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New Technology, Human Capital, Total Factor Productivity and Growth Process for Developing Countries

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Abstract

Solowian view on miracle growth rate in NIEs as a result of productivity growth whereas many others (e.g. Krugman [1997]) convince that broad capital accumulation is only true engine underlying NIEs' growth. Krugman's view is correct in the short and mid terms, however in the long term, TFP is the main engine of growth. We show that the optimal strategy for a developing country consists of accumulating physical capital first and there is no research activity. When the country reaches a certain level of development, which is endogenously determined in the model, the technological progress may be generated. Three critical factors: the amount of available human capital; the relative price of technological capital; and the initial income of the economy.

1 Introduction

The growth performance of the East Asian newly industrialized economies (NIEs) gave rise to a broad and diversified literature aiming at explaining the reasons for such a long lasting period of expansion. On one hand, the supporters of endogenous growth theory pinpoint productivity growth as the key factor of East Asian success. According to these authors, Asian countries have adopted technologies previously developed by more advanced economies (assimilation view) and "the source of growth in a few Asian economies was their ability to extract relevant technological knowledge from industrial economies and utilize it productively within domestic economy" (Pack [1992]). Implicitly, they admit that the TFP is one of the main factors of growth in accordance with the thesis developed by Solow [1957]. Solow, in this paper, used US data from 1909 to 1949 and showed that the capital intensity contributed for one eight to the US economic growth. The remainder is due

*this lecture uses many results in the paper by O. Bruno, C. Le Van, B. Masquin, 2007 and another paper by C. Le Van, M.H Nguyen, Th-B Luong and T-A Nguyen, 2007

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to increased productivity. On the other hand, the supporters of the accumulation view stress the importance of physical and human capital accumulation in the Asian growth process. According to this standard growth view, poorer countries should grow faster than wealthier ones during their first stage of development. This result is rooted in the assumption of diminishing marginal returns on capital accumulation that induce a catching-up process compatible with conditional convergence (Cass [1965]). King and Rebelo [1993] run simulations with neo-classical growth models and conclude that the transitional dynamics can only play a minor role in explaining observed growth rates. They suggest endogenous growth models such as human capital formation or endogenous technical progress. Krugman [1997] wrote that Larry Lau and Alwyn Young works suggested that Asian growth could mostly be explained by high saving rates, good education and the movement of underemployment peasants into the modern sector.

Aside this theoretical debate, on the empirical ground the continuous development of growth accounting analysis gives us an insight into the respective role of assimilation and accumulation on Asian growth process. In a first stream of empirical studies, Young [1994, 1995], Kim and Lau [1994, 1996] found that the postwar economic growth of the NIEs was mostly due to growth in input factors (physical capital and labor) with no increase in the total factor productivity. Moreover, the hypothesis of no technical progress cannot be rejected for the East Asian NIEs (Kim and Lau [1994]). Consequently, accumulation of physical and human capital seems to explain the major part of the NIEs' growth process. Krugman's [1994] interpretation of these results is very pessimistic since, according to him, the lack of technical progress will inevitably bound the growth engine of East Asian NIEs as a result of the diminishing returns affecting capital accumulation.

However, this pessimistic view is challenged by a second series of works (Collins and Bosworth [1996] or Lau and Park [2003]) that show Total Factor Productivity (TFP) gains actually matter in Asian NIEs growth and that future growth can be sustained. For these authors "it is possible that the potential to adopt knowledge and technological from abroad depends on a country's stage of development. Growth in the early stages may be primarily associated with physical and human capital accumulation, and significant potential for growth through catchup may only emerge once a country has crossed some development threshold" (Collins and Bosworth [1996]). These findings concerning the East Asian economies in the post-war period are also valid for developed economies in the early stages of their development (Lau and Park [2003]). They suggest that in these stages, economic growth is generally based on physical accumulation rather than technological progress. Greater gains in TFP are possible only during the second stage of development.More precisely, Lau and Park show there was no technical progress for Hong Kong, Korea, Singapore, Taiwan, Indonesia, Malaysia, Thailand until 1985. But suddenly, it appeared in these countries between 1986 and 1995. For Western Germany, United Kingdom, France, and Japan, technical progress always existed.

We come now to the divergence of economic growth among countries. Indeed, cross-countries empirical studies show that development patterns differ considerably between countries in the long run (Barro&Sala-i-Martin [1995], Barro [1997]). These differences can be explained within a model of capital accumulation with convex – concave technology. In such a framework, Dechert and Nishimura [1983] prove the existence of threshold effect with poverty traps explaining alternatively “growth collapses” or taking-off. For Parente and Prescott [1993], the popular thesis that countries which start below a minimum level of output will fail to grow seems not supported by the facts. Azariadis and Drazen [1990] propose an elaboration of the Diamond model that may have multiple stable steady states because the training technology has many thresholds. They give an explanation to the existence of convergence clubs in Barro&Sala-i-Martin [1995], Barro [1997]. Here, we share the view of Dollar [1993] that divergence between countries is also due to differences in TFP. Why is technology important? Because it can be simultaneously employed in different uses (public good and productive good as well). Dollar [1993] wrote "there are a number of pieces of evidence indicating that succesful developing countries have borrowed technology from the more advanced economies". We think the so-called Solow-Krugman controversy is not really one. Krugman’s view is correct in the short and mid terms. But in the long term, TFP is the main factor of growth. In this sense, Solow is right and his 1956 model is basically a long term growth model. Even if these results seem widespread in the empirical literature on growth accounting, there is no theoretical model explaining the optimal shift of a country from the first stage (accumulation) to the second stage (assimilation) of development. The aim of our talk is to establish the formal conditions under which a country may realise (or not) this shift. More precisely, we define an endogenous threshold of development from which a country is encouraged to adopt new technologies and builds a part of its growth process on technological advances. Before reaching this threshold, the country must root its growth process in capital accumulation.

Our model is based on the existence of complementarities in the use of new technologies as it is necessary to have a minimum amount of adoption of new technologies in order for them to be efficient. This assumption may be justified by institutional structure (Atawell [1992], Castro et al. [2006]), by start-up cost effect (Ciccone and Matsuyama [1999]), set-up costs (Azariadis and Drazen [1990]) or by several kinds of technical barriers relating to the diffusion of innovation (Fichman [1992]). In order to encompass these different aspects we assume the existence of a threshold effect from which new technologies begin to have an impact on Total Factors Productivity. Note that threshold effect is also used by Le Van and Saglam [2004] who show that a developing country can restrain to invest in technology if the initial knowledge amount of the country and the quality of knowledge technology are low or if the level of fixed costs of the production technology is high. Capital accumulation and innovative activity take place within a two sector growth model. The first sector produces a consumption good using physical capital and non skilled labor according to a Cobb-Douglas production function. Technological progress in the consumption sector is driven by the research activity that takes place in the second sector. Research activity which produces new technologies requires technological capital and skilled labor along the line of a Cobb-Douglas production function. We introduce an educational sector with which the developing country would invest in to train more skilled labor. When new technologies produced by the research activity are used in the consumption sector they induce an endogenous increase of the Total Factor Productivity. The two kinds of capital are not substitutable. We suppose that technological capital, used by the research activity, is not produced within the economy. The domestic economy must purchase it in the international

market at a given price. Consequently, the consumption good can be consumed, invested as physical capital or exported against technological capital. The price of the consumption good is given by the international market and is used as numeraire in our economy. Finally, we assume that physical capital is less costly than technological capital.
We show that under our conditions on the adoption process of new technologies, the optimal strategy for a developing country consists in accumulating physical capital first; thus postponing the importation of technological capital to the second stage of development. All resources of the economy are devoted to consumption or investment in the physical capital sector and there is no research activity. Later, the technological progress may be generated when the country has reached a certain level of development. This threshold in the level of development is endogenously determined in the model and is related to three factors: the amount of available human capital, the relative price of technological capital and the initial income of the economy. For given values of these factors, we show that there is a time period after which it is optimal for the economy to import technological capital in order to produce new technologies which require high skilled workers. We show further that with possibility of investment in human capital and given "good" conditions on the qualities of the new technology, production process, and/or the number of skilled workers there exists alternatives for the country either to purchase new technology and spend money in training high skilled labor or only purchase new technology but not to spend on formation of labor. Following this direction, we can determine the level of wealth at which the decision to invest in training and education has to be made. In the whole, we determine the optimal share of the country's investment in physical capital, new technology capital and human capital formation in the long-run growth path. Two main results can be pointed out: (1) the richer a country is, the more money will be invested in new technology and training and education, (2) and more interestingly, the share of investment in human capital will increase with the wealth while the one for physical and new technology capitals will decrease. In any case, the economy will grow without bound.

2 The Solow Model (Solow, 1956)

We consider a simple intertemporal growth model for a closed economy.

$$
\begin{aligned}
C_t + S_t &= Y_t \\
S_t &= sY_t,\ s \text{ is the exogenous saving rate} \\
K_{t+1} &= K_t(1-\delta) + I_t \\
L_t &= L_0(1+n)^t \\
Y_t &= a(1+\gamma)^t K_t^\alpha L_t^{1-\alpha},\ 0<\alpha<1 \\
I_t &= S_t
\end{aligned}
$$

$C_t, S_t, Y_t, K_t, I_t, L_t$ denote respectively the consumption, the saving, the output, the capital stock, the investment and the labour at period t. The labour force grows with an exogenous rate n. The Total Factor Productivity (TFP) grows at rate γ.

It is easy to solve the model given above. Actually, we have

$$\forall t,\ K_{t+1} = (1-\delta)K_t + saK_t^{\alpha}L_t^{1-\alpha}(1+\gamma)^t \tag{1}$$

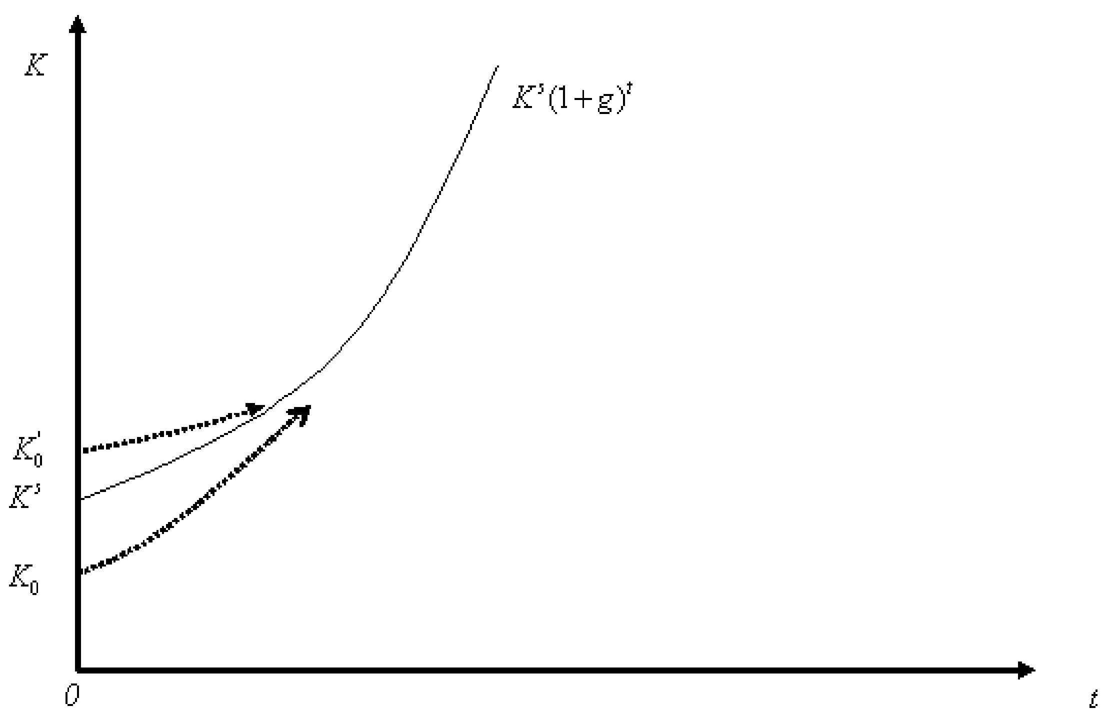
We can easily check that there exists a Balanced Growth Path (BGP) with rate g

$$(1+g) = (1+n)(1+\gamma)^{\frac{1}{1-\alpha}}$$

On the BGP, we have $K_t^* = K^s(1+g)^t,\ \forall t$, where $K^s = \left(\frac{sa}{g+\delta}\right)^{\frac{1}{1-\alpha}} L_0$. Given $K_0 > 0$, the path generated by equation (1) satisfies

$$\frac{K_t}{(1+g)^t} \to K^s$$

In other words, the path $\{K_t\}_t$ converges to the steady state K^s. It is interesting to notice that the rate of growth g is positively related to the rate of growth γ of the TFP.



3 The Ramsey Model (Ramsey, 1928)

Two criticisms may be adressed to the Solow Model. The first one is the saving rate is exogenous. The second one is the rate of growth is exogenous. In this section, we will endogeneize the rate of saving of the households. But we do not solve the question of the exogeneity of the rate of growth. This problem will be studied later with some endogenous growth models. The model we present here, is a discrete-time horizon version of the well-known Ramsey model (1928) which was formalized in continuous-time horizon. This model has been studied in more details by Cass

(1965) and Koopmans (1965). The basic idea in the Ramsey model is to introduce an infinitely lived consumer who maximizes an intertemporal utility function of her intertemporal sequence of consumptions. At each date, her consumption is constrained by the maximum output produced by a stock of physical capital, and by the necessesity of saving for obtaining a physical capital stock for the next period production process. The main results are that, under some conditions, optimal sequences of capital stocks and of consumptions exist, and converge to an optimal steady state. Moreover, the sequence of optimal capital stocks is monotonic.

We consider an economy in which there are, at each period t, L_t identical consumers. We denote by c_t the consumption, at period t, of one consumer. We assume that the number of consumers grow at rate n, i.e., $L_t = L_0(1+n)^t$, for every t. In this economy, there is a social planner whose task is to promote the welfare of its population . So, she wants to maximize the global utility of the consumers :

$$\max L_0 \sum_{t=0}^{\infty} (1/(1+\rho))^t (1+n)^t u(c_t)$$

Here, the function u is called the static utility function or instantaneous utility function and the parameter ρ is the positive time preference rate. A large value of ρ means that the consumers are more impatient and prefer the present to the future. At each date t, consumption c_t is subject to the constraint:

$$L_t c_t + I_t \leq F_t(K_t, L_t),$$

where I_t is the investment, F_t is the production function, K_t is the capital stock, L_t is the number of workers (we implicitly assume that the consumers and the workers are physically identical). The capital stock of period $t+1$ is defined by:

$$K_{t+1} = K_t(1-\delta) + I_t,$$

where $\delta \in]0,1[$ is the depreciation rate of the capital stock. Let us assume that the production function F_t exhibits constant returns to scale and let us introduce the per capita capital stock $k_t = K_t/L_t$. The constraint for each period, between consumption and investment becomes:

$$c_t + k_{t+1}(1+n) - (1-\delta)k_t \leq F_t(k_t, 1).$$

Assume that $F_t(k_t, 1) = A(1+\gamma)^t k_t^\alpha$, with $0 < \alpha < 1$. The parameter γ is the rate of growth of the productivity. We then obtain:

$$c_t + k_{t+1}(1+n) \leq A(1+\gamma)^t k_t^\alpha + (1-\delta)k_t.$$

If the utility function u is strictly increasing, then, at the optimum, the constraints will be binding at each period. If the optimal sequences of capital stock and consumption grow at rate g, i.e., for any t, $k_t = k_0(1+g)^t$, $c_t = c_0(1+g)^t$, we then have

$$(1+g)^{(1-\alpha)} = 1+\gamma.$$

In other words, the rate of growth of the economy is determined by the exogenous rate of growth of the productivity. Using the variables capital per capita k_t and consumption per capita c_t, the Ramsey model can be written as:

$$\max \sum_{t=0}^{\infty} \beta^t u(c_t)$$

under the constraints:

$$\forall t, c_t + k_{t+1}(1+n) \leq Ak_t^{\alpha} + (1-\delta)k_t,$$

and k_0 is given, and by definition, $\beta = (1+n)/(1+\rho)$. The parameter β will be called discount factor. If we assume, for simplicity, that $n = 0$, and if we define the function f by $f(k) = Ak^{\alpha} + (1-\delta)k$, then the Ramsey model will have the following compact form:

$$\max \sum_{t=0}^{\infty} \beta^t u(c_t)$$

under the constraints:

$$\forall t, c_t + k_{t+1} \leq f(k_t),$$

$$\forall t, c_t \geq 0, k_t \geq 0,$$

and $k_0 \geq 0$ is given. In the following, we will make use of this form. Notice that the production function is $F(k) = f(k) - (1-\delta)k$. The following assumptions will be maintained throughout this section.

H0 $0 < \beta < 1$.
H1 The function $u : \mathbb{R}_+ \to \mathbb{R}_+$, is twice continuously differentiable and satisfies $u(0) = 0$. Moreover, its derivatives satisfy $u' > 0$ (strictly increasing) and $u'' < 0$ (strictly concave).
H2 Inada Condition : $u'(0) = +\infty; u'(\infty) = 0$.
H3 The function $f : \mathbb{R}_+ \to \mathbb{R}_+$ is twice continuously differentiable and satisfies $f(0) = 0$. Its derivatives satisfy $f' > 0$ (strictly increasing), $f'' < 0$ (strictly concave), $\lim_{x \to +\infty} f'(x) < 1, f'(0) = M \leq +\infty$.

We get the following results:

Theorem 1 *Let* $r = \frac{1}{\beta} - 1$.
(1) If $F'(0) \leq \delta + r$, *then the optimal path* $\{k_t^*\}$ *will converge to* 0
(2) If $F'(0) > \delta + r$, *then the optimal path* $\{k_t^*\}$ *will converge to the steady state* k^s *defined by* $F'(k^s) = \delta + r$.

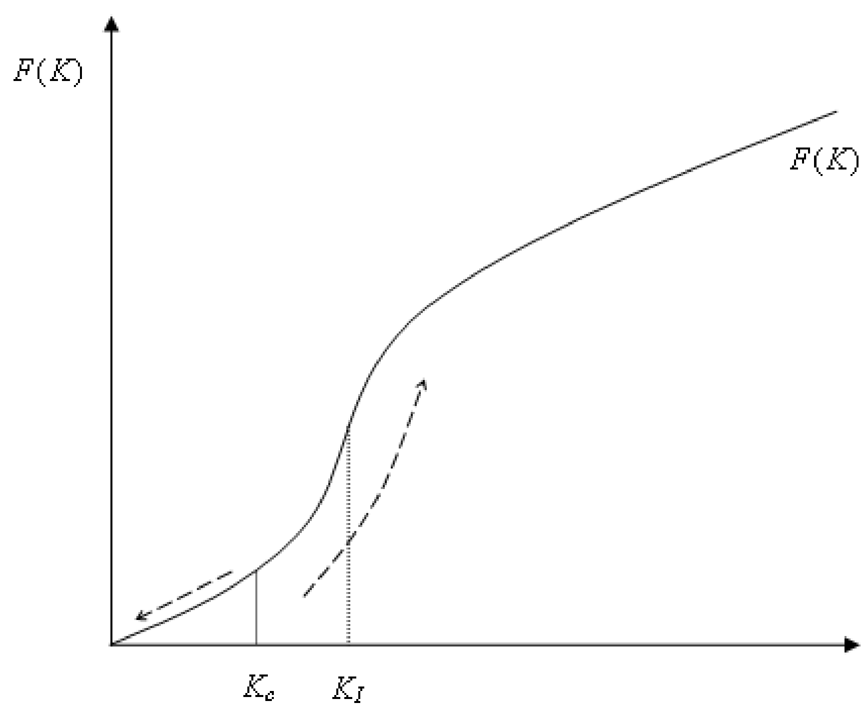
For a proof see e.g. Le Van and Dana (2003).
Following this results, if the countries have the same technology they will ″converge″ in the long term provided the initial capital stock is non null. In this case, the International Aid to developing countries helps them an initial endowment, even very small, then every country will reach in the long term the same stage of development. The reality is far to coincide with this claim. An explanation of the non-convergence between the countries may be found in the next section. Observe that one can relax the assumption $\lim_{x \to +\infty} f'(x) < 1$ and assume $f(k) = (A + 1 - \delta)k$. Assume $u(c) = \frac{c^{\theta}}{\theta}$ with $0 < \theta < 1$. If $\beta(A + 1 - \delta)^{\theta} < 1$ then the optimal solution to the Ramsey model is a BGP with rate of growth $g = [\beta(A+1-\delta)]^{\frac{1}{1-\theta}} - 1$. We see that the rate of growth is positively related the non-impatience of the consumer (large β) and the TFP A. The saving rate is constant $s = \frac{[\beta(A+1-\delta)]^{\frac{1}{1-\theta}} - 1}{A}$ and positively related to β and A. We have a Solow model but we can explain why the saving rate is high (the consumer is patient, the technology is good).

4 The Convex-Concave Production Function

We change the assumption **H3** in Section 3. Assume
H3 The function $f : \mathbb{R}_+ \to \mathbb{R}_+$ is twice continuously differentiable and satisfies $f(0) = 0$. Its derivatives satisfy $f' > 0$ (strictly increasing). There is a point k_I such that $f''(k) < 0$ if $k > k_I$, and $f''(k) > 0$ if $k < k_I$. There exists a point $k_{max} > k_I$ such that $f(k_{max}) = k_{max}$ and $f(k) < k$ if $k > k_{max}$.
We then get the following result

Theorem 2 *[Dechert-Nishimura, 1983] Let* $r = \frac{1}{\beta} - 1$.
(1) If $F'(0) > \delta + r$, *then any optimal path* $\{k_t^*\}$ *will converge to the highest steady state* k^s *defined by* $F'(k^s) = \delta + r$.
(2) If $F'(0) < r + \delta < \max_{k>0}\{\frac{F(k)}{k}\}$, *then there exists a critical value* k^c *such that: (i) if* $k_0 < k^c$ *then any optimal path* $\{k_t^*\}$ *will converge to* 0*; (ii) if* $k_0 > k^c$*, then any optimal path* $\{k_t^*\}$ *will converge to the highest steady state* k^s *defined by* $F'(k^s) = \delta + r$.

King and Rebello (1993) calibrate, with the US Data [1948-1979] the Ramsey model with decreasing returns. They run simulations and show that the neoclassical dynamics can only play a minor role in explaining the observed growth rates. They conclude that their results point to the use of models which do not rely on exogenous technical change. We now present some models which endogeneize the rates of growth of the economy. They answer the concern: how to make growth endogenous, or more precisely, technical change endogenous?



5 The Solow-Krugman Controversy

The Solow [1957] implies that the TFP is the core factor of economic growth. If the economy bases merely on capital accumulation without technological progress, the diminishing returns on capital accumulation will eventually depresses economic growth to zero. Accordingly, Solowian supporters attribute the miracle economic growths in Newly Industrialized Economies (NIEs) in second half of 20th centrury to adoption of technologies previously developed by more advanced economies. Pack [1992] suggests "the source of growth in a few Asian economies was their ability to extract relevant technological knowledge from industrial economies and utilize it productively within domestic economy".

Empirically, however, Young [1994, 1995], Kim and Lau [1994, 1996] found that the postwar economic growth of the NIEs was mostly due to growth in input factors (physical capital and labor) with no increase in the total factor productivity. Moreover, the hypothesis of no technical progress cannot be rejected for the East Asian NIEs (Kim and Lau [1994]). Consequently, accumulation of physical and human capital seems to explain the major part of the NIEs' growth process. Krugman's [1994] concludes that "it (high growth rate) was due to forced saving and investment, and long hours of works...So if we are forced to save 40% of our income, and get only two weeks off a year of course a country will growth". Accordingly, due to diminishing returns the lack of technological progress will inevitably bound the growth engine of East Asian NIE.

In the following we will prove that the so-called Solow-Krugman controversy is not a real one.

Let's revisit the Solow model, from equation (1)we have:

$$\forall t,\ K_{t+1} = (1-\delta)K_t + saK_t^{\alpha}L_0^{1-\alpha}(1+\gamma)^t(1+n)^{t(1-\alpha)} \tag{2}$$

and $\{K_t\}$ converges to $\{K^s(1+g)^t\}$ where g is growth rate of capital stock and output at steady state and $1+g=(1+n)(1+\gamma)^{\frac{1}{1-\alpha}}$ and $K^s=[\frac{sa}{g+\delta}]^{\frac{1}{1-\alpha}}L_0$.

Now let's consider two economies which are identical in everything, except for technological progress. The technological progress in economy 1 is γ and in economy 2 is γ' and assume that $\gamma<\gamma'$. It is obvious that $g<g'$ and $K^s>K^{s'}$.Furthermore, from equation (2) we have: $K_1=K_1'$ and $K_t<K_t'$,$\forall t>1$.

Define growh rates in these two economies as follows:

$$\nu_t = \frac{K_t}{K_{t-1}} \text{ and } \nu_t' = \frac{K_t'}{K_{t-1}'}$$

We prove that if $\gamma<\gamma'$ then $\nu_t<\nu_t'$,$\forall t>1$. It is obviously to see that $\nu_1=\nu_1'$ and $\nu_2<\nu_2'$

From equation (2) we have:

$$\frac{K_t}{K_{t-1}} - (1-\delta) = saL_0^{1-\alpha}(1+\gamma)^t(1+n)^{t(1-\alpha)}K_{t-1}^{\alpha-1} \tag{3}$$

$$\frac{K_t}{K_{t-1}} - (1-\delta) = saL_0^{1-\alpha}(1+\gamma)^{t-1}(1+n)^{(t-1)(1-\alpha)}K_{t-2}^{\alpha-1} \tag{4}$$

$$(1+\gamma)(1+n)^{1-\alpha}\left(\frac{K_{t-1}}{K_{t-2}}\right)^{\alpha-1} \tag{5}$$

$$\nu_t - (1-\delta) = (1+\gamma)(1+n)^{1-\alpha}\nu_{t-1}^{\alpha-1}[\nu_{t-1} - (1-\delta] \tag{6}$$

Lemma 1 *Let $\varphi(\nu) = [\nu - (1-\delta)]\nu^{\alpha-1}$ with $\nu > 0$ then φ is increasing with ν.*

Proof:

$$\begin{aligned}
\varphi'(\nu) &= \nu^{\alpha-1} + [\nu - (1-\delta)](\alpha-1)\nu^{\alpha-2} \\
&= \nu^{\alpha-2}[\nu + (\alpha-1)\nu + (1-\delta)(1-\alpha)] \\
&= \nu^{\alpha-2}[\alpha\nu + (1-\delta)(1-\alpha) > 0]
\end{aligned}$$

■

Recall that $\nu_2 < \nu_2^{'}$ then applying lemma (1) into equation (6) and by induction we get $\nu_t < \nu_t^{'}, \forall t > 1$.Hence the economy with higher rate of technological progress not only has higher growth rate at steady state but also has higher growth rate in transitional period.

If the economies initially operate below the steady state leve (i.e. $K_0 < K^s$) we prove that the economy with higher rate of technological progress also converges faster to its own steady state than the other.

Let's define $\zeta_t = \frac{K_t}{K^s(1+g)^t}$ as speed of convergence, then $0 < \zeta_t < 1$ and $\zeta_t \to 1$ as $t \to \infty$.

Define $\hat{K}_t = \frac{K_t}{(1+g)^t}$ from equation (2) we have:

$$\zeta_{t+1} = \frac{1}{1+g}\left[(1-\delta)\zeta_t + saL_0^{1-\alpha}\zeta_t^{\alpha}\frac{1}{(K^s)^{1-\alpha}}\left(\frac{(1+n)^{1-\alpha}(1+\gamma)}{1+g}\right)\right]$$

Since $1+g = (1+n)(1+\gamma)^{\frac{1}{1-\alpha}}$ then

$$\zeta_{t+1} = \frac{1}{1+g}\left[1-\delta)\zeta_t + saL_0^{1-\alpha}\zeta_t^{\alpha}\frac{1}{(K^s)^{1-\alpha}}\right]$$

Since $K^s = [\frac{sa}{g+\delta}]^{\frac{1}{1-\alpha}}L_0$ then

$$\zeta_{t+1} = \frac{1}{1+g}\left[1-\delta)\zeta_t + (g+\delta)\zeta_t^{\alpha}\right] \tag{7}$$

Take partial derivative equation (7) by g we get:

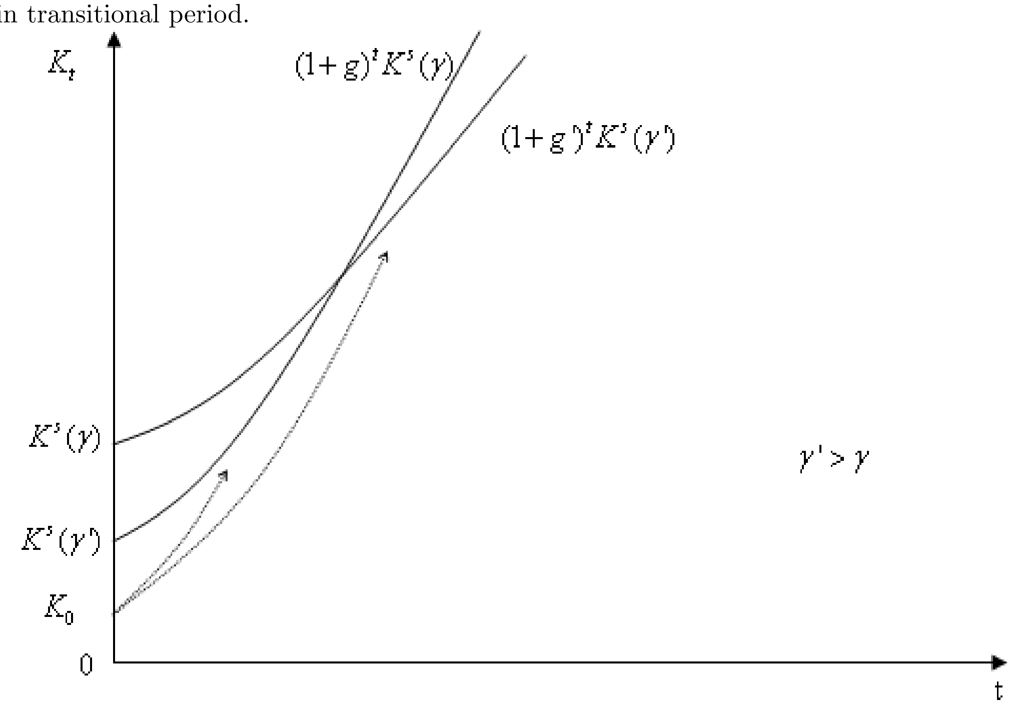
$$\frac{\partial\zeta_{t+1}}{\partial g} = \frac{1-\delta}{(1+g)^2}\left(\zeta_t^{\alpha-1} - 1\right) + \frac{\partial\zeta_t}{\partial g}\left(\frac{1-\delta}{1+g} + \frac{g+\delta}{1+g}\alpha\zeta_t^{\alpha-1}\right) \tag{8}$$

We can see that the first part of the LHS of equation (8) is positive since $0 < \zeta < 1$ hence $\left(\zeta^{\alpha-1} - 1\right) > 0$. Therefore if $\frac{\partial\zeta_t}{\partial g} > 0$ then $\frac{\partial\zeta_{t+1}}{\partial g} > 0$.Recall that $\zeta_0 = \frac{K_0}{K^s} = \frac{K_0}{\left[\frac{sa}{g+\delta}\right]^{\frac{1}{1-\alpha}}L_0}$ and then $\frac{\partial\zeta_0}{\partial g} > 0$. By induction we have $\frac{\partial\zeta_{t+1}}{\partial g} > 0, \forall t \geq 0$,which means that the economy whose rate of technological progress higher (then higher g) will converge faster to its own steady state.

Now let us consider the role of saving rate versus growth rate ν_t.From the equation (6) we know that if $\frac{\partial\nu_{t-1}}{\partial s} > 0$ then $\frac{\partial\nu_t}{\partial s} > 0$. Using equation (3) we have

$$\nu_1 = (1-\delta) + saL_0^{1-\alpha}(1+\gamma)(1+n)^{(1-\alpha)}K_0^{\alpha-1}$$

and it is obviously that $\frac{\partial \nu_1}{\partial s} > 0$. By induction, $\frac{\partial \nu_t}{\partial s} > 0, \forall t \geq 0$, which implies that eventhough saving rate does not affect on the growth rate at steady state but does on the growth rate in transitional period. The higher saving rate the higher growth rate in transitional period.



Remark 1 *1. In short and medium term (transitional period), the saving rate (hence capital accumulation) does matter for growth rate. A permanent increase in saving rate not only raises the level of steady state but also increases the economic growth rate in transitional period.*

2. In development process, the economies where technological progress are higher will converge faster to their own steady states; grow faster not only in steady state but also in transitional period. This result is consistent with findings of King and Rebelo (1993), who run simulations with neo-classical growth models and conclude that the transitional dynamics can only play a minor role in explaining observed growth rates.

3. The model also figures out the reason why there is no convergence in economic growth among developing economies (Barro and Sala-i-Martin 2004). According to the reasoning in the model the divergence in technological progress among developing economies will induce the divergence in development process among developing world.

6 Human Capital Growth Model (Lucas, 1988)

We present a simplified version of the Lucas model which is given in Stokey and Lucas (1989), p.111. In this version, there is no physical capital.

The consumption good is produced through a production function using only effective labor. At date t, effective labor is $\theta_t h_t N_t$ with N_t denoting the number of workers at date t and θ_t is the number of working hours. We assume that $N_t = 1,\ \forall t$. We assume that the accumulation of the human capital h is given by

$$h_{t+1} = h_t(1 + G(1 - \theta_t))$$

Where G satisfies $G(1) = \lambda,\ \lambda > 0,\ G(0) = -\delta$ and G is strictly increasing, continuous. In other words, we assume that without training ($\theta_t = 1$) the human capital depreciates with rate δ and if the worker devotes his whole time for training, his human capital will grow at rate λ. Hence, λ is the maximal rate of growth of human capital.

The model is

$$\max \sum_{t=0}^{+\infty} \beta^t u(c_t),$$

$$\text{such that } \forall t,\ 0 \le c_t \le f(\theta_t h_t),$$

$$h_{t+1} = h_t(1 + G(1 - \theta_t)),\ 0 \le \theta_t \le 1,$$

and $h_0 > 0$ is given.

We make the following assumptions:
(i) $u(c) = c^\mu,\ 0 < \mu < 1,$
(ii) $\beta > 0,$
(iii) $f_h(L) = A(h)L^\alpha,\ 0 < \alpha < 1,\ A(h) = h^\gamma,\ L = \theta h, \theta \in [0, 1]$
(iv) $\beta(1 + \lambda) < 1.$

We have the following result

Theorem 3 *The optimal path $(h_t^*)_t$ is :*

$$\exists u^* \in [1 - \delta,\ 1 + \lambda],\ s.t.\ \forall t, h_t^* = h_0(u^*)^t$$

The optimal output is

$$y_t^* = (\theta^*)^\alpha (u^*)^{(\alpha+\gamma)t} h_0^{(\alpha+\gamma)}$$

where θ^* determined by

$$G(1 - \theta^*) = 1 - u^*$$

The TFP $A(h_t^*)$ will growth at rate $(u^*)^\gamma$ which is endogenously determined. Now suppose $G(x) = (\lambda + \delta)x - \delta$ where $x \in [0, 1]$. The parameter λ may be considered as an indicator of the quality of the human capital technology. The next proposition shows that the quality of the human capital technology will enhance the TFP and hence growth.

Proposition 1 *If λ increases then u^* increases.*

For a proof see e.g. Gourdel et al (2004).

7 The Romer Model (Romer, 1986)

A closed economy is considered. There are S identical consumers. Their preferences are globally represented by an intertemporal utility function $\sum_{t=0}^{+\infty} \beta^t u(c_t)$ where $\beta,\ u$ satisfy the assumptions **H0,H1** in section 3. We assume that the consumers own firms. The output of each firm is represented by a function $F(k_t, K_t)$ where k_t is the firm-specific knowledge at time t and K_t is the economywide knowledge at date t. At equilibrium we have $K_t = Sk_t$. We assume

F1: F is concave with respect to the first variable

F2: $F(k, Sk)$ is convex in k

By investing an amount I_t we obtain an additional knowledge $k_{t+1} - k_t = G(I_t, k_t)$. Assume

F3: G is concave and homegeneous of degree one.

Then

$$\frac{k_{t+1} - k_t}{k_t} = G(\frac{I_t}{k_t}, 1) = g(\frac{I_t}{k_t})$$

where $g(x) = G(x, 1)$. Assume

F4: $g(0) = 0, g'(0) = +\infty, g'(x) > 0,\ \forall x$

For simplicity, we assume $S = 1$. Let $\mathcal{F}(k) = f(k, k)$. The problem becomes:

$$\begin{array}{lll} \text{Maximize} & & \displaystyle\sum_{t=0}^{\infty} \beta^t u(c_t) \\ \dfrac{k_{t+1} - k_t}{k_t} & \leq & g(\dfrac{\mathcal{F}(k_t) - c_t}{k_t}),\ k_0 > 0 \text{ is given} \end{array}$$

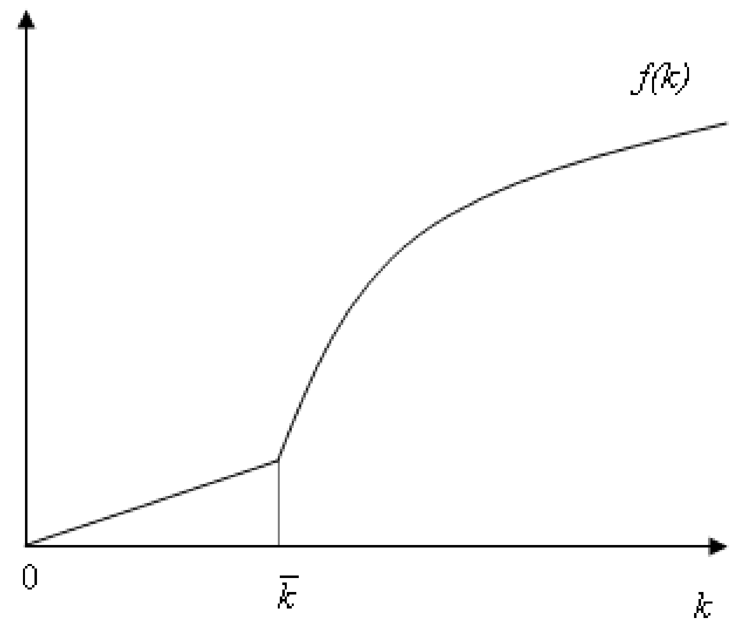
Assume

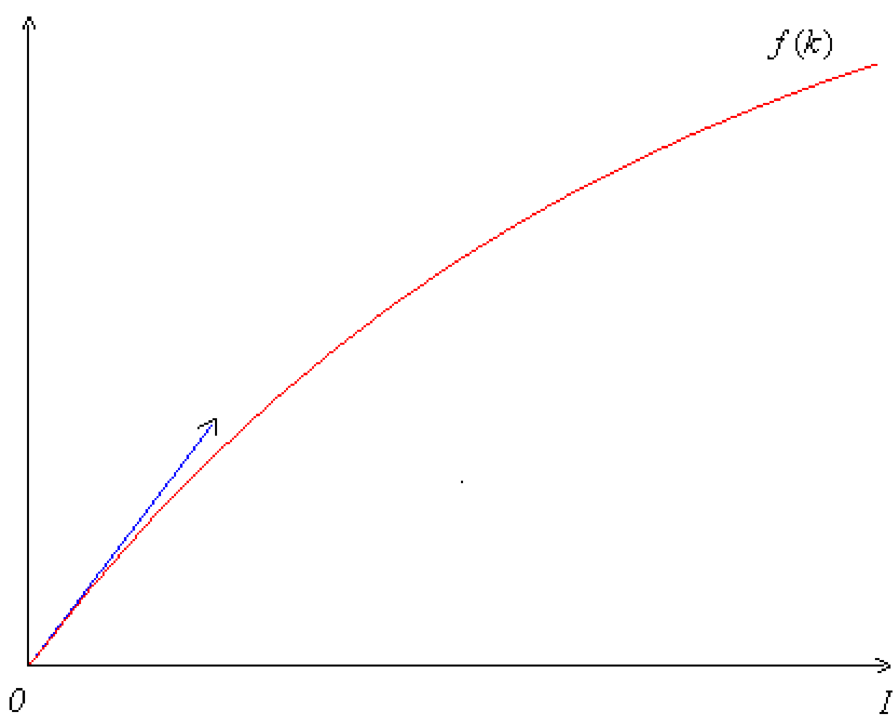
F5: $\mathcal{F}(k) \leq \mu + k^\rho,\ \rho > 1$, and $\mathcal{F}$ is C^1

F6: $0 \leq g(x) \leq \alpha, \forall x$

F7: $0 < \beta < 1$ and $\beta(1+\alpha)^\rho < 1$

We have the following result, the proof of which may be found in Le Van et al., 2002.





Theorem 4 *There exists an optimal path with grows without bound.*

This result is based on many crucial ingredients: (i) the private technology $f(., K)$ is concave, the quality of the knowledge technology is very good ($g'(0) = +\infty$). Le Van and Saglam (2004) weaken these assumptions:
F1′ : $F(k, K) = f(k)h(K)$ where $f(k) = \delta k$ if $k \leq \overline{k}$, $f(k) = A + k^{\mu},\ 0 < \mu < 1$ if

$k \geq \overline{k}$, $h(K) = K^{\rho},\ \rho > 0$
F4' : $g(0) = 0, g'(0) = \lambda < +\infty, g'(x) > 0,\ \forall x$
We have the following result

Theorem 5 *1. Let $\lambda > 0$ be given. There exists k_c such that if $k_0 < k_c$ any optimal path $\{k_t\}$ will satisfy $k_t = k_0,\ \forall t$. If $k_0 > k_c$ then for any optimal path $\{k_t\}$ we have $k_t \to +\infty$.*
2. Given $k_0 > 0$, if the quality of knowledge technology increases (λ increases) then the tendency of the economy to take off will increase.
3. Given k_0 and λ, if the influence of fixed costs diminishes (i.e. δ increases or $\overline{k}$ decreases) then the tendency of the economy to take off will increase.

These results point out two factors: fixed costs in the production induce a poverty trap. The latter may be passed over if the quality of knowledge technology is good enough.

8 New Technology, Human Capital and Growth

8.1 The Model and Its Results

Consider an economy where exists three sectors: domestic sector which produces an aggregate good Y_d, new technology sector with output Y_e and education sector characterized by a function $h(T)$ where T is the expenditure on training and education. The output Y_e is used by domestic sector to increase its total productivity. The production functions of two sectors are Cobb-Douglas, i.e, $Y_d = \Phi(Y_e)K_d^{\alpha_d}L_d^{1-\alpha_d}$ and $Y_e = A_eK_e^{\alpha_e}L_e^{1-\alpha_e}$ where $\Phi(.)$ is a non decreasing function which satisfies $\Phi(0) = x_0 > 0$, K_d, K_e, L_d, L_e and A_e be the physical capital, the technological capital, the low-skilled labor, the high-skilled labor and the total productivity, respectively, $0 < \alpha_d < 1, 0 < \alpha_e < 1$.[1]

We assume that price of capital goods is numeraire in term of consumption goods. The price of the new technology sector is higher and equal to λ such that $\lambda \geq 1$. Assume that labor mobility between sectors is impossible and wages are exogenous.

Let S be available amount of money denoted to the capital goods purchase. We have:

$$K_d + \lambda K_e + p_T T = S.$$

For simplicity, we assume $p_T = 1$, or in other words T is measured in capital goods.

Thus, the budget constraint of the economy can be written as follows

$$K_d + \lambda K_e + T = S$$

where S be the value of wealth of the country in terms of consumption goods.

The social planner maximizes the following program

[1] This specification implies that productivity growth is largely orthogonal to the physical capital accumulation. This implication is confirmed by facts examined by Collins, Bosworth and Rodrik (1996), Lau and Park (2003)

$$\max\ Y_d = \max\ \Phi(Y_e) K_d^{\alpha_d} L_d^{1-\alpha_d}$$

subject to

$$\begin{aligned} &Y_e = A_e K_e^{\alpha_e} L_e^{1-\alpha_e}, \\ &K_d + \lambda K_e + T = S, \\ &0 \le L_e \le L_e^* h(T), \\ &0 \le L_d \le L_d^*. \end{aligned}$$

Where h is the human capital production technology; L_e^* is number of skilled workers in new technology sector; L_e is effective labor; L_d^* is number of non-skilled workers in domestic sector.

Assume that $h(.)$ is an increasing concave function and $h(0) = h_0 > 0$ or Y_d is a concave function of education investment. This assumption captures the fact that marginal returns to education is diminishing (see Psacharopoulos, 1994). Let

$$\Delta = \{(\theta, \mu) : \theta \in [0,1], \mu \in [0,1], \theta + \mu \le 1\}.$$

From the budget constraint, we can define $(\theta, \mu) \in \Delta$:

$$\lambda K_e = \theta S\ , K_d = (1 - \theta - \mu)S \text{ and } \ T = \mu S.$$

Observe that since the objective function is strictly increasing, at the optimum, the constraints will be binding. Let $L_e = L_e^* h$, $L_d = L_d^*$, then we have the following problem

$$\max_{(\theta,\mu)\in\Delta} \Phi(r_e \theta^{\alpha_e} S^{\alpha_e} h(\mu S)^{1-\alpha_e})(1-\theta-\mu)^{\alpha_d} S^{\alpha_d} L_d^{*1-\alpha_d}.$$

where $r_e = \frac{A_e}{\lambda^{\alpha_e}} L_e^{*1-\alpha_e}$.

Let

$$\psi(r_e, \theta, \mu, S) = \Phi(r_e \theta^{\alpha_e} S^{\alpha_e} h(\mu S)^{1-\alpha_e})(1-\theta-\mu)^{\alpha_d} L_d^{*1-\alpha_d}.$$

The problem now is equivalent to

$$\max_{(\theta,\mu)\in\Delta} \psi(r_e, \theta, \mu, S). \qquad \text{(P)}$$

Since the function ψ is continuous in θ and μ, there will exist optimal solutions. Denote

$$F(r_e, S) = \max_{(\theta,\mu)\in\Delta} \psi(r_e, \theta, \mu, S).$$

Suppose that function $\Phi(x)$ is a constant in an initial phase and increasing linear afterwards:

$$\Phi(x) = \begin{cases} x_0 \ \text{ if } \ x \le X \\ x_0 + a(x - X) \text{ if } x \ge X, a > 0. \end{cases}$$

We will denote by $\theta(S),\ \mu(S)$ the optimal shares of investment in newtechnology and in human capital. We first have

Proposition 2 *1. There exists S^c such that $\theta(S) = \mu(S) = 0$ if $S < S^c$. If $S > S^c$ then $\theta(S) > 0$.*
2. If $h'(0) = +\infty$ then for all $S > S^c$ we have $\theta(S) > 0,\ \mu(S) > 0$.
3. Assume $h^{'}(0) < +\infty$. Then there exists S^M such that $\mu(S) > 0, \theta(S) > 0$ for every $S > S^M$.
4. There exists $\alpha > 0$ such that, if $h'(0) < \alpha$, then there exists $S^m > S^c$ such that $\mu(S) = 0, \theta(S) > 0$ for $S \in [S^c, S^m]$.
5. Assume $h'(0) < +\infty$. Let $S^1 > S^c$. If $\mu(S^1) = 0$, then for $S^2 < S^1$, we also have $\mu(S^2) = 0$.

For a proof, see Le Van et al. (2008).

Corollary 1 *Assume $h'(0) < +\infty$. Then there exists $\widehat{S} \geq S^c$ such that:*
(i) $S \leq \widehat{S} \Rightarrow \mu(S) = 0$,
(ii) $S > \widehat{S} \Rightarrow \mu(S) > 0,\ \theta(S) > 0$

We now consider an economy with one infinitely lived representative consumer who has an intertemporal utility function with discount factor $\beta < 1$. At each period, her savings will be used to invest in physical capital or/and new technology capital and/or to invest in human capital. We suppose the capital depreciation rate equals 1 and growth rate of population is 0 and $L^*_{e,t} = L^*_e; L^*_{d,t} = L^*_d$.

The social planner will solve the following dynamic growth model

$$\begin{aligned} \max \quad & \sum_{t=0}^{\infty} \beta^t u(c_t) \\ \text{s.t} \quad & c_t + S_{t+1} \leq \Phi(Y_{e,t}) K_{d,t}^{\alpha_d} L_{d,t}^{1-\alpha_d} \\ & Y_{e,t} = A_e K_{e,t}^{\alpha_e} L_{e,t}^{1-\alpha_e} \\ & K_{d,t} + \lambda K_{e,t} + T_t = S_t, \\ & 0 \leq L_{e,t} \leq L^*_e h(T_t), 0 \leq L_{d,t} \leq L^*_d. \\ & \text{ the initial resource } S_0 \text{ is given.} \end{aligned}$$

The problem is equivalent to

$$\begin{aligned} \max \quad & \sum_{t=0}^{\infty} \beta^t u(c_t) \\ \text{s.t} \quad & c_t + S_{t+1} \leq H(r_e, S_t), \forall t, \end{aligned}$$

with

$$H(r_e, S) = F(r_e, S) S^{\alpha_d}.$$

where $r_e = \frac{A_e}{\lambda^{\alpha_e}} L_e^{*1-\alpha_e}, \beta$ is time preference discount rate $0 \leq \beta \leq 1$ Obviously, $H(r_e, .)$ is continuous, strictly increasing and $H(r_e, 0) = 0$.

As in the previous section, we shall use S^c defined as follows:

$$S^c = \max\{S \geq 0 : F(r_e, S) = x_0 L_d^{*1-\alpha_d}\}$$

where

$$F(r_e, S_t) = \max_{0 \leq \theta_t \leq 1, 0 \leq \mu_t \leq 1} \psi(r_e, \theta_t, \mu_t, S_t).$$

We shall make standard assumptions on the function u under consideration.

H2. The utility function u is strictly concave, strictly increasing and satisfies the Inada condition: $u^{'}(0) = +\infty, u(0) = 0$.

At the optimum, the constraints will be binding, the initial program is equivalent to the following problem

$$\begin{aligned} & \max \sum_{t=0}^{\infty} \beta^t u(H(r_e, S_t) - S_{t+1}) \\ \text{s.t} \quad & 0 \leq S_{t+1} \leq H(r_e, S_t), \forall t. \\ & S_0 > 0 \text{ given.} \end{aligned}$$

The main result in this section is:

Theorem 6 *Assume $h(z) = h_0 + bz$, with $b > 0$ and $\alpha_e + \alpha_d \geq 1$. If a or/and r_e are large enough then the optimal path $\{S_t^*\}_{t=1,+\infty}$ converges to $+\infty$ when t goes to infinity. Hence:*

(i) there exists T_1 such that

$$\theta_t^* > 0 \ \forall t \geq T_1$$

(ii) there exists $T_2 \geq T_1$ such that

$$\theta_t^* > 0 \ , \mu_t^* > 0, \ \forall t \geq T_2$$

The sum $\theta_t^* + \mu_t^*$ and the share μ_t^* increase when t goes to infinity and converge to values less than 1.

8.2 A Look At Evidence

There are numerous discusses in literature on the role of physical capital, human capital and technological progress in economic growth. King and Rebelo (1993) run simulations with neoclassical growth models and conclude that the transitional dynamics (contribution of physical capital accumulation) can only play a minor role in explaining observed growth rates. They suggest endogenous growth models such as human capital formation or endogenous technical progress. Hofman (1993) examines economic performances of Latin American countries, three Asian economies (S. Korea, Taiwan and Thailand), Portugal, Spain and six advanced economies (France, Germany, Japan, The Netherlands, UK and US) in the 20th century. The evidences show that growth in developing economies bases mainly on physical capital accumulation while growth in developed economies motivated essentially by human capital and technological progress. Young (1994), Kim and Lau (1994), Krugman (1994), Collins and Bosworth (1996) and Lau and Park (2003) all attribute the miracle growth in East Asia Economies mostly to physical capital accumulation and find no significant role of technological progress in miracle growth of East Asia Economies, which plays a crucial role in economic growth in Industrial Economies (see Table 2 in Appendix 3). Collins and Bosworth (1996) suggests "it is possible that the potential to adopt knowledge and technological from abroad depends on a country's stage of development. Growth in the early stages may be primarily associated with physical and human capital accumulation, and significant potential for growth through catchup may only emerge once a country has crossed some development thresholds". Lau and Park (2003) on the one hand, shows that the hypothesis of no technological progress in East Asia NIEs until 1986 can not rejected. On the other hand, since 1986 when these economies started investing heavily on R&D, technological progress plays significant role in growths of these economies. This evidence supports our model's prediction that there exists threshold for investing in new technology in process of economic development. Nevertheless, the question of threshold of investment in human capital is rarely raised in literature.

In this section we use pooled time-series aggregate data of educational attainment for 71 non-oil exporting, developing economies compiled by Barro and Lee (2000)[2] and real GDP per capita (y) (in PPP) of these countries in Penn World table 6.2, Heston, *et al.*, (2006) to find the correlation between human capital and level of development. In Barro and Lee (2000) we use five variables to measure human capital: percentage of labor force with completed primary school (l_1); with completed secondary school (l_2); with completed higher secondary school (l_3); and average schooling years of labor force (A). Those data are calculated for 5-year span from 1950 (if available) to 2000. Oil exporting countries are excluded from the sample because they enjoy peculiarly high level of GDP per capita regardless of production capacity of non-oil sectors. Some other developing countries whose data of human capital are available for two years also excluded.

We run two simple OLS regression equations

$$\ln y = \alpha + \beta_1 l_1 + \beta_2 l_2 + \beta_3 l_3 \tag{9}$$

and

$$\ln y = \alpha + \gamma_1 A \tag{10}$$

These equations are tested for two sub-samples: the first with GDP per capita is less than 1000 (75 observations); and the second with GDP per capita more than 1000 (533 observations). The results are presented in table 1 below and show that when GDP per capita below 1000 USD (y in PPP and constant price in 2000) all hypotheses of no contribution of human capital to economic growth can not be rejected, while when $y > 1000$ those hypotheses are decisively rejected

Table 1: **Contributions of human capital to economic growth**

	Equation 9		**Equation 10**	
	$y \leq 1000$	$y > 1000$	$y \leq 1000$	$y > 1000$
R^2	4.7%	**46.6%**	2.1%	**54.3%**
$\overline{R^2}$	0.7%	**46.3%**	0.75%	**54.2%**
β_1	−0.015 (0.08)	0.002 (**0.000**)*		
β_2	0.002 (0.88)	0.050 (**0.000**)*		
β_3	0.040 (0.63)	0.042 (**0.000**)*		
γ_1			−0.03 (0.22)	0.25 (**0.000**)*
Obs	75	533	75	533

Note: the numbers in the parentheses are p-values of corresponding coefficients;

* Indicates statistically significant at the level of significance of 0.1%

[2]See Table 3 in appendix for list of economies

Furthermore, when $y > 1000$ coefficients of variables: percentage of labor force with completed primary school (l_1), completed secondary school, and completed higher secondary school are all in expected sign and statistically significant at level of significance of 0.1%. The results of regression on equation (10) also solidly confirms the positive contribution of human capital when it is measured by average year of schoolings.

By contrast, when $y \leq 1000$, the values of adjusted R-square in both equations are nearly zero. There is no coefficient is statistically significant at level of siginificance of 5%. These results imply that human capital, by all means, plays no role in economic growth. Put it differntly, they support our model's prediction that when income is lower than a critical level there is no demand for investing in human capital, or equivalently, there exists threshold for investing in human capital in process of development.

In the following we look closely at movement of expenditures on human capital and new technology in three economies, namely China, South Korea and Taiwan. The reasons to choose these economies are: (i) the availability of data; (ii) these economies have experienced high growth rates for long time from very low stage. The purpose of this section is to examine the our third point, that is the share of human capital and expenditure for new technology in total investment (S) in these economies shows the increasing trend in the examined periods and human capital increasingly becomes more important than two others.

Since the data for expenditure on human capital is not directly available, hence we follow Carsey and Sala-i-Martin (1995) to assume that wage paid to a worker consists of two parts: one for human capital and the other (non-skilled wage) for other things other than human capital. According to Carsey and Sala-i-Martin (1995) the latter part of wage depends on many factors such that: ratio of aggregate physical capital stock to human capital due to the complementary between physical capital and human capital; and change in relative supplies of workers. The former part depends not only on number of schooling years but also on others: on-the-job training, job experience, schooling quality, and technological level. Accordingly, this labor-income-based human capital that taking all these factors into account reflects the value of human capital more comprehensively than the conventional measurement that based on schooling years.

We assume further that minimum wage is the non-skilled wage. Consequently the expenditure for human capital can be calculated by following formula:

$$EHC_t = E_t * (AW_t - MW_t)$$

Where EHC is expenditure for human capital, E is total employed workers, AW is average wage, and MW is minimum wage. Recall that $AW - MW$ represents the part in the average wage which is rewarded for skill.

In our model, the new technological capitals are produced in R&D sector, then we use indicator of expenditure for R&D as a proxy for investment in technological capital (λK_e), and the fixed capital formation (if not available, then the gross capital formation) for expenditure on K_d.

Data

For China, the data of AW, GDP, and E are available in CEIC database from 1952 to 2006. The minimum wages in China vary from provinces and within province. Provinces and cities usually have multiple levels of minimum wage standards based upon different geographic locations and industries. The minimum wages for all provinces were only available discretely in period 2004-2006 from the Ministry of Labor and Social Security of China 2005 statistics[3]. Therefore we use average wage in sector of Farming, Forestry, Animal Husbandry & Fishery where use least human capital and physical capital as a proxy of minimum wage. All entries of this variables can be taken from CEIC database. Based on this series of indices we come up with an estimated time-series national minimum wage in China from 1980 to 2006. Since data of fixed capital formation in China are not available, we then use the data of gross capital formation, which are available in WDI database of World Bank. Finally, the statistics for R&D expenditure in period 1980-2006 are available in China statistical yearbook in various issues.

For Taiwan, the data for total compensation for employees ($E * AW$), employment (E), fixed capital formation, GDP, and average wage in manufacturing sector are available in CEIC database in period 1978-2006. The minimum wage rates are only available in period 1993-2006 and in 1984 at US Department of State[4]. For missing data in period 1983-1992 we fill in by estimated ones. For that, we assume that minimum wage (MW) is a concave function of average wage in manufacturing sector (AW_m) or more specifically, the ratio of $\frac{MW}{AW_m}$ is linearly correlated with AW_m. The result of OLS regression strongly confirms our hypothesis. Based on coefficients of this OLS regression we come up with the estimations of missing data. The data of R&D expenditure is taken from National Science Council (2007) and Lau and Park (2003).

For South Korea, CEIC database provides data of employment (E), compensations for employees ($E * AW$), fixed capital formation, GDP, and nominal wage index. The minimum wages in period 1988-2006 are taken from GPN (2001) and US State Department website. If we assume that in period 1976-1987 the minium wages proportionally change with nominal wage index, then we have the estimation of expenditure for human capital in the period 1976-1987. The data for R&D expenditure is taken from UNESCO.

[3] Updates are based upon news reports prior to July 2006. Minimum wages listed as monthly-based

[4] Cited at website: http://dosfan.lib.uic.edu/ERC/economics/commercial_guides/Taiwan.html and http://www.state.gov/g/drl/rls/hrrpt/2006/78770.htm

Figure 1: Human capital and R&D in total available investment

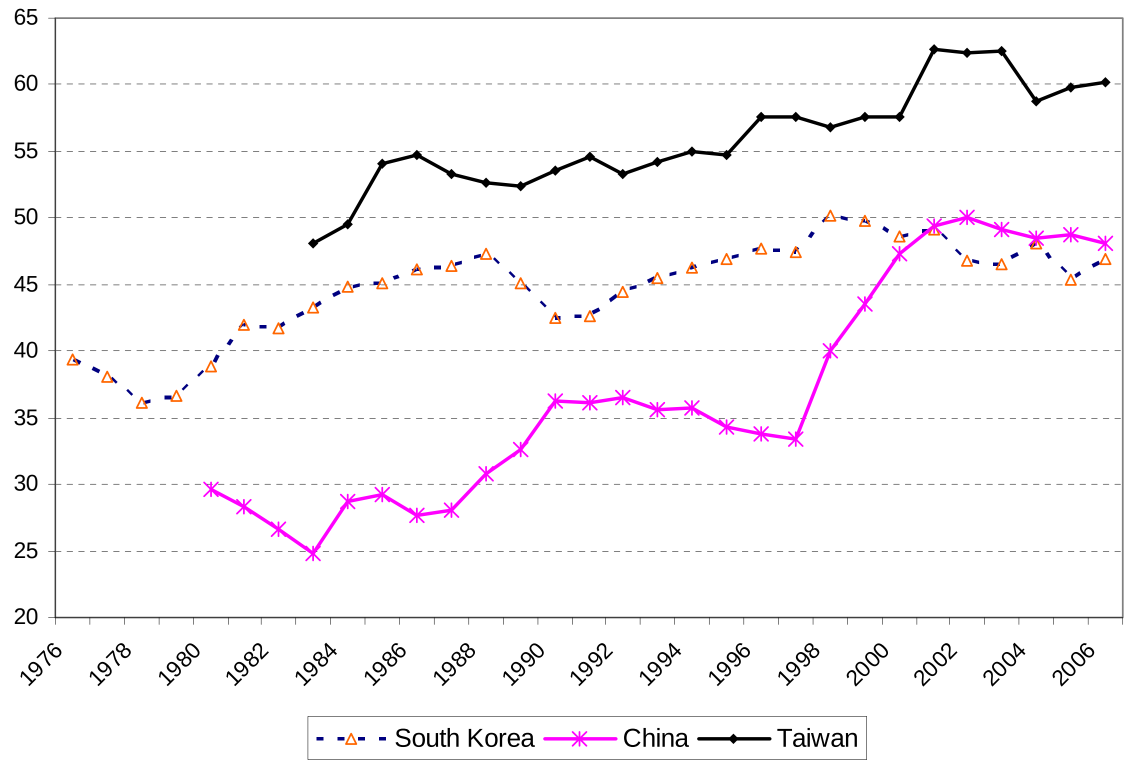


Figure 2: Share of Human Capital in Total available Investment

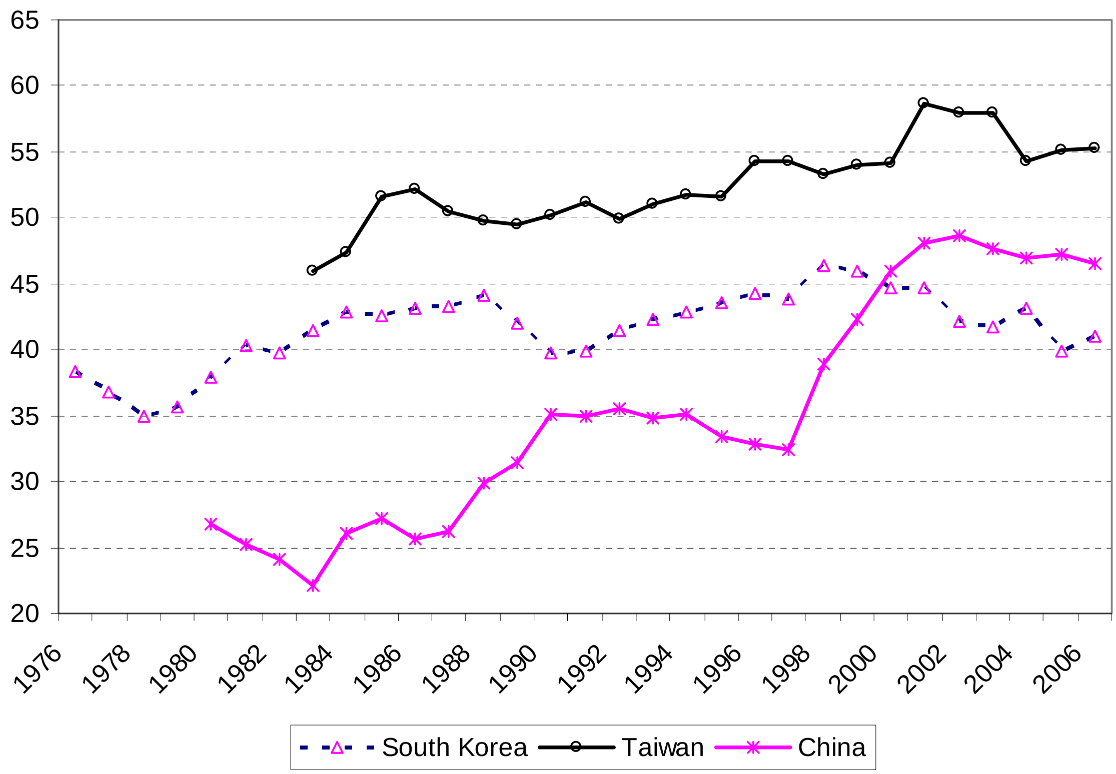
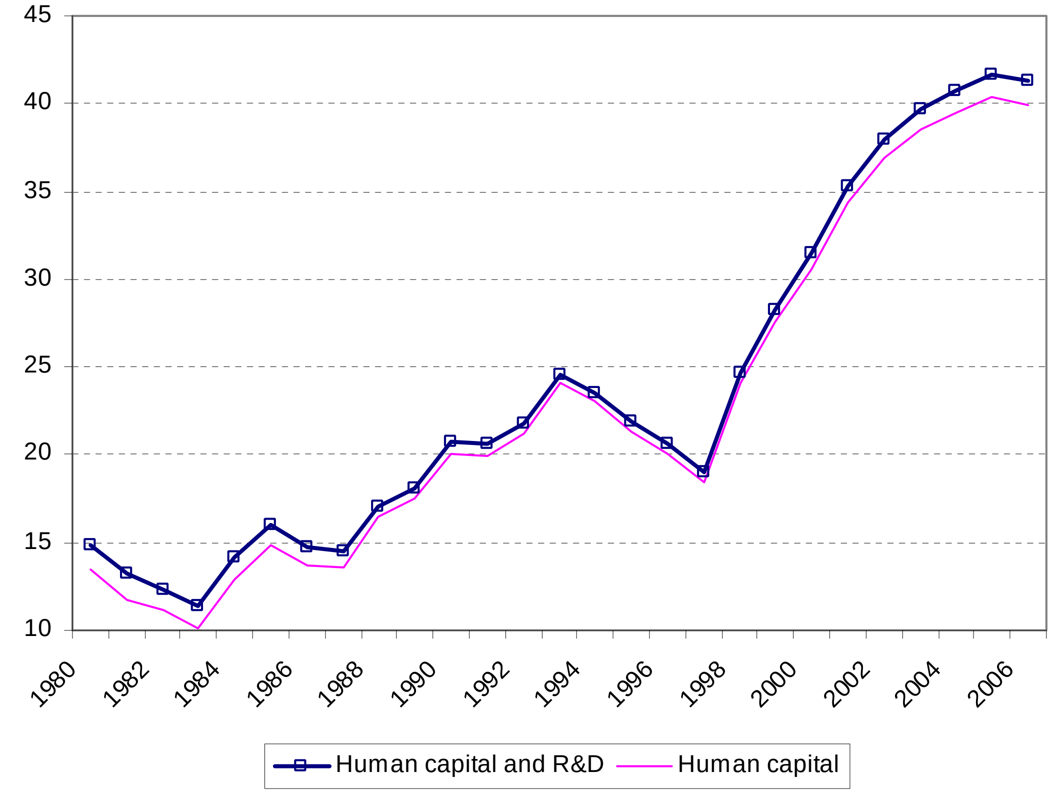


Figure 1 show the steadily increasing trend of shares of human capital and R&D in total available investment in all three economies in the examined periods. The movement of share of human capital in total available investment shown in figure 2 also show steadily increasing trend in Taiwan and China, while in South Korea the trend seems more fluctuant, nevertheless, increasing. Hence our predictions on the movements of the shares of human capital and of new technology on the one hand, and of physical capital on the other hand, cannot be rejected by evidences from these economies.

Let's consider the movements on another dimension. Assuming that the budget available (S) for total investment is positively related to GDP in the whole period. Thereby, the movement of ratios of λK_e and expenditure for human capital (T) to GDP are congruent to the movement of ratios of λK_e and T to S.

Figures below (3,4 and 5) all support our model's prediction, $\mu_t + \theta_{t,}$the sum of the share of human capital and R&D as well as share of human capital in GDP both increase. The figures also show the effects of Asian crisis in 1997 on investment in human capital and R&D these economies. China is the least affected and then quickly recovered the momentum investing activities. S. Korea, the most affected one and had to have recourse to IMF for help. Under pressure of IMF South Korea had to apply severely tightening expenditure policy. Even though South Korea started recovering since 1999 and GDP recovered high growth rate in following years, they remained tightening expenditure policy till early 2000s. That's why the figure 5 shows the declining trend of both variables, shares of human capital and R&D, and of human capital, since 1997.

Figure 3: Human capital and R&D (%GDP): China



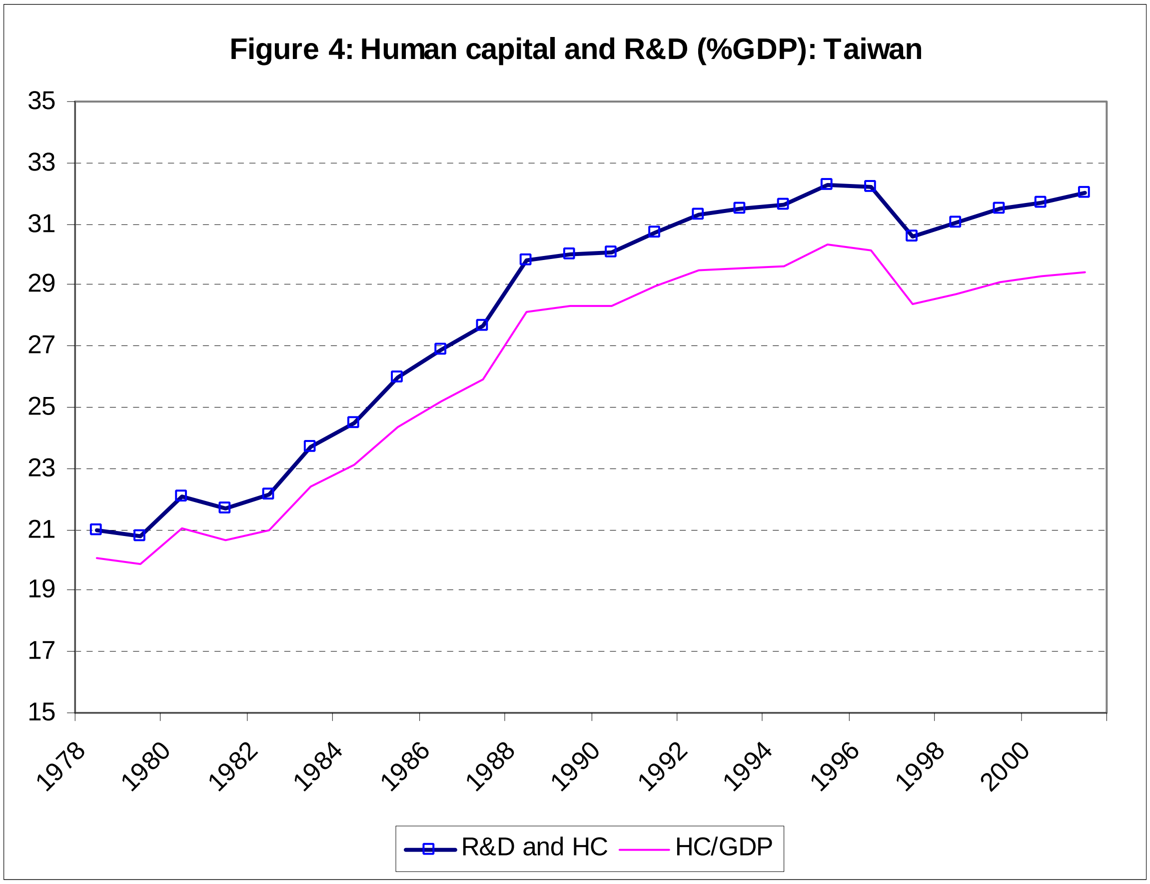


Figure 4: Human capital and R&D (%GDP): Taiwan
35
33
31
29
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25
23
21
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17
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1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
R&D and HC
HC/GDP

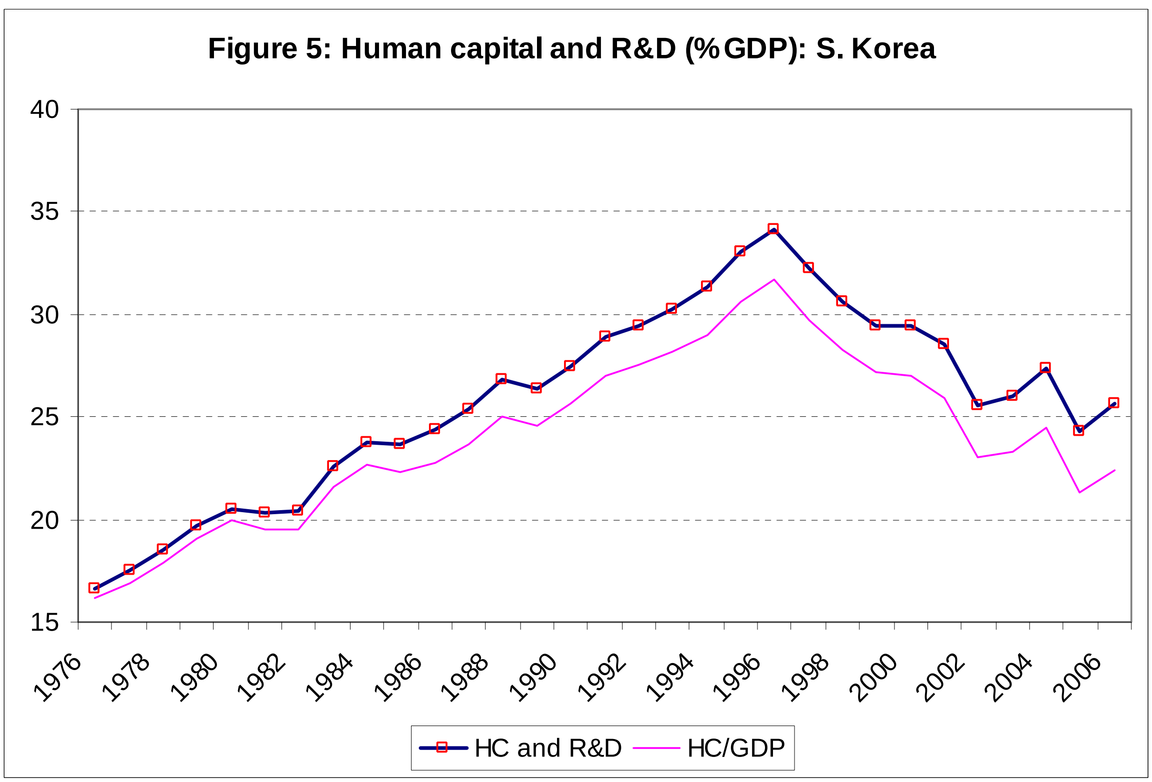
Figure 5: Human capital and R&D (%GDP): S. Korea
40
35
30
25
20
15
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
HC and R&D
HC/GDP

References

[1] Azariadis, C, and A. Drazen, Threshold Externalities in Economic Development, *The Quarterly Journal of Economics*, 105, 501-526, 1990.

[2] Atawell, P., Technology Diffusion and Organizational Learning: the Case of Business Computing, *Organizational Science*, 3(1), 1-19, 1992.

[3] Barro, R. Determinants of Economic Growth. A Cross-Country Empirical Study, MIT Press, Cambridge, 1997.

[4] Barro, R. and J. W. Lee (2000), "International Data on Educational Attainment: Updates and Implications," *Working Paper No. 42*, Center for International Development (CID), Havard University.

[5] Barro, R. and Sala-i-Martin, X., Economic Growth, McGraw Hill, New York, 1995.

[6] Bruno, O., C. Le Van and B. Masquin, "When does a developing country use new technologies, *Economic Theory*, forthcoming.

[7] Carsey, B. M. and X. Sala-i-Martin (1995), "A Labor-Income-Based Measure of the Value of Human Capital: An Application to the United States," NBER *Working paper No. 5018*, National Bureau of Economic Research, Cambridge.

[8] Cass, D., Optimal Growth in an Aggregative Model of Capital Accumulation, *Review of Economic Studies*, 32, 1965.

[9] Castro, R., Clementi, G.L. and G. MacDonald, Legal Institutions, Sectoral Heterogeneity, and Economic Development, *Working Paper, Departement de Sciences Economiques, Universite de Montreal*, 2006.

[10] CEIC database: http://www.ceicdata.com/

[11] Ciccone, A and Matsuyama, K., Start-up Costs and Pecuniary Externalities as Barriers to Economic Development, *Journal of Development Economics*, 49, 33-59, 1996.

[12] Clarke ,F.H., Optimization and Nonsmooth Analysis, John Wiley and Sons, 1983.

[13] Collins, S. and B. Bosworth, Lessons from East Asian Growth: Accumulation versus Assimilation, *Brookings Papers on Economic Activity*, 1996.

[14] Dechert, W.D. and Nishimura, K., A Complete Characterization of Optimal Growth Paths in an Aggregated Model with a Non-Concave Production Function, *Journal of Economic Theory*, 31, pp. 332-354,1983.

[15] Dollar, D., Technological Differences as a Source of Comparative Advantage, *The American Economic Review*, 83, 431-435, 1993.

[16] Dowrick, S. and D. T. Nguyen (1989) "OECD Comparative Economic Growth 1950-85," *American Economic Review*, vol.79, No. 5, pp.1010-1030

[17] GPN (2001), *GPN Global Labor Market Database: Korea*, Global Policy Network

[18] Heston, H., R. Summers and B. Aten, *Penn World Table Version 6.2*, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, September 2006.

[19] Kamihigashi, T., and Roy, S., A Nonsmooth, Nonconvex Model of Optimal Growth, *Journal of Economic Theory*, 132, 435-460, 2007.

[20] Kim, J., and Lau, L., The Sources of Economic Growth in the East Asian Newly Industrial Countries, *Journal of Japanese and International Economics*, 8, 1994.

[21] King, R.G. and S. Rebelo, Transitional Dynamics and Economic Growth in the Neoclassical Model, *The American Economic Review*, 83, 908-931, 1993.

[22] Kumar, K.B.(2003) "Education and Technology Adoption in a Small Open Economy: Theory and Evidence," *Macroeconomic Dynamics*, 7, pp. 586-617.

[23] Krugman, P., The Myth of Asia's Miracle, *Foreign Affairs*, 73, 62-78, 1994.

[24] Krugman, P. What Ever Happened to the Asian Miracle?, *Fortune*, Aug. 18, 1997

[25] Lau, L. and J. Park, The Sources of East Asian Economic Growth Revisited, *Conference on International and Development Economics in Honor Henry Y. Wan, Jr.*, Cornell University, Ithaca, September 6-7, 2003.

[26] Le Van, C. and Dana, R.A., Dynamic Programming in Economics, Kluwer Academic Publishers, 2003.

[27] Le Van, C., L. Morhaim and Ch-H. Dimaria, The dicrete time version of the Romer model, *Economic Theory*, 20, pp. 133-158, 2002.

[28] Le Van, C. and C. Saglam, H., Quality of Knowledge Technology, Returns to Production Technology, and Economic Development, *Macroeconomic Dynamics*, 8, 147-161, 2004.

[29] Lucas, R.E. Jr. (1988), "On the Mechanics of Economic Development," *Journal of Monetary Economics*, 22, 1 (July), pp. 3-42.

[30] Ministry of Labor and Social Security of China 2005 statistics, Cited at http://www.chinalaborwatch.org/2006%20Editorials/07-24-2006%20Minimum%20Wage%20Chart.htm

[31] National Science Council (2007), *Indicators of Science and Technology Taiwan*, Taiwan.

[32] Ramsey F.(1928), "A Mathematical Theory of Saving," *Journal of Economic Theory*, 38, pp. 543-559.

[33] Romer, P., Increasing Returns and Long Run Growth, *Journal of Political Economy*, 1002-1037, 1986.

[34] Solow, R., A Contribution to the Theory of Economic Growth, *The Quarterly Journal of Economics*, 70, 65-94, 1956.

[35] Solow, R., Technical Change and the Aggregate Production Function, *Review of Economics and Statistics*, 39, 312-320, 1957.

[36] World Bank, *World Development Indicators*, www.worldbank.org/data

[37] Young, A., Lessons from East Asian NICs: a Contrarian View, *European Economic Review*, 38, 964-973, 1994

[38] Young, A., The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience, *The Quarterly Journal of Economics*, 110, 641-680, 1995.