 0$.

(ii) If $\alpha_f < \alpha_h$, we have $d\Lambda_k / d\Gamma_k < 0 \Leftrightarrow \Lambda_k < 2\alpha_f \zeta /(\alpha_h - \alpha_f) \equiv \bar{\Lambda}$. The latter inequality always holds for $\alpha_f < \alpha_h$: for $\varepsilon \to 0 \wedge \Gamma = 0$, we have $D_k \to 0$ and $\Lambda_k = \Lambda_{CM} \to 0$; for $\varepsilon \to \infty \wedge \Gamma = 0$, l'Hopital's formula applied to (X.6) gives $\Lambda_k = \Lambda_{CM} \to 2\alpha_f \zeta /(\alpha_h - \alpha_f)$; since Λ_k is continuous in ε, we therefore have $\alpha_f < \alpha_h \Leftrightarrow 0 < \Lambda_{CM} < 2\alpha_f \zeta /(\alpha_h - \alpha_f)$.

Hence, $d\Lambda_k / d\Gamma_k < 0$. Since $\varepsilon > 1 \Leftrightarrow \Gamma_{BT} > \Gamma_{CM}$, see (4), we have $\Lambda_{BT} < \Lambda_{CM}$.

Aggregate production

Proposition: $\tilde{L}_D^W(0) > 0$.

Proof: From (18), we see that $d\tilde{L}_k^W(0)/d\Lambda_k > 0$ under assumption (13). Since $\Lambda_{BT} < \Lambda_{CM}$, we have $\tilde{L}_D^W(0) \equiv \tilde{L}_{CM}^W(0) - \tilde{L}_{BT}^W(0) > 0$.

Aggregate welfare

Claim: $\tilde{U}_D^W(0) > 0$.

Proof for σ < 1: Substituting (18) into (24), we find

$\tilde{U}_D^W(0) = (\alpha_f + \alpha_h) g (2s^A - 1)\alpha_f \sigma (\Psi_{BT} - \Psi_{CM})\tilde{h}^R(0)$,

where $\Psi_k \equiv (\vartheta + \Lambda_k)/(\bar{\zeta} + \Lambda_k)(r - g + \Lambda_k)$ and $\bar{\zeta} \equiv (\alpha_f + \alpha_h + \sigma^{-1})\sigma\zeta L$. Under assumption (13), we have $d\Psi_k / d\Lambda_k < 0 \Leftrightarrow \Psi_{BT} > \Psi_{CM} \Leftrightarrow \tilde{U}_D^W > 0$. Differentiation gives $sign\, d\Psi_k / d\Lambda_k = sign[(\bar{\zeta} - \vartheta)(g/\sigma)(1-\sigma) - (\vartheta + \Lambda_k)^2]$, which is negative for $\sigma \geq 1$ under assumption (13). Also for σ < 1, it is likely to be negative; I have not found numerical examples of the contrary.