Time Preference, Productivity, and the Growth Effects of Integration

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Abstract

Traditional trade theory emphasizes static gains form trade, whereas the growing literature on endogenous growth is able to explain dynamic gains from trade, i.e., how trade influences economic growth. Empirical studies suggest that dynamic gains are likely to be significantly more important than static gains. More recently, a debate has evolved around the question: do welfare improving effects of trade still prevail when countries are "unequal" in some sense? This paper extends the discussion by investigating how differences in time preference rates and R&D productivity under alternative assumptions concerning knowledge diffusion affect the effect growth. We show that even when a developing country completely looses competitiveness in R&D, it experiences positive welfare improving effects with opening trade.

1. Introduction

Traditional trade theory emphasizes static gains form trade, whereas the growing literature on endogenous growth is able to explain dynamic gains from trade, i.e., how trade influences economic growth. Empirical studies suggest that dynamic gains are likely to be significantly more important than static gains. Among the theoretical approaches on dynamic trade effects, the Romer (1990) model has become one of the mainstream models for analyzing the interdependence between trade and growth issues. In this model, growth is driven by private, profit-seeking R&D entrepreneurs who invent designs for new capital goods. These goods simultaneously increase productivity of further R&D and manufacturing activities. Rivera-Batiz and Romer (1991a) extend the Romer model to an open economy and investigate the growth enhancing effects of integration between two equal countries. Their analysis shows that both countries experience positive level and growth effects. In their model, the dynamic gains from trade stem almost entirely from the opening of two channels of international technology transfer. Firstly, imports of high-tech capital goods increase the productivity in manufacturing because of the uniqueness of each capital good, and it augments the diversity of the capital stock. This, in turn, increases the potential benefit from specialization. Secondly, technological knowledge may flow more freely across the borders after trade liberalization, which causes researchers and engineers to become more productive in inventing new designs.

More recently, a debate has evolved around the question: do welfare improving effects of trade still prevail when countries are "unequal" in some sense? Grossman and Helpman (1990) show that trade may be detrimental for the growth process of some countries. Rivera-Batiz and Romer (1991b) add to the discussion that technology transfer may induce allocation effects that can lead to a decline in the growth rate. Furthermore, it was argued that developing countries, in particular, could loose from trade liberalization and should, therefore, protect their markets from foreign competition. Rivera-Batiz and Xie (1993) investigate the effects of integration when countries differ in their endowments of human capital. They show that indeed economic growth may fall in one country but, nevertheless, the overall welfare effects across all countries would be positive. Frenkel and Trauth (1996) consider other differences between countries but analyze only situations of complete knowledge diffusion.

The purpose of the following analysis is to extend the discussion by investigating in more detail how different assumptions concerning knowledge diffusion alter the effects of integration among countries that differ in their demand or supply side structure. We show that even when a developing country completely looses competitiveness in R&D, it experiences positive welfare improving effects with opening trade. In this paper, we focus on economic integration between countries endowed with a given amount of skilled and unskilled labor.[1]

The rest of the paper is structured as follows: Section 2 briefly presents the model which is taken from Romer (1990). This section also develops key implications which are used later in the analysis. Sections 3 and 4 study effects for countries with different time preference rates. Sections 5 and 6 analyze the influence of productivity differences on the integration effects. The main results are summarized in section 7.

2. The structure of the model

The following model is based on Romer's (1990) analysis of endogenous growth. There are two countries, referred to as the home and the foreign country, respectively. Production in each country comprises two sectors: the manufacturing sector producing consumption and capital goods and the R&D sector producing designs or blueprints for innovative capital goods. The knowledge stock in the economy increases as a byproduct of each invention. Therefore, the output of the R&D sector is two-dimensional. On the one hand, there are good specific designs for which intellectual property rights can be enforced and, thus, be sold. On the other hand, each invention adds to the knowledge stock and can therefore facilitate future research. Knowledge as such can be seen as a public good, i.e., everyone can use it at the same time without any restriction. For simplicity, it is assumed that each invention of a new design incorporates a certain constant amount of knowledge. Therefore, the number of designs in an economy can be regarded as a proxy for the size of the knowledge stock. Both aspects of innovations increase productivity in the economy. New designs increase the diversity of the capital stock and, thereby, total factor productivity in the manufacturing sector. A higher knowledge stock leads to more sophisticated researchers and, therefore, more inventions with a given factor input. In other words, the R&D sector produces technological progress, embodied in new designs and the increasing knowledge stock, and thereby drives the growth process.

Supply side

The manufacturing sector produces output, Y, using unskilled labor, L, human capital, H_Y,

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[1] Another approach to investigate the effects of integration on growth is chosen by Young (1991). He uses a learning-by-doing model and presents ambiguous results as to the effects of integration on learning-by-doing induced growth. However, there is no R&D activity in his model. In Young (1993) invention and learning by doing are integrated in one model but the focus is on the closed economy. Grossman and Helpman (1994) survey different approaches that deal with dynamic effects of trade induced by technology transfer.

and a set of capital goods, produced at home, x(i), and abroad, m(i). The production functions are

$$Y = H_Y^{\alpha} L^{\beta} \left[\int_0^{A} x(i)^{\gamma}\, di + \int_0^{A^*} m(j)^{\gamma}\, dj \right] , \tag{1}$$

$$Y^* = H_Y^{*\alpha} L^{*\beta} \left[\int_0^{A^*} x^*(j)^{\gamma}\, dj + \int_0^{A} m^*(i)^{\gamma}\, di \right] . \tag{2}$$

Note that home economy variables are denoted without asterisks and foreign economy variables with asterisks. The $x^*(j)$ are the capital goods produced and used abroad, while the $m^*(i)$ are the capital goods produced at home and used abroad. The output, Y, is a composite good consisting of homogeneous consumption goods, C, and the various capital goods x(i) and $m^*(i)$. Consumption goods and capital goods are produced with the same technology and, for simplicity, it is assumed that the same amount of resources is needed to manufacture one unit of the consumption good or alternatively one unit of the capital good. Therefore, the marginal rate of transformation between consumption and capital goods is one.

The indices, i and j, represent distinct capital goods that have already been invented, so that $i \in (0,A)$ and $j \in (0,A^*)$. To avoid integer problems, i and j are defined continuously. With a given level of A and A^* the production functions (1) and (2) are assumed to exhibit constant returns to scale, i.e., $1=\alpha+\beta+\gamma$. New designs increase the set of capital goods and, thereby, production possibilities because a more differentiated capital stock is more productive.

The capital stock, K, is defined as the sum of foregone consumption. Since the amount of each type of a capital good equals the amount of consumption goods foregone, the capital stock is simply the sum of all capital goods produced at home and imported from abroad:[2]

$$K = \int_0^{A} x(i)\, di + \int_0^{A^*} m(j)\, dj \; . \tag{3}$$

The private R&D sector only uses human capital to produce designs. The R&D production functions for the two countries are

$$\dot{A} = \delta\, A_A H_A \; , \tag{4}$$

$$\dot{A}^* = \delta^* A_A^* H_A^* \; . \tag{5}$$

[2] The home and foreign capital goods fit in the home capital stock with the same weight, because the terms of trade between home and foreign capital goods are one. This is due to the fact that production costs of capital are determined by the interest rate which is the same in both countries.

Here $\dot{A}$ denotes new designs. H_A is the human capital used in R&D, δ is a productivity parameter, and A_A is the knowledge stock available to researchers. In the following we want to distinguish between two cases. In the first case, it can be assumed that capital and goods markets are integrated but that the exchange of technological knowledge cannot occur. This might be the case when communication channels like research exchange do not work because of, e.g., language or cultural barriers. In this case researchers cannot benefit from the foreign knowledge stock and, as a result, there are distinct national knowledge stocks, i.e. $A_A = A$. In the second case, it can be assumed that knowledge can freely flow between the countries so that researchers benefit from scientific insights regardless of the origin of the inventions. As a result, both countries share a common knowledge stock, i.e., $A_A = A_A^*$. For simplicity, we assume that all ideas in both countries are distinct, i.e. no redundancy occurs so that $A_A = A_A^* = A + A^*$.

The endowment of human capital and labor is fixed. While labor is only used in manufacturing, human capital can be used in manufacturing as well as R&D. By assuming full employment, human capital is divided between the two sectors, i.e.:

$$H = H_Y + H_A \; . \tag{6}$$

Market structure

The model assumes that within all sets of capital goods, i.e., x(i), x^*(j), m(j), and m^* (i), demand and supply conditions are the same. As a consequence, prices and quantities of each type of capital good within these sets are the same so that the indices can be left out. Furthermore, perfect capital mobility leads to international interest rate equalization.

Each manufacturer has to decide how many units of consumption goods and how many capital goods he produces. In order to produce capital goods, the manufacturer must buy a patent right from an R&D enterprise. The costs of the patent right are independent of the number of capital goods produced. These costs add as fixed costs to the variable costs for human capital, labor, and capital goods. The manufacturer is able to pay for the patent right because he becomes a monopolist for one distinct type of capital good and is therefore able to reap a monopoly rent. The representative monopolist rents the capital goods to other manufacturers. His marginal costs can be expressed in terms of forgone consumption goods. Since he has to forego one unit of consumption good for producing one unit of capital good and since there is no depreciation, his marginal opportunity costs are simply the interest rate. The other manufacturers are willing to pay a periodical price, p, expressed in units of consumption goods, equal to the marginal product of a capital good, which is:

$$p = \frac{\partial Y}{\partial x} = \gamma \, H_Y^{\alpha} L^{\beta} x^{\gamma - 1} \; . \tag{7}$$

Likewise, the inverse demand function for imported capital goods is[3]

$$p^{*} = \frac{\partial Y}{\partial m} = \gamma H_Y^{\alpha} L^{\beta} m^{\gamma - 1} \ . \tag{8}$$

The monopolist knows the demand curve of the manufacturers and maximizes his profits, π. The latter is the difference between his rental income, $p(x+m^*)$, and the opportunity costs, which equal his capital costs, $r(x+m^*)$. Equations (7) and (8) imply that the price elasticity of demand for capital goods is equal to $1/(\gamma-1)$. According to Chamberlinian markup pricing it is optimal for the monopolist to charge a constant markup over marginal costs. This implies $p=r/\gamma$. Note that the price for the patent paid by the monopolist represents his fixed costs and, therefore, does not affect his profit maximizing price. International interest rate equalization and identical mark-up parameters in both countries lead to identical prices for all types of capital goods, i.e., $p=p^*$. Based on these arguments, the profits of the monopolist are

$$\pi = p(x + m^{*}) - r(x + m^{*}) = \frac{r}{\gamma}(x + m^{*}) - r(x + m^{*}) = \frac{1 - }{\gamma} \tag{9}$$

Equations (7) and (8), together with $p=r/\gamma$, can be transformed to yield the demand for x and m as functions of the endowment with labor, the allocation of human capital, and the interest rate

$$x = m = \gamma^{2/(1-\gamma)} H_Y^{\alpha/(1-\gamma)} L^{\beta/(1-\gamma)} r^{-1/(1-\gamma)} \ . \tag{10}$$

The demand for capital goods of the foreign manufacturers is

$$x^{*} = m^{*} = \gamma^{2/(1-\gamma)} H_Y^{*\alpha/(1-\gamma)} L^{*\beta/(1-\gamma)} r^{-1/(1-\gamma)} \ . \tag{11}$$

The price of a patent right, P_A, is determined in a polypolistic market between potentially many manufacturers of capital goods and many R&D enterprises. The manufacturers' willingness to pay for a design depends on the present value of all future monopoly profits, which, together with equation (9), is

$$P_A = \int_0^{\infty} e^{-rt} \pi \, dt = \frac{\pi}{r} = \frac{1 - \gamma}{\gamma}(x + m^{*}) \ . \tag{12}$$

Hence, in equilibrium, the monopolist uses all his profits from producing and selling capital goods to pay for the patent. The price of the patent, in turn, determines the wage paid to human capital in the R&D sector so that profits in this sector are also zero.

Technology equilibrium

A crucial feature of the model is the allocation of human capital between the manufacturing

[3] Alternatively, it could be assumed that the manufacturers are willing to pay the present value of an ever lasting stream of rents, which would be $p/r=(r/\gamma)\cdot(1/r)=1/\gamma$.

and the R&D sector, because human capital is the only rival factor between both sectors. It is assumed that human capital is perfectly mobile and that wages are flexible. Therefore, an equilibrium allocation is reached when the wage rate for human capital in manufacturing, w_{HY}, is equal to the wage rate for human capital in R&D, w_{HA}. Factor market equilibrium implies that the wage rates for human capital in both sectors must equal their marginal products. Together with x=m and equation (10) this yields

$$\begin{aligned} w_{H_Y} &= \frac{\partial Y}{\partial H_Y} = \alpha H_Y^{\alpha-1} L^{\beta} \left(A x^{\gamma} + A^* m^{\gamma} \right) = \frac{\alpha}{\gamma^2} H_Y^{-1} r (A + A^*) \\ &= \alpha \gamma^{2\gamma/(1-\gamma)} (A + A^*) L^{\beta/(1-\gamma)} r^{-\gamma/(1-\gamma)} H_Y^{-\beta/(1-\gamma)} \ . \end{aligned} \tag{13}$$

The first line of equation (13) is derived by replacing L^{β} through an expression derived from equation (10). The second line of equation (13) expresses the wage rate as a function of L rather than x.[4]

The marginal product of human capital in R&D, measured in units of consumption goods, can be derived together with equations (10), (11), and (12)

$$w_{H_A} = P_A \frac{\partial \dot{A}}{\partial H_A} = \frac{1-\gamma}{\gamma} (x + m^*) \, \delta A_A \tag{14}$$

or

$$w_{H_A} = (1-\gamma) \gamma^{(1+\gamma)/(1-\gamma)} \delta A_A r^{-1/(1-\gamma)} \Big(H_Y^{\alpha/(1-\gamma)} L^{\beta/(1-\gamma)} + H_Y^{*\alpha/(1-\gamma)} L \tag{15}$$

When both sectors are active, i.e. $w_{HA}=w_{HY}$, a technology equilibrium can be described by the interest rate, r_t, that ensures equilibrium in the market for human capital. Using equation (13) and (14) together with wage rate equalization yields

$$r_t = \frac{\delta}{\psi} \left[\frac{A_A (x + m^*)}{x^{1-\gamma} (A x^{\gamma} + A^* m^{\gamma})} \right] (H - H_A) \qquad with \ \psi = \tag{16}$$

Alternatively, equation (16) can be transformed to

$$r_t = \frac{\delta}{\psi} \left[\frac{A_A}{A + A^*} \left(1 + \left(\frac{H^* - H_A^*}{H - H_A} \right)^{\frac{\alpha}{1-\gamma}} \left(\frac{L^*}{L} \right)^{\frac{\beta}{1-\gamma}} \right) \right] (H - H_A) \ . \tag{17}$$

If the R&D sector is not active, i.e. the wage rate in R&D is smaller than the wage rate in manufacturing, then the following inequality applies

$$r_t \geq \frac{\delta}{\psi} \left[\frac{A_A (x + m^*)}{x^{1-\gamma} (A x^{\gamma} + A^* m^{\gamma})} \right] (H - H_A) \ . \tag{18}$$

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[4] This can be derived from the first line of equation (13) by using equation (10) again.

Demand side equilibrium

The representative agent is assumed to have Ramsey preferences with constant intertemporal elasticity of substitution, 1/σ, and discounting future utilities with a constant rate of time preference, ρ:

$$U_s = \int_s^{\infty} e^{-\rho(t-s)} \frac{C^{1-\sigma} - 1}{1 - \sigma} dt \ . \tag{19}$$

The Keynes-Ramsey rule gives

$$\frac{\dot{C}}{C} = \frac{r - \rho}{\sigma} \ . \tag{20}$$

The consumption optimum, described by the Keynes-Ramsey rule, depends on the interest rate and the equilibrium growth rate of consumption. The equilibrium growth rate of consumption is closely connected to human capital allocation. This can be shown by considering the definition of the balanced equilibrium growth path (steady state). In equilibrium, the aggregated variables must grow at the same rate, g^w. This implies

$$g^w = \frac{\dot{C} + \dot{C}^*}{C + C^*} = \frac{\dot{Y} + \dot{Y}^*}{Y + Y^*} = \frac{\dot{K} + \dot{K}^*}{K + K^*} = \frac{\dot{A} + \dot{A}^*}{A + A^*} = \delta H_A \frac{A_A}{A + A^*} \tag{21}$$

If world consumption and the world knowledge stock grow at the same pace and both countries exhibit the same intertemporal elasticity of substitution, then the following world Keynes-Ramsey rule can be derived

$$r_p = \rho \frac{C}{C + C^*} + \rho^* \frac{C^*}{C + C^*} + \sigma \delta H_A \frac{A_A}{A + A^*} + \sigma \delta^* H_A^* \frac{A_A^*}{A + A^*} \tag{22}$$

For a given foreign human capital allocation, an increase in human capital employed in R&D induces a higher steady state growth rate and thus the interest rate, that ensures household optimum, r_p, must rise, too. This is due to the fact that in order to ensure higher growth, households must shift more consumption to the future, i.e., the interest rate must rise in order to provide the incentive to do so.

Total equilibrium

While equation (17) represents the condition supply side (technology) equilibrium, equation (22) is a condition for demand side (preference) equilibrium. Both equilibria depend on the interest rate and the human capital allocation. Therefore, total equilibrium can be derived by both conditions and can be described by an equilibrium interest rate and the equilibrium human capital allocation.

Equilibrium in autarky

In the following sections the autarky situation serves as our benchmark case. Therefore, autarky equilibrium must be studied first. In autarky, the following steady state condition holds:

$$g = \frac{\dot{C}}{C} = \frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \frac{\dot{A}}{A} = \delta H_A \ . \qquad (23)$$

The technology equilibrium in autarky can be derived from equation (16) together with $m=m^*=0$:

$$r_t = \frac{\delta}{\psi} H_Y = \frac{\delta}{\psi}(H - H_A) \ . \qquad (24)$$

It is now possible to derive a curve r_t, showing combinations of r and H_A that ensures equilibrium of the factor market for human capital. We refer to this curve as the technology curve. In human capital market equilibrium, this curve reflects that marginal productivity of human capital in the manufacturing sector is equal to its marginal productivity in R&D. The slope of the r_t curve in Fig. 1 is negative, since an interest rate increase leads to more human capital in manufacturing and less human capital in R&D.[5]

In autarky, which implies that $C^*=A^*=0$, equation (22) becomes

$$r_p = \rho + \sigma \delta H_A \ . \qquad (25)$$

The above equation is shown in Fig. 1 by the preference curve, r_p. The steady state is reached when r_t equals r_p, because here human capital allocation is optimized and private agents utility is maximized here.

If $\delta H/\psi \leq \rho$ neither innovation nor growth is taking place. The endowment with human capital is too small to enable growth: in other words, the interest rate that ensures equilibrium allocation of human capital is smaller than the time preference of private agents.

[5] The appendix explains in more detail the allocation effects of moving along the r_t curve, i.e., of a change in the interest rate.

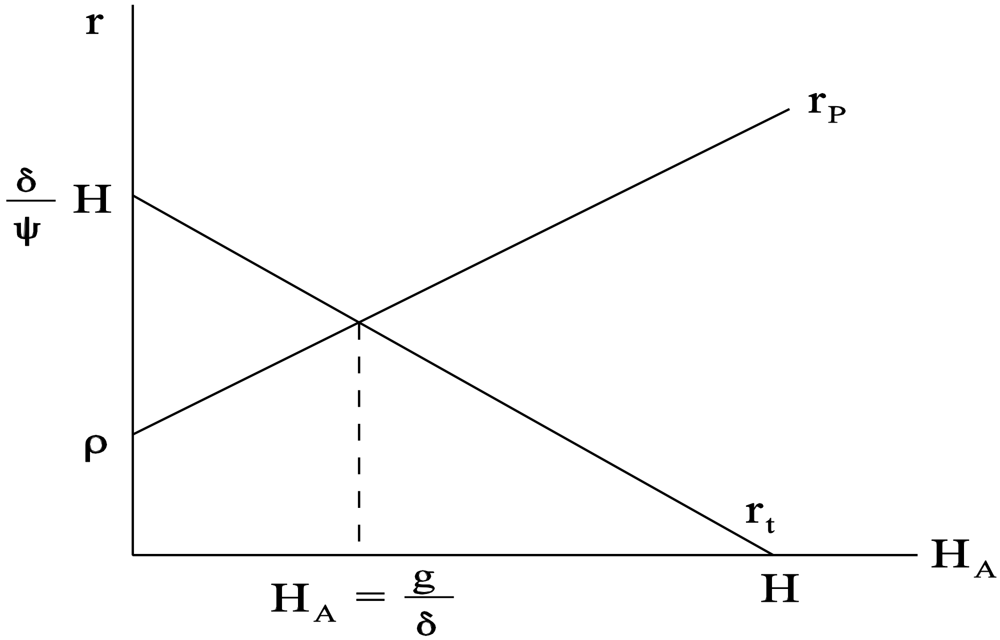

Figure 1

Equations (24) and (25) can be combined to derive the steady state growth rate in autarky, g, which is

$$g = \frac{\delta H - \psi \rho}{\sigma \psi + 1} . \tag{26}$$

In the next two sections we study the specific effects of integration on the growth rate and the allocation of human capital.

3. Integration effects without knowledge diffusion when rates of time preference differ between countries

We begin the analysis by briefly examining the pre-integration situation of two countries which differ only in their rates of time preference. Otherwise, they have the same technology and also the same endowment of labor and human capital. The initial growth equilibria of the two economies in isolation are shown in Fig. 2. In the following analysis we assume that the domestic economy has a lower rate of time preference. Equation (25) shows that, in this case, the domestic economy's r_p schedule has a smaller intercept with the vertical axis as compared to the corresponding foreign schedule, r_p^*. However, both curves have the same slope. Since the r_t schedule is independent of the rate of time preference, it is the same in both countries. The autarky equilibria in Fig. 2 reveal that along the initial equilibrium growth path the domestic interest rate is lower and the human capital use in the domestic R&D sector is higher than in the foreign economy. By contrast, given the same endowment with human capital in both countries, the foreign economy uses more human capital in the manufacturing sector:

$$H_A > H_A^* \ ; \qquad H_Y < H_Y^* \ .$$

The equation $g=\dot{A}/A=\delta H_A$ explains why along the balanced growth path in the pre-integration situation the growth rate is higher and the interest rate is lower in the domestic economy compared to the foreign economy. It is interesting to see which country uses larger quantities (x) of any type of capital goods. Since the r_t curve is the same in both countries, we need to examine how x changes along the r_t curve. Replacing the interest rate or alternatively H_Y in equation (10) by the expression in equation (24), the demand function for capital goods can be expressed as a function of H_A or r:

$$\begin{aligned} x &= \gamma^{2/(1-\gamma)} \left(\frac{\delta}{\psi} \right)^{-1/(1-\gamma)} L^{\beta/(1-\gamma)} (H - H_A)^{-(1-\alpha)/(1-\gamma)} \\ &= \gamma^{2/(1-\gamma)} \left(\frac{\delta}{\psi} \right)^{-\alpha/(1-\gamma)} L^{\beta/(1-\gamma)} r^{-(1-\alpha)/(1-\gamma)} \ . \end{aligned}$$

This shows that moving down the r_t curve is associated with an increase in capital goods, x. There are two opposite effects which cause this result. On the one hand, a less intensive use of human capital in the manufacturing sector implies a lower productivity of capital goods and, therefore, demand for capital goods decreases. On the other hand, lower interest rates reduce the costs of capital. As explained before and shown by the equation above, this is the dominating effect. Hence, in the initial equilibrium, the domestic economy uses more capital goods of each type than the foreign economy.

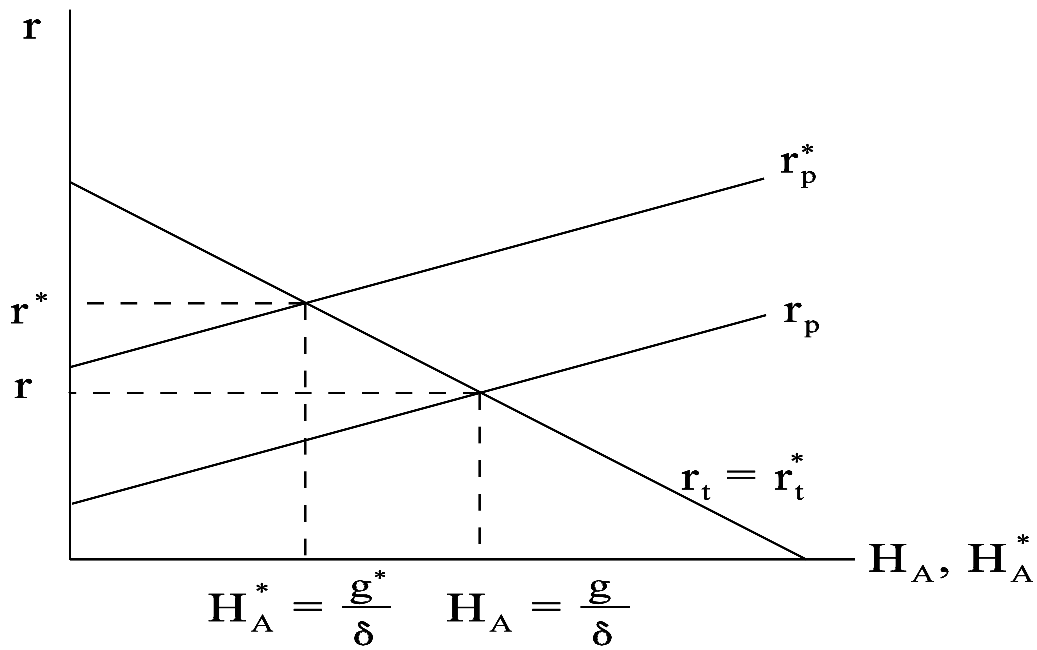

Figure 2

We now assume that the policymakers in the two countries decide to abolish all barriers to international trade and capital flows. In the context of the model analyzed here, economic developments in the two countries can be affected through two international channels: through the flow of goods and the flow of ideas between countries. While the first is the result of international trade, the latter is determined by the process of communicating ideas through telecommunication networks, printed media, studies abroad, travel, and investment by multinational corporations. However, language barriers and lack of communication impede the diffusion of technology. Although in most cases of integration both forms play a role, a better examination of the different channels through which integration affects the growth rate can be made if the two forms of integration separation of these two forms is useful in the analysis in order to examine different channels through which integration affects the growth rate of an economy.

Initially, we assume that integration of the goods and the capital market is not accompanied by international knowledge diffusion. We begin the analysis with two observations. First, with perfect capital markets, the domestic interest rate cannot deviate from the foreign interest rate. With $p=r/\gamma$, interest-rate equalization implies that there is no price difference between domestic-designed and foreign-designed capital goods ($p=p^*$). As a result, equations (7) and (8) show that $x=m$ and $x^*=m^*$. Second, since in isolation the domestic economy is more innovative than the foreign economy, it can also be assumed that also the level of invented designs in the pre-integration situation is higher in the domestic than the foreign economy so that $A>A^*$. This implies that $A/(A+A^*)\in(0.5, 1)$.

The reallocation of human capital between the manufacturing and the R&D sector triggered by integration depends on the relative wage effects given the initial production structure and the interest rate level. The wage effect can be seen from equation (17) which, together with $L=L^*$ as assumed above, we can write as

$$r_t = \frac{\delta}{\psi}\left[\frac{A}{A+A^*}\left(1+\left(\frac{H_Y^*}{H_Y}\right)^{\alpha/(\alpha+\beta)}\right)\right]H_Y \ .$$

Note that the numerator of the first factor in brackets on the right side of this equation is A. The reason for this is that in the absence of knowledge diffusion the knowledge level available to the R&D sector (A_A) is given by A for the home country. Since we assume that the level of invented designs is higher in the domestic economy prior to integration, A is bigger than A^*, i.e. $0.5<A/(A+A^*)<1$. Since $H_Y^*>H_Y$, the second factor in brackets on the right hand side of the preceding equation is greater than two. Therefore the total value of the expression in brackets is greater than one. Recalling that the function for the r_t schedule in the pre-integration situation is identical to the preceding equation without the brackets, a value of the brackets greater than one implies that for given values of the interest rate, w_{HA}/w_{HY} is greater than one. This induces a shift of human capital out of the manufacturing sector and into the R&D sector. When human capital increases in the R&D sector in the home country, the wage rate declines in this sector while it increases in manufacturing. The opposite effects are induced in the foreign country where human capital migrates from R&D into manufacturing.

So far, we have only analyzed the migration of human capital triggered by goods and capital market integration. We still have to investigate the new balanced growth path. After an increase in human capital in the R&D sector of the domestic economy and a decline abroad, one factor continues to drive a wedge between the wage rates of the two sectors. Since the home country is more innovative, the share of the home country in the total number of designs, i.e., $A/(A+A^*)$ increases. This is tantamount to a faster growing productivity of human capital in R&D than in manufacturing in the home economy. The opposite holds in the foreign country. Hence, migration continues until the foreign country is completely specialized in manufacturing and the home country is diversified into manufacturing and R&D. To formally see the described dynamics, we consider a change in the share of one country's designs in the total designs of both countries. Denoting this share for the home country as $\theta = A/(A+A^*)$, we can derive the following expression for the change in this share as

$$\frac{\dot{\theta}}{\theta} = \frac{\dot{A}}{A} - \frac{\dot{A}+\dot{A}^*}{A+A^*}$$

which we can rearrange by using the production functions for the domestic and the foreign R&D sector, i.e., equations (4) and (5), to get

$$\frac{\dot{\theta}}{\theta} = \delta\,(1-\theta)\,(H_A - H_A^*)\ .$$

This shows that the share of the home country (θ) increases as long as it uses more human capital in the R&D sector than the foreign country does. Thus, this process can halts only when $\theta=1$. Likewise, since the share of the foreign country in total designs is $1-\theta$, the share of foreign designs will asymptotically approach zero. This result for the effects of integration without knowledge diffusion in the case of diverging rates of time preference corresponds to the Devereux and Lapham (1994) result of complete specialization in the case of countries which have identical preferences and technological structures but differ in their initial level of designs invented.

Having analyzed the effects of integration on the production structure we now turn to the effects on economic growth. To do so, first we examine the change in the capital stock (K). With all types of capital goods used in the same amount we get $K=Ax+A^*m$. If the foreign country ceases to invent new designs, then the growth rate of the capital stock in the home country eventually is

$$\frac{\dot{K}}{K} = \frac{\dot{A}\,x}{A\,x + A^*\,m} = \frac{\dot{A}}{A + A^*} < \frac{\dot{A}}{A} \qquad \textit{with} \qquad \lim_{t\to\infty} \frac{\dot{K}}{K} = \frac{\dot{A}}{A}\ .$$

The growth rate of the capital stock approaches the growth rate of new designs since foreign designs become negligible over time compared to the amount of domestic designs. However, this is an asymptotic process as $\theta\to 1$. With given levels of x and m (with x=m) the production function of the manufacturing sector shows that the growth rate of Y is equal to the growth rate of the capital stock:

$$\lim_{t\to\infty} \frac{\dot{Y}}{Y} = \lim_{t\to\infty} \frac{\dot{K}}{K}\ .$$

This implies that the growth of production approaches the growth of new designs. Since the home country uses more human capital in the R&D sector along the new (asymptotic) balanced growth path (the new level is indicated by H_A') the growth rate of new designs is higher after integration:

$$\lim_{t\to\infty} \left(\frac{\dot{Y}}{Y}\right)_{integration} = \delta H_A^{/} > \delta H_A \ .$$

Thus, growth increases through integration. For the foreign country the growth rate will also increase and approach $\delta H_A'$. To show this, first we have to consider the change in the foreign country's capital stock. With its level being $K^*=A^*x^*+Am^*$, the capital stock grows at the rate

$$\frac{\dot{K}^*}{K^*} = \frac{\dot{A}}{A+A^*} \quad \Rightarrow \lim_{t\to\infty} \frac{\dot{K}^*}{K^*} = \frac{\dot{A}}{A} \ .$$

Since growth of foreign manufacturing output is asymptotically equal to the growth rate of the capital stock, the foreign country experiences the same growth rate as the domestic economy. Therefore, our result is that integration has a positive growth effect. The country with the lower R&D activity initially exhibits a particularly strong increase in growth. Integration thus leads to an increase in the worldwide growth of production and identical growth rates even if, due to different rates of time preference, the growth of production was different in the pre-integration situation.

An important feature of the integration process analyzed here concerns the growth path of consumption. A first observation in this context refers to the implications of interest rate equalization and diverging rates of time preference. The Keynes-Ramsey rule yields

$$r = \rho + \sigma\frac{\dot{C}}{C} = \rho^* + \sigma\frac{\dot{C}^*}{C^*} \ .$$

Since $\rho<\rho^*$, identical interest rates imply that even after integration

$$\frac{\dot{C}}{C} > \frac{\dot{C}^*}{C^*} \ .$$

For the growth rate of world consumption which is indicated by superscript "z" we get

$$\frac{\dot{C}^z}{C^z} = \theta_C \frac{r-\rho}{\sigma} + (1-\theta_C)\frac{r-\rho^*}{\sigma} \qquad with \ \theta_C = \frac{C}{C+C^*} \ .$$

Thus, world consumption growth is a weighted average of the consumption growth of the two countries.

A second observation is that the difference between output and investment grows at the same rate in both countries.[6] This is due to the fact that integration leads to an identical growth rate in manufacturing output and the capital stock in the home country and abroad. Hence, this is only consistent with different rates of consumption growth if the home country with the lower rate

[6] Note that this refers to the steady state that is reached asymptotically in our analysis.

of time preference initially runs a current account surplus, while the foreign country initially runs a current account deficit. Denoting variables for the world as a whole again by a superscript "z", the balanced growth path is thus characterized by

$$\frac{\dot{C}}{C} > \frac{\dot{C}^z}{C^z} = \frac{\dot{Y}^z}{Y^z} = \frac{\dot{Y}}{Y} = \frac{\dot{Y}^*}{Y^*} > \frac{\dot{C}^*}{C^*} .$$

The analysis shows that integration is beneficial for both countries since output growth increases worldwide. The integration of the goods and capital markets allows countries to disconnect the growth rate of consumption and production. While this effect is well known from intertemporal macroeconomics, it is new in the setting of the Romer model.

In sum, the benefits of integration discussed here are threefold. First, integration increases worldwide growth. This effect stems from the fact that integration allows for a better allocation of world resources and induces a growth-related form of international specialization. Through integration, the more innovative country can increase its R&D activity, which is a type of comparative advantage given the R&D production functions used here.[7] The country with the higher time preference rate will eventually give up R&D activities, but it can nevertheless increase its growth rate of production.[8] Thus, while one country is completely specialized in manufacturing, the other country produces both new designs and manufactured goods. Second, diverging rates of time preference integration allows countries to choose different growth paths for consumption and production. The new growth path only forces world consumption to grow at the same rate as production. Third, assuming that capital goods are produced in the country in which the designs are invented, integration leads to international trade flows that reflect that the more innovative country produces the capital goods for the foreign country and receives consumption goods from the less innovative country. The trade surplus of the home country in capital goods is Am^*-A^*m. As A^* remains constant and A increases, the trade surplus of the home country increases too.

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[7] Note that the marginal productivity of human capital in R&D is δA and is thus an increasing function in A_A.

[8] The analysis assumes that $A>A^*$ in the pre-integration situation. However, the results are the same even if $A=A^*$ in the pre-integration situation. In this case the upward pressure on the wage rate in the R&D sector relative to the change in the wage rate in manufacturing is relatively higher in the home country because it uses more capital goods ($x=m>x^*=m^*$) and thus experiences a smaller increase in productivity in the manufacturing sector.

4. Diverging rates of time preference and the effects of integration with knowledge diffusion

When the establishment of establishing free trade and perfect capital mobility is accompanied by knowledge diffusion, the productivity in the R&D sectors increases due to the enhanced knowledge stock.[9] Assuming that there is no redundancy, each pre-existing design is distinct, i.e. $A_A = A_A^* = A + A^*$, and the production functions of the domestic and the foreign R&D sectors become

$$\dot{A} = \delta H_A (A + A^*) \; ; \qquad \dot{A}^* = \delta H_A^* (A + A^*) \; .$$

Integration also increases the market size of manufactured goods which, in turn, induces a rise in the price of patents and the wage rate for human capital in R&D. In addition, the increase in productivity triggered by knowledge diffusion drives up the wage rate further. Equation (14) together with the fact that x=m and $x^* = m^*$ implies that, in this case, international wage equalization occurs:

$$w_{H_A} = \frac{1-\gamma}{\gamma}\left(x + m^*\right)\delta\,(A + A^*) = w_{H_A^*} = \frac{1-\gamma}{\gamma}\left(x^* + m\right)\delta\,(A + A^*) \; .$$

This implies that also $w_{HY} = w_{HY}^*$ because in each country intersectoral wage equalization holds in equilibrium due to human capital mobility between the manufacturing sector and the R&D sector. Thus, in this case factor price equalization holds. Note that even when the two countries are not symmetric both countries will continue to engage in R&D activities. This results from the fact that neither country loses international competitiveness in R&D. In fact, R&D productivity in both countries is the same and equals

$$\frac{\partial \dot{A}}{\partial H_A} = \frac{\partial \dot{A}^*}{\partial H_A^*} = \delta\left(A + A^*\right) \; .$$

The productivity of human capital rises in both sectors by θ in the home country and by 1-θ in the foreign country. This can be shown when the wage rates after integration are divided by the wage rates in isolation, given the price of patents. Therefore, no reallocation incentives arise from the productivity effects. However, the price of the patents also rises in the home economy by $(x+m^*)/x$ and in the foreign economy by $(x^*+m)/x^*$. In autarky x was strictly greater than x^*, because both countries formed an identical r_t curve and the home country had a lower H_Y and r (see equation (3a'')). After integration, with interest rate equalization, $x+m^* = x^*+m$. As a result the rise of the home patent price and the home wage rate in R&D is smaller than in the foreign

[9] This case was first studied by Frenkel and Trauth (1996).

country. Thus, the incentive for human capital to change to the R&D sector is higher in the foreign country. Ultimately, with technology being the same in both countries, the human capital allocation cannot differ either, i.e., $H_A = H_A^*$.

Since H_A increases to the same level in both countries and the foreign country starts from a lower level than the home country, the reallocation of human capital in the foreign country must exceed the allocation effect in the home country.

Equation (21) can be used to derive the growth rate of the world stock of patents, as

$$\frac{\dot{A} + \dot{A}^*}{A + A^*} = \delta \left(H_A + H_A^* \right) .$$

This result is crucial to our analysis. It shows that integration increases the worldwide growth rate because both countries employ more human capital in the R&D sector. The Keynes-Ramsey rule implies for worldwide consumption, $\hat{C}^z$, that

$$\frac{\dot{C}^z}{C^z} = \frac{\dot{C} + \dot{C}^*}{C + C^*} = \frac{r - \left(\rho\, \theta_C + \rho^* (1 - \theta_C) \right)}{\sigma} \qquad \textit{with} \;\; \theta_C = \frac{C}{C + C^*} .$$

Since interest rates are the same in both countries, we get

$$r = \rho + \sigma \frac{\dot{C}}{C} = \rho^* + \sigma \frac{\dot{C}^*}{C^*} .$$

If the foreign country has a higher time preference rate, then consumption growth is

$$\frac{\dot{C}}{C} > \frac{\dot{C}^z}{C^z} > \frac{\dot{C}^*}{C^*} .$$

Hence, despite the same production growth rates in both countries the consumption growth paths are different. More specifically, the country with less patient consumers which here is the foreign country, experiences a smaller growth rate over time, which reflects higher levels of consumption in the more immediate periods. As a result, the home country initially runs a current account surplus which, in present value terms, is exactly offset by future current account deficits.

5. Integration effects if countries differ in productivity and no knowledge diffusion occurs

We now turn to differences on the supply side of the economies. Rather than assuming differences in the endowment of human capital, which Rivera-Batiz and Xie (1993) discuss regarding the implications for integration effects, we focus on differences in productivity. Specifically, the home country is assumed to be more productive in the R&D sector which is reflected by $\delta > \delta^*$ in the production functions (4) and (5). The pre-integration growth equilibria are illustrated in Fig. 3. by the intersection of the r_t curve (reflecting equation (23)) and the r_p curve (reflecting equation (25)). Since the productivity parameter for the R&D sector enters the expression for the slope of both curves, these autarky curves are steeper for the home economy than the foreign economy. Setting equation (23) equal to equation (25) yields the equilibrium human capital allocation to the R&D sector:

$$H_A = \frac{H}{\sigma\psi + 1} - \frac{\psi\rho}{\delta(\sigma\psi + 1)} .$$

Thus, the balanced growth path in autarky is associated with a higher human capital input in the R&D sector in the home country. A higher productivity level allows the R&D sector to pay higher wages for human capital and, thus, to attract more human capital. This primary effect is partly reversed by the induced interest rate increase which is required to retain intertemporal consumption equilibrium. The higher interest rate increases capital costs and thus leads to higher demand for human capital in this sector. This, in turn, leads to higher wages and lowers the incentives for human capital to move to the R&D sector.

If now the home and the foreign country establish free trade and liberalize international capital flows and if there is no knowledge diffusion the allocation effects can be analyzed using equation (17), which we reproduce here for convenience using again the simplifying assumption that $L=L^*$ again:

$$r_t = \frac{\delta}{\psi}\left[\frac{A}{A + A^*}\left(1 + \left(\frac{H_Y^*}{H_Y}\right)^{\alpha/(\alpha+\beta)}\right)\right]H_Y .$$

Since $H_Y < H_Y^*$, the expression in brackets on the right hand side of the preceding equation is greater than two. This more than doubles the factor on the right side of the equation as compared to the expression in equation (23) for the autarky situation, even if the more innovative home country only has as many designs as the foreign country in the pre-integration situation. As a result, given the initial allocation of human capital, the wage rate in the R&D sector increases relative to the wage rate in manufacturing. This induces a shift of human capital out of manufacturing and into the R&D sector in the home country. In the foreign country the opposite effect occurs. With more human capital used in the R&D sector, the home country is more innovative and human capital continues to migrate into R&D in the home country. Gradually, the foreign country gives up R&D and eventually completely specializes in manufacturing.

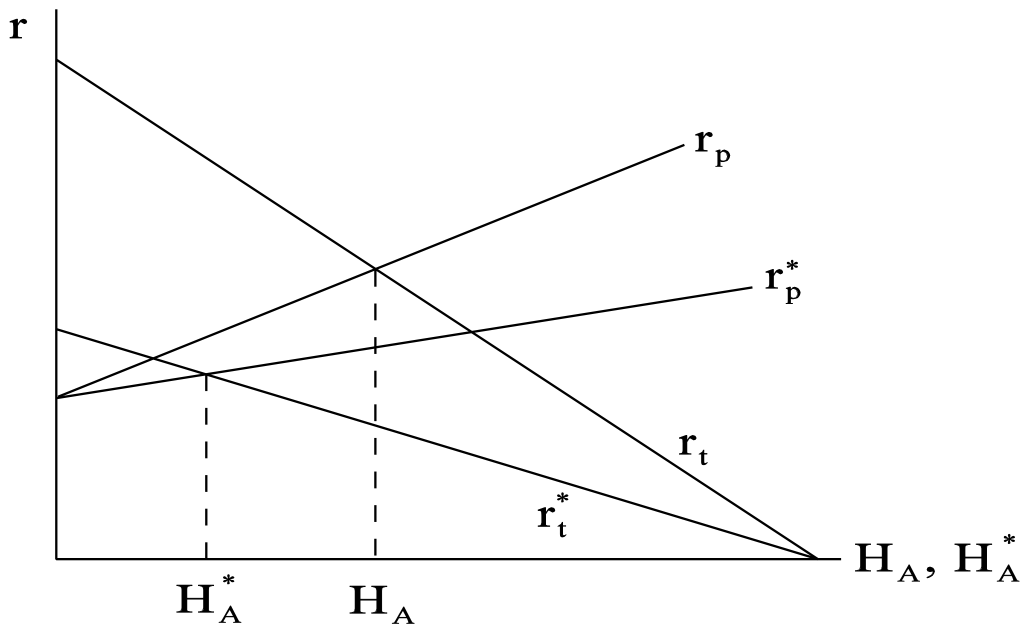

Figure 3

In sum, integration leads to a higher worldwide growth rate since, as already discussed in the context of integration with different time preference rates, free trade and perfect capital mobility create advantages in international specialization. Since the asymptotic balanced growth path is characterized by converging growth rates of capital, production, and consumption of the home and the foreign country, the foreign country also benefits from integration. This is the case even though the R&D sector of the foreign economy is eventually eliminated.

6. Productivity differences and the effects of integration with knowledge diffusion

In order to investigate the integration effects on the demand side of the economies in the presence of knowledge diffusion, we investigate the Keynes-Ramsey rule which yields, as a result of interest rate equalization:

$$r = \rho + \sigma \frac{\dot{C}}{C} = \rho + \sigma \frac{\dot{C}^*}{C^*} .$$

Thus, the growth rates of consumption in both countries are equal along the new balanced growth path.

Turning to the supply side of the economy, the wage rate paid in the R&D sector is a function of marginal productivity of human capital:

$$w_{H_A} = P_A \delta (A + A^*) \; ; \qquad w_{H_A^*} = P_A^* \delta^* (A + A^*) \; ,$$

where A_A=A+A*. The R&D wage rate is higher in the country with the higher R&D productivity parameter since both countries can make use of the same knowledge level and because interest rate equalization implies that patent prices do not differ internationally (see equation (12)). The two preceding equations imply that the R&D wage ratio equals the ratio of the productivity parameters

$$\frac{w_{H_A}}{w_{H_A^*}} = \frac{\delta}{\delta^*} .$$

This shows that R&D wages are higher in the more productive country. Therefore, no international wage equalization occurs. However, national wage equalization is triggered by intersectoral mobility of human capital which implies that, in the example of $\delta > \delta^*$, also manufacturing wages are also higher in the home economy than abroad after integration.

If the expression for the manufacturing wage rate from equation (13) is divided by the corresponding equation for the foreign country and set equal to the ratio of $w_{H_A}/w_{H_A^*}$, we get the human capital allocation:

$$\frac{H_Y}{H_Y^*} = \left(\frac{\delta^*}{\delta} \right)^{(\alpha+\beta)/\beta} .$$

Our results show that integration with knowledge diffusion leads to a more extensive use of human capital in the R&D sector of the more productive country. At the same time, unlike in the case without knowledge diffusion, the less productive country continues to engage in R&D activities. However, since the home economy is more productive in R&D, more new designs are invented in the domestic economy than abroad. In addition, integration induces a shift of human capital toward the R&D sector in both countries. This is due to the fact that knowledge diffusion has a similar effect on the allocation of human capital as an increase in the human capital endowment. As a result, both the worldwide growth rate and the interest rate increase. Moreover, because knowledge diffusion increases the productivity of R&D activities, the growth effect of integration is higher in the case of knowledge diffusion.

7. Summary and conclusions

This paper extends previous analyses of Rivera-Batiz and Xie (1993) and Frenkel and Trauth (1996) on the growth effects of integration to countries which differ in the demand or the supply side structure of their respective economies. Unlike previous papers, it examines the relevance of international differences in productivity and time preference for the results of the integration process, both with and without international knowledge diffusion. We show that not only do these differences matter, but that the results depend on whether international knowledge diffusion occurs or not as well. Certainly, reality may not be characterized by either of the two extreme cases but the analysis helps to understand the channels through which integration works. Even with advanced communication technologies, knowledge diffusion may well be prevented by patent owners in cases where patents do not work or, for example, appear to be costly for producers.

Although our results emphasize the beneficial effects of integration for all countries even if they are unequal, the integration process may temporarily imply frictions during the adjustment process. Moreover, the positive growth effects materialize even for those countries that experience relatively smaller growth in their R&D sectors than other countries. The analysis shows that one result of integration could be that a country may even give up R&D altogether because of a complete loss of international competitiveness, but, nevertheless, still gain from integration. This can be called a dynamic specialization effect which is a new finding in the literature on the growth effects of integration. Likewise, a very innovative country can benefit from integration with a less innovative partner country.

Applications of our results could be to the recent integration process of the NAFTA agreement or the discussion of extending the EU to the East. With respect to NAFTA, our results imply beneficial output growth and level effects for all member countries. Regarding the effects on allocation, the results also suggest that Mexico may lose competitiveness in the R&D sector and could therefore specialize in manufacturing.

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Appendix

The slope of the r_t curve reflects that an increase in the interest rate leads to a decrease in the human capital used in R&D. This can be illustrated by two curves reflecting the marginal product of human capital in the two sectors. The human capital allocation can, for a given human capital endowment, H, alternatively be described by H_A or H_Y. The distance of the horizontal line shows the total human capital available in the economy. The left hand scale shows the marginal product of human capital in manufacturing while the right hand scale shows the marginal product of human capital in R&D. The marginal product of H_Y declines with increasing factor input (see equation (13)) according to the standard neoclassical assumptions. The marginal product of human capital in R&D is shown as a function of H and H_Y. It is bounded from above and approaches zero as H_A approaches the total endowment with human capital. To understand the shape of the curve, note that the marginal product of human capital in R&D measured in designs is constant for a given knowledge stock and equal to

$$\frac{\partial \dot{A}}{\partial H_A} = \delta A_A .$$

The relative price between designs and consumption goods, as given by the patent price, varies with the human capital allocation. If all human capital is used in manufacturing, the demand for capital goods and, in turn, the monopoly rents and the patent prices are highest. Since the market size is limited, the patent price and, therefore, the marginal product of human capital will never approach infinity. If all human capital is used in R&D, there is no demand for capital goods since the assumed Cobb-Douglas production function implies that manufacturing is impossible if the manufacturing sector lacks one of the factors. In this case the patent price would be zero.[10]

The intersection of the respective demand and supply curves in the diagram (solid lines) indicates a point of full employment and efficient allocation. A special case arises when the intersection of the w_{HY} curve with the w_{HA} axis lies above the intersection of the w_{HA} curve with the w_{HA} axis. Then, the R&D sector is not able to pay a competitive wage rate to attract human capital. The manufacturing sector employs all the human capital.

Marginal product curves can be derived for every given interest rate. Therefore, every interest rate implies a certain human capital allocation. A rise in the interest rate shifts both marginal product curves down, as can be seen by the second lines of equations (13) and (14).

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[10] The slopes of the two curves are interrelated. Starting from a point where most of the human capital is used in manufacturing, a decline in H_Y leads to a modest increase in the marginal product of human capital in manufacturing. Therefore, the incentives to substitute human capital for capital goods in manufacturing are relatively low. Then, the market size for monopolists, their profits, the patent price, and the marginal product of human capital in R&D increase only moderately. The less human capital is used in manufacturing, the higher the increase in the marginal product of human capital in manufacturing is, the bigger the substitution process in the manufacturing sector is, and the higher is the increase in the marginal product of human capital in R&D is. As a result, when one curve becomes steeper the other curve does as well.

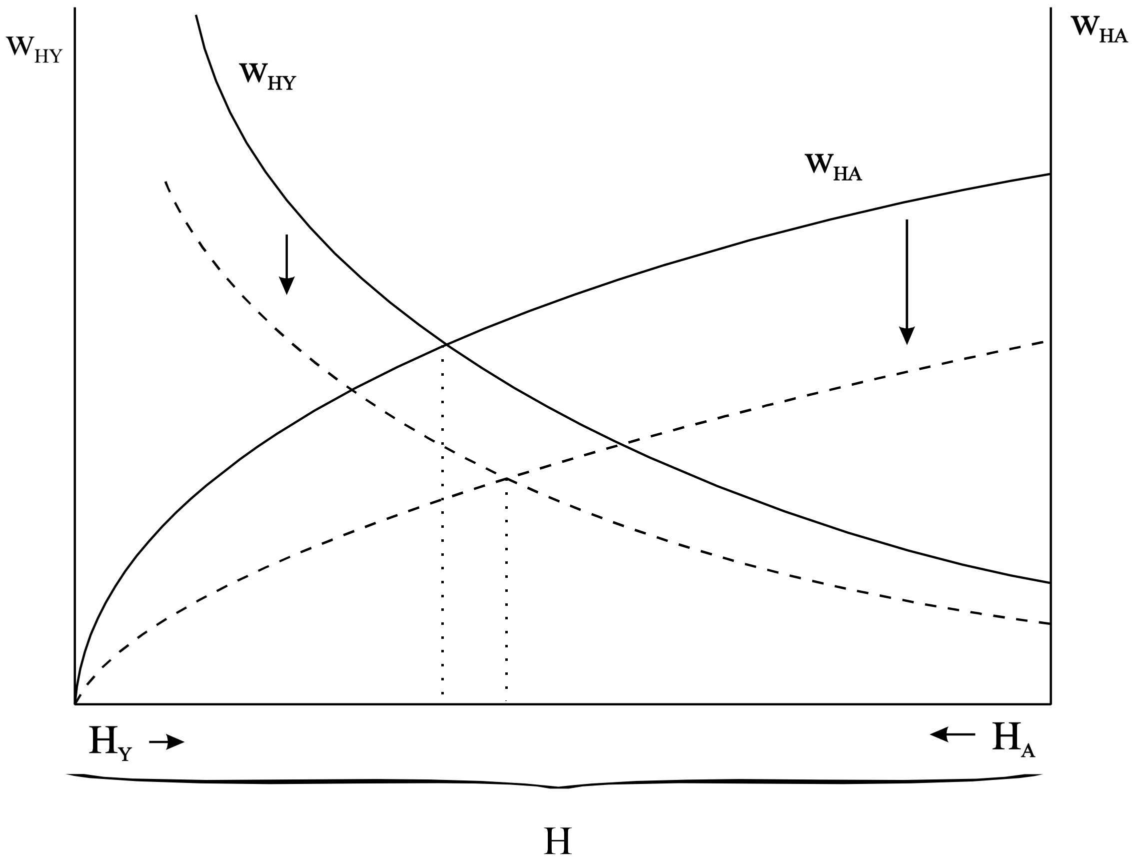

Figure 4: Marginal products of human capital

Furthermore, these equations show that the w_{HA} curve is shifted down by more than the w_{HY} curve. As a result, a rising interest rate implies a shift of human capital from R&D to manufacturing. The intuition of the allocation effect of a rising interest rate is as follows. The interest rate influences the marginal products of human capital via two channels. Firstly, a rising interest rate increases production costs of capital goods, and, in turn, the demand for capital goods declines. Since x and m^* are affected in the same way, the marginal products of human capital in both sectors decline proportionally, as can be seen by equations (10) and (11) and (13) and (14), respectively.[11] As a result, both curves are shifted to the same extent, and the human capital allocation does not change. Secondly, an increase in the interest rate reduces the optimal

[11] The decline of the marginal product of human capital in R&D is due to the decline in the market size and the induced depreciation of the patent price.

input ratio of capital goods to human capital used in manufacturing.[12] This represents an incentive to substitute human capital for capital goods in this sector. The substitution of human capital for capital goods in manufacturing puts upward pressure on the human capital wages in manufacturing. As a result, the downward shift of the w_{HY} curve is partly reversed. The marginal product curves, after a rise in the interest rate, are indicated in Fig. 4 by the dashed lines.

[12] This can also be illustrated if equation (1) is differentiated with respect to H_Y and equation (7), together with r/γ is rearranged to yield an expression for the factor price ratio in manufacturing

$$\frac{w_{H_Y}}{r} = \frac{\alpha}{\gamma^2} \frac{(A + A^*)\,x}{H_Y} .$$