HEALTH, HUMAN CAPITAL AND ECONOMIC GROWTH: A SCHUMPETERIAN PERSPECTIVE

by

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1. Introduction

At the start of the 21st Century, the gap in living standards between rich and poor nations is large and rising. The developing world suffers persistent poverty, while the developed world enjoys growing prosperity. According to Maddison (2001) the ratio of per-capita GDP in the richest group of nations to per-capita GDP in the poorest[1] grew from 11 in 1950 to 19 in 1998. The same ratio between Mayer's (2002) richest and poorest convergence groups grew by a factor of 2.6 from 1960 to 1995. This situation is undesirable, and probably unsustainable. The challenge to economists is to find remedies that will close the gap by raising the growth rates of poor countries.

Useful prescription depends on accurate diagnosis. Why has the growth performance of poor countries been so disappointing? Among the many causal factors that economists have proposed, poor health stands out as a likely candidate. Although life expectancy has increased dramatically in developing countries over the past sixty years, many people in poor countries still face shocking health conditions. The average rate of mortality for children under the age of five is 84 deaths per 1000 in developing countries. Over a billion people in low and middle-income countries lack access to safe water. [2] Sub-Saharan Africa has been ravaged by AIDS, malaria and tuberculosis. That health conditions such as these are likely to play a strong causal role in the growth process is confirmed by the time series analysis of Arora (2001).

Different theories of economic growth produce different answers to the question of how health conditions affect a country's per-capita GDP over time. (Barro and Barro, 1996). For example, the neoclassical growth theory of Solow (1956) and Swan (1956) imply that in the long run only the level of per-capita GDP will be affected, not the

[1] The richest group was the "western offshoots": Australia, Canada, New Zealand and the United States. The poorest was Africa.

[2] These facts are drawn from Stern (2003).

growth rate, which is determined by the global rate of technological progress. The first generation of endogenous growth models, in which the rate of technological progress varies from country to country depending on local economic conditions, predicts a permanent effect on the growth rate.

The purpose of this paper is to show how the question might be answered from the most recent vintage of endogenous growth theories, namely the "Schumpeterian" growth theory that Philippe Aghion and I, among others, have been developing (for example, Aghion and Howitt, 1998; Howitt, 2000; Howitt and Mayer, 2002). This recent theory differs from neoclassical theory in assuming that technological progress is endogenous and can vary from country to country. But it is also unlike the first generation of endogenous growth theories because it takes into account the process of international technology transfer, which makes the rate of technological progress in each country depend on global as well as local conditions.

The structure of the paper is as follows. Section 2 below presents an introduction to the main ideas of Schumpeterian theory. Section 3 lays out a simple formal model. Section 4 discusses how health conditions impinge on the growth process according to this model. Section 5 concludes with a brief summary.

2. Schumpeterian growth theory.

The basic ideas of endogenous growth theory are quite simple. The first is that technological progress is the driving force behind long-run growth. This proposition follows inescapably from the fact of diminishing returns. That is, if people continued to produce the same products, of the same quality, using the same means of production and the same procedures, with no growth in knowledge, then sustained growth in per-capita output would require sustained growth in the amount of capital used per worker. But beyond some point increases in capital per worker would eventually reduce its marginal product to zero. This force would eventually reduce a country's growth rate (that is, the growth rate of its per-capita GDP) to zero. The only force that can prevent this eventual stagnation is increasing productivity, coming from new products, processes and markets; that is, technological progress.

So far we are in agreement with neoclassical growth theory. Endogenous growth theory departs from neoclassical theory, however, in emphasizing that technological progress is itself an economic process, with economic determinants, much like the process of capital accumulation. The first version of endogenous growth theory was the so-called AK theory, which did not make an explicit distinction between capital accumulation and technological progress. In effect it just lumped together the physical capital whose accumulation is studied by neoclassical theory and the intellectual capital that is accumulated when technological progress is made. When this aggregate bundle of different kinds of capital is accumulated there is no reason to think that diminishing returns will drag its marginal product down to zero because part of that accumulation is the very technological progress needed to counteract diminishing returns.

Schumpeterian growth theory goes beyond AK by distinguishing explicitly between physical and intellectual capital, and between saving, which makes physical capital grow, and innovation, which makes intellectual capital grow. It supposes that technological progress comes from innovations carried out by firms motivated by the pursuit of profit, and that it involves what Schumpeter called "creative destruction". That is, each innovation is aimed at creating some new process or product that gives its creator a competitive advantage over its business rivals; it does so by rendering obsolete some previous innovation; and it is in turn destined to be rendered obsolete by future innovations.

Recent versions of Schumpeterian theory also assume that the rate of technological progress in one country depends not only on innovations in that country but also on technology spillovers resulting from innovations in other countries. In this way it takes into account the international diffusion of technology, or what is sometimes known as "technology transfer." It therefore recognizes what Gerschenkron (1952) called the "advantage of backwardness." That is, a country that lags behind the world's technology leaders has the advantage of being able to advance just by making use of inventions that have already been made elsewhere, without having to break new ground.

The advantage of backwardness is a strong force towards convergence of growth rates. For it tends to make a country's rate of technological progress larger the larger the gap separating it from the global technological frontier, thus tending to stabilize the gap. The fact that the gap between rich and poor nations continues to grow into the 21st Century as it has since the early 19th suggests however that there are countervailing forces at work on the evolution of the gap. In Schumpeterian theory the countervailing force comes from two additional factors.

The first of these additional factors is the necessity to make technological investments if one is to take advantage of technology transfer. Technologies developed in one country are typically not available to be taken off the shelf and used without further modification in another country. This is partly because much technological knowledge is what Polanyi (1958) calls "tacit", and cannot be codified. Thus adopters must spend time and other resources learning and experimenting before they can master what has been mastered elsewhere. It is also partly because of what Evenson and Westphal (1995) call "circumstantial sensitivity." That is, because of differences in climate, available raw materials, skills, customs, preferences, regulations, etc., what works in one country will often not work in another.

The other additional factor is increasing complexity. As technology develops, the size of investment needed in order to transfer it to any given country tends to grow, because it becomes harder to master and to modify. For example, new technologies are often embedded in physical capital. As the capital becomes more advanced it involves more complex interdependencies, so that changing one component in response to local conditions may imply a long and unpredictable series of further changes before the technology will again work properly.

These two additional factors create a disadvantage of backwardness, because as a country falls further behind the technological frontier, its income falls relative to the size of investments that must be made in order to keep drawing on foreign technology at the same rate. This disadvantage is constantly fighting Gerschenkron's advantage, and Schumpeterian theory helps us understand why in some countries the advantage prevails, allowing the country eventually to grow at the same rate as the technology leaders, with a stable proportional income gap, while in other countries the disadvantage prevails, causing the country to grow indefinitely at a lower rate than the technology leader, with an ever increasing proportional gap.

Two observations are in order concerning the relevance of Schumpeterian theory to the situation of very poor countries. First, unlike neoclassical theory, the theory attributes differences in growth rates between rich and poor countries to differences in rates of productivity growth rather than to differences in rates of factor accumulation. This is consistent with a large number of recent empirical studies. For example, Easterly and Levine (2001) estimate that about 60% of the cross-country variation in growth rates of per-capita GDP is attributable to differences in productivity growth, while Klenow and Rodríguez-Clare (1997) estimate that in their sample about 90% of the variation is attributable to differences in productivity growth.

Second, Cohen and Levinthal (1989) and Griffith, Redding and Van Reenen (2001) present evidence that technology investments, in the form of R&D expenditures, are indeed an important ingredient in the technology transfer process, at least between developed countries. Although developing countries do not conduct formal R&D on a significant scale, nonetheless the investments that they make in adapting and implementing foreign technologies share many of the analytical characteristics of R&D in an economic model. Specifically, like R&D these implementation investments are costly, they make use of ideas developed elsewhere through technology spillovers of the sort that Griliches and others have shown to be very important,[3] and they become increasingly expensive as the technology frontier advances. Thus for example the role of technology investments in the diffusion of agricultural technology through the developing world during the Green Revolution that Evenson and Westphal (1995) describe is much like the role of R&D in Griliches's (1958) celebrated account of the diffusion of hybrid corn technology in the United States.

3. A formal model.

In this section I construct a simple formal model illustrating the main ideas of Schumpeterian theory. The model ignores many details that would be important in applications, in the aim of providing a simple framework that allows us to see the various channels through which health can influence a country's long-run growth rate.

Consider the situation of a single country in a world of many. This country produces final output using capital, skills and a variety of intermediate products which in turn are produced by capital and skills. The model of this economy can be described by the following eight equations:

[3] See Griliches (1984 and 1998).

(1) $$Y = \psi F\left(K, AS\left(1-\varepsilon\right)\right)$$

(2) $$dK / dt = \sigma Y - \delta K$$

(3) $$dL / dt = \eta L$$

(4) $$dS / dt = \lambda \varepsilon L - \phi S$$

(5) $$R = \rho Y$$

(6) $$dA / dt = v\left(A^{*} - A\right)$$

(7) $$dA^{*} / dt = g^{*} A^{*}$$

(8) $$v = \mu R / \left(A^{*} L\right)$$

where the endogenous variables are:

Y	Final output (GDP)
K	Capital stock
S	Stock of skills
A	Aggregate productivity
L	Labor force (and population)
R	Technology-investment expenditures
v	Rate of innovation
A^{*}	Global technology frontier

and the parameters (all of them defined to be positive-valued) are:

ψ Productive efficiency

ε School attendance ($\varepsilon < 1/2$)

σ Saving rate ($\sigma < 1$)

δ Depreciation rate

η Population growth rate

λ Learning efficiency

ϕ Skill-adjusted death rate

ρ Research intensity ($\rho < 1$)

g^* Frontier growth rate

μ Research efficiency

The first four equations constitute a neoclassical Solow-Swan model of growth through factor accumulation, augmented to include the accumulation of skills as well as physical capital. Equation (1) represents the country's reduced-form aggregate production function, where F exhibits constant returns, concavity, and the usual Inada boundary conditions. The fraction $1 - \varepsilon$ of skills are applied to production rather than to learning, and technological progress is represented by growth in the labor-augmenting productivity variable A. Equations (2) and (3) describe net investment and population growth as in the original Solow-Swan model assuming a given saving rate σ, a given depreciation rate δ and a given population growth rate η. Equation (4) indicates that the economy's net investment of skills equals gross skill-investment minus depreciation. Gross skill-investment consists of the number of people engaged in the learning process, multiplied by a learning-efficiency parameter. Depreciation occurs through death of people embodying skills. As in the original Solow-Swan model these first four equations imply that in the long run the country's per-capital GDP (Y/L) will grow at the rate of technological progress (dA/dt) / A.

The next four equations endogenize the rate of technological progress, assuming that the country spends a given fraction of its GDP on technology investments. This fraction ρ is referred to as the country's "research intensity". Equation (6) indicates how technological progress depends on both the domestic rate of innovation v and the country's "distance to the frontier". It is similar to the technological progress function postulated by Nelson and Phelps (1966), and highlights the role of innovation in determining what Nelson and Phelps call a country's "absorptive capacity". This equation captures Gerschenkron's advantage of backwardness because the annual increase in the productivity variable A is the product of the frequency of technological innovations v and the gap ($A^* - A$) between domestic productivity and the global technology frontier.

Equation (7) indicates that the frontier grows at the given rate g^*. This and (6) together imply that if the country were to maintain a constant innovation rate v then its productivity would eventually grow at the same proportional rate as the global frontier, so that its economic growth rate (that is, the growth rate of its per-capita GDP) would converge in the long run to the global growth rate g^*.

Whether or not the country is *able* to maintain a constant innovation rate is one of the central questions to be determined by the model. The reason why this is problematical is the above-mentioned disadvantage of backwardness, which is captured in the equation (8) representing the technology of innovation. According to this equation the country's rate of innovation is proportional to its technology investments but also inversely proportional to the global technology frontier. Thus the further behind it falls the slower will be the pace of innovations.

Note that equation (8) also makes the rate of innovation inversely proportional to the size of population. This assumption nullifies the “scale” effect[4] that would otherwise make more populous nations grow faster because they have more innovators. In more detailed accounts this assumption follows from a “product proliferation” effect whereby a larger population leads to more ideas for new products, which spreads quality-improving innovations over a broader range of products thereby diluting their aggregate effectiveness.[5]

These eight equations can be simplified by the following process of elimination to result in a simple two-dimensional dynamical system. Note first that the population-growth equation (3) and the skill-investment equation (4) imply that the stock of skills per worker used in manufacturing ($S(1-\varepsilon)/\ L$) will converge in the long run to:

$$s = \frac{\lambda\varepsilon(1-\varepsilon)}{\phi+\eta} \tag{9}$$

independently of the other forces in the model. At the expense of missing some short-run dynamics, I will simplify the analysis by assuming that this convergence has already taken place.

Next, from (1) ~ (4) using (9), the law of motion governing the evolution of the capital stock per effective worker ($k \equiv K/AL$) can be written as:

$$dk/dt = \sigma\psi F(k,s) - (\delta+\eta+g)k \tag{10}$$

which is precisely the fundamental differential equation of the Solow-Swan model, where $g \equiv (dA/dt)/A$ is the rate of technological progress.

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[4] Jones (1995)

[5] Young (1998) and Howitt (1999).

Define $a \equiv A / A^*$ as the country's relative productivity. In the long-run the proportional income gap between this country and the world's technology leaders will be proportional to a. It follows directly from (7) and the definition of a that:

(11) $$da / dt = a\left(g - g^*\right)$$

and it follows from (1), (5), (6) and (8) that:

(12) $$g = \mu\rho\psi F(k,s)(1-a).$$

Substituting this expression for g into (10) and (11) yields a system of two differential equations in the two dynamic variables k, the capital stock per effective worker, and a, the country's relative productivity. The behavior of this two-dynamical system is illustrated in Figures 1 and 2 below.

FIGURE 1 HERE

In Figure 1, the curve labeled K depicts the steady-state value of the capital stock per effective worker as a function of the country's relative productivity.[6] It is upward sloping because according to (12) the larger is the country's relative productivity, given k, the slower will be its rate of technological progress (that is, as a grows the country loses some of its advantage of backwardness). As in the Solow-Swan model, a slower rate of labor-augmenting technological progress g will imply a higher steady-state capital stock per effective worker because it reduces the rate at which this adjusted capital stock is diluted by growth in efficiency units. Anywhere to the left of this curve k will be increasing, and anywhere to the right k will be decreasing.

The curve labeled A in Figure 1 depicts the steady-state value of the country's relative productivity as a function of the capital stock per effective worker.[7] It is upward

[6] That is, the solution k to the equation: $\sigma\psi F(k,s) - \left(\delta + \eta + \mu\rho\psi F(k,s)(1-a)\right)k = 0$.

[7] That is, the solution a to the equation: $\mu\rho\psi F(k,s)(1-a) = g^*$.

sloping because according to (12) the larger is the country's capital stock per effective worker, given *a*, the more income it will have to finance technology investments and hence the faster will be its rate of technological progress, which will lead to a higher steady-state relative productivity. Anywhere above the curve *a* will be decreasing, and anywhere below *a* will be increasing.

It is easy to verify[8] that the K curve is steeper than the A curve at the point of intersection ($\hat{k}, \hat{a}$). Therefore this point of intersection defines a unique stable long-run equilibrium. Every trajectory will end up being trapped in a region, either where both variables are increasing or where both are decreasing, in which all paths lead monotonically to the steady state ($\hat{k}, \hat{a}$).

Per-capita GDP in the country described by Figure 1 will grow at the same rate g^* as the global technology frontier in the long run, because its relative productivity $a = A/A^*$ has stabilized at a positive level, which is only possible if the growth rate of the numerator (the rate of domestic technological progress *g* which will be the long-run rate of economic growth) is the same as the growth rate of the denominator (which is g^*). However, there is no guarantee that the two curves *A* and *K* will intersect in the positive quadrant as depicted in Figure 1. On the contrary, it is possible that the *K* curve could lie everywhere to the left of the *A* curve, as shown in Figure 2. In this case, the unique stable steady state is the point ($\hat{k}, \hat{a}$) = ($\hat{k}, 0$) where the K curve intersects the horizontal axis.

FIGURE 2 HERE

[8] $\left.\frac{da}{dk}\right|_K = -\frac{g_k}{g_a} + \frac{\sigma\psi F_k - (\delta+\eta+g)}{k\, g_a} = -\frac{g_k}{g_a} + \frac{\sigma\psi F_k - \sigma\psi F/k}{k\, g_a} > -\frac{g_k}{g_a} = \left.\frac{da}{dk}\right|_A$, where the subscripts denote partial derivatives evaluated at the steady state, and the function g is defined by (12).

The country described by Figure 2 will not grow as fast as the global frontier, because even if its relative productivity falls to zero, the advantage that this extreme backwardness conveys on its ability to grow is outweighed by the disadvantage of backwardness described above. Instead its growth rate will be endogenously determined by local conditions according to equation (12):

$$\hat{g} = \mu\rho\psi F\left(\hat{k}, s\right) < g^* \tag{13}$$

The country's per-capita GDP will fall forever relative to that of countries with a positive steady-state relative productivity.

Thus according to Schumpeterian theory countries will divide into two convergence groups, depending on the local conditions defined by the parameters of the model. Each country in the first convergence group, described by Figure 1, will end up with a growth rate equal to g^*, the growth rate of the global technology frontier. The relative gap between it and the richest countries in the world will not grow forever but will eventually stabilize. Its relative productivity, and hence its relative per-capita GDP, will be endogenously determined in the long run by local conditions.

Each country in the second convergence group, described by Figure 2, will end up with a growth rate that is strictly less than g^*, the growth rate of the global technology frontier. Its long-run growth rate will be endogenously determined in the long run by local conditions. The relative gap between it and the richest countries in the world will grow forever, without stabilizing. Its relative productivity, and hence its relative per-capita GDP, will fall asymptotically to zero.

4. The effect of health on a country's long-run growth path

The state of health in a country will affect its growth path through various channels, in a way that depends on local conditions. The nature of these effects will depend on which convergence group the country belongs to. For example, a small parameter change in a country in group 1 will affect the long-run level of per-capita GDP relative to the world's technology leaders, without affecting its long-run growth rate, whereas the same change in a country in group 2 will affect its long-run growth rate. Moreover, a large parameter change can shift the country from one convergence group to another. This section identifies six different channels through which population health impinges on growth and analyzes their effects.

A. Productive efficiency

Healthier workers are more productive for a variety of reasons – increased vigor, strength, attentiveness, stamina, creativity, and so forth. This means that when health improves the country can produce more output with any given combination of skills, physical capital and technological knowledge. One way to think about this effect is to treat health as another component of human capital, analogous to the skill component. In the formal model above the effect would be represented by an increase in the efficiency parameter ψ that multiplies the production function in equation (1).

For a country in the first convergence group an increase in health working through this channel would have no long-run effect on growth but it would have a positive effect on the long-run level of relative per-capita GDP. Not only would there be the direct effect that raises GDP for any given combination of factor inputs but this parameter change would also lead to a higher level of capital per effective worker, exactly as in the Solow-Swan model. In addition, there would be another effect that goes beyond what the Solow-Swan model would predict. That is, because the country is now more productively efficient it will end up with a higher relative productivity level *a*, which will further raise its relative per-capita GDP.

More specifically, the steady-state capital stock per effective worker $\hat{k}$ of a country in group 1 is the solution to the familiar neoclassical steady-state equation:

(14) $$\sigma\psi F(k,s) = \left(\delta + \eta + g^*\right)k ,$$

its steady-state relative productivity is:

(15) $$\hat{a} = 1 - \frac{g^*}{\mu\psi\rho F\left(\hat{k},s\right)}$$

and its steady-state relative per-capita GDP is:

(16) $$\hat{y} = \psi F\left(\hat{k},s\right)\hat{a} ,$$

which will be increased directly by the increase in ψ, by the resulting increase in $\hat{k}$ that can be derived from equation (14), and also by the resulting increase in $\hat{a}$ that can be derived from equation (15).

For a country in the second convergence group, the improvement in health will raise the steady-state growth rate, through two different channels. First, because the economy is now more productive it will have more income out of which to finance technology investments. For a given research intensity this means a higher rate of innovation, which will raise the country's steady-state rate of technological progress (which is also its rate of economic growth) even if there is no change in its capital stock per effective worker $\hat{k}$. Second, because the increase in productive efficiency will tend to raise $\hat{k}$ this will give a further boost to growth by further raising the income out of which to finance technology investments.

In addition, if the increase in productive efficiency is large enough it will shift the country from the second convergence group to the first, allowing it finally to stabilize the relative gap in living standards that separates it from the world's technology leaders.

These effects on a country in convergence group 2 can be seen with the aid of Figure 3 below, in which the curves *K* and *G* represent the two steady-state conditions:

(17) $$\sigma\psi F(k,s) = (\delta + \eta + g)k$$

(18) $$g = \mu\rho\psi F(k,s).$$

The first is the familiar neoclassical steady-state condition for *k*, and the second is the steady-state growth equation (13) already presented above. The *K* curve is downward sloping for the same reason that the *K* curves in Figures 1 and 2 are upward sloping, namely because of the diluting effect on *k* of an increase in the steady-state rate of technological progress. The *G* curve is upward sloping because of the effect of increased capital on the country's ability to finance growth-enhancing technology investments.

FIGURE 3 HERE

An increase in the productivity parameter ψ will shift both curves up in Figure 3. The upward shift of the *G* curve is the direct growth effect of productive efficiency described above and the upward shift of the *K* curve is the indirect effect that works through capital accumulation. Both effects work to raise the steady-state growth rate. Moreover, if the increase in productive efficiency is large enough to raise the intersection point of the two curves in Figure 3 above the horizontal line at g^*, then the country will now join the first convergence group, and will eventually grow at the same rate as the world's technology leaders.

B. Life expectancy

Increases in life expectancy have a direct effect on the steady-state average skill-level of the population, by affecting the skill-adjusted death rate ϕ which constitutes the effective depreciation rate of aggregate skills, and hence affecting the steady-state level of skills per effective worker *s*, according to equation (9) above. The sign of this effect depends on its demographic incidence. If the increase in life expectancy works primarily through prolonging the lifetime of productive workers who have already formed most of their skills, then ϕ will decrease, leading to an increase in *s*. But if it works primarily through a reduction in infant mortality then ϕ may actually increase, because the average age of the population will be reduced and the average death will destroy a larger fraction of the existing stock of skills.

Suppose first that the increase in life expectancy reduces the skill-adjusted death rate and hence raises *s*. Then it will affect the country's growth path exactly like an increase in productive efficiency, except that in this case it works by raising the education component of human capital per effective worker instead of the health component. Thus for a country in the first convergence group relative per-capita income will be raised through three separate channels. In terms of equation (16) there is the direct effect of increasing *s*, the indirect effect that works through the induced increase in $\hat{k}$ and the indirect effect that works through the induced increase in $\hat{a}$. For a country in the second convergence group the effect will be to raise growth through two channels – the direct effect of having more income with which to finance technology investments and the indirect effect that works through increased capital accumulation which also raises the income with which to finance technology investments. If the increase in life expectancy is large enough this will raise the country up to the first convergence group, allowing it to overcome the disadvantage of backwardness and to stabilize the relative gap in living standards that separates it from the world's technology leaders.

Of course if the effect on infant mortality is the dominant one, and the skill-adjusted death rate increases, then all of the above effects will be reversed. In this case it is possible for a country that was in the first convergence group to fall back into the second group, no longer able to overcome the disadvantage of backwardness with its relative income falling to zero. This effect may help to account for the fact that so many poor countries that appeared to be growing as fast as the developed world in the early and mid 20th Century have had such disappointing growth performances since then.

In a more detailed working out of the theory, the effects of an increase in life expectancy would go beyond the direct effect on the parameter ϕ. In particular, by lengthening the time horizon over which the return to saving and to education can be earned, an increase in life expectancy is likely to raise the saving rate σ and the enrolment rate ε. The increase in the saving rate will work much like the increase in productive efficiency studied under A above. For a country in the first convergence group it will raise relative income by increasing the steady-state capital stock per effective worker, as in neoclassical theory, and also by the positive effect on the country's relative productivity induced by the increased capital accumulation. A country in the second group will enjoy an increase in growth, because of a rightward shift of the K curve in Figure 3, which induces more growth by raising the income out of which technology investments are financed. If large enough the increase in saving will allow the country to shift into the first convergence group, with a growth rate equal to that of the world's technology leaders.

All of the effects of an increased saving rate will be reinforced by the increase in the enrollment rate, which works by changing the steady-state level s of skills per effective worker, with exactly the same effects as a decrease in the skill-adjusted death rate ϕ as described above.

C. Learning capacity

Health plays an important role in determining the rate of return to education. Children who are well nourished, vigorous and alert will gain more from a given amount of education that will children who are malnourished and suffering the debilitating effects of disease. In terms of our formal model this effect shows up as an increase in the learning-efficiency parameter λ. The effects are the same as the above-analyzed effects of an increase in the attendance rate ε and a decrease in the skill-adjusted depreciation rate ϕ. In all cases the parameter change works by raising the steady-state level s of skills per effective worker. For a country in the first convergence group relative per-capita income will be raised through three separate channels. In terms of equation (16) there is the direct effect of increasing s, the indirect effect that works through the induced increase in $\hat{k}$ and the indirect effect that works through the induced increase in $\hat{a}$. For a country in the second convergence group the effect will be to raise growth through two channels – the direct effect of having more income with which to finance technology investments and the indirect effect that works through capital accumulation which also raises the income with which to finance technology investments. If the increase in learning efficiency is large enough this will raise the country up to the first convergence group.

In addition to these effects, anything that raises the steady-state level of skills is likely to have a further effect that works through the country's innovation technology.

That is, to the extent that innovation is a more skill-intensive activity than production, we would expect that the increase in learning efficiency would induce an increase in the research-efficiency parameter μ, and that it would also lead the country to allocate a larger fraction of its resources to the activity of innovation, which would mean an increase in the research-intensity parameter ρ.

Both of these additional parameter changes would work in the same way, because only the product $\rho\mu$ matters for determining the steady-state values of a, k and g. Thus for a country in the first convergence group the combined increase in the efficiency and intensity of research would raise the steady-state value of relative productivity, through equation (15) above, which would raise the country's relative per-capita income according to equation (16). For a country in the second convergence group the growth curve G in Figure 3 would shift up, resulting in a higher steady-state growth rate, which if large enough would allow the country to join the first convergence group and stabilize the relative gap in living standards separating it from the world's technology leaders.

These same additional effects would follow also from the increase in life expectancy studied under *B* above, in the case where it led to an increase in skills per effective worker.

D. Creativity

One of the benefits of good health, especially good childhood health and good maternal health, is that it tends to make a person more creative.[9] Just as a healthier person will be more efficient in producing goods and services, so will the person be more efficient in producing new ideas. In other words, one of the effects that one would expect

[9] The neural pathways involved in this connection are discussed at some length by McCain and Mustard (1999, ch.1).

to come from an improvement in the state of health in a country is an increase in the research-efficiency parameter μ that affects the country's ability to generate innovations. As discussed under *C* above this would also likely raise the equilibrium research intensity ρ, and the combined effect of the two increases would be to raise relative productivity and relative per-capita income in a countries in the first convergence group, and to raise steady-state growth in a country in the second convergence group, possibly allowing it to joint the first group.

E. Coping skills

Another benefit of improved childhood health and maternal health is that young people develop a better ability to cope with stress, and hence to adapt to the frequently disruptive and stressful effects of rapid technological change.[10] One simple way to capture this effect in the above model would be to make the productive efficiency parameter ψ a decreasing function of the rate of technological progress *g*, and to suppose that improved health shifts this function, resulting in more productivity for any give value of *g*. The long-run effect of this shift would again be an increase in relative per-capita GDP for a country in group 1, an increase in growth for a country in group 2, and a shift of some countries from group 2 to group 1.

In more elaborate versions of Schumpeterian theory[11] the ability of workers to adapt to technological change can be shown also to raise the equilibrium research intensity ρ. The idea is that when workers are more adaptable then innovators will face a bigger payoff to creating fundamentally different new technologies to which workers will have to adjust. One could also imagine various labor-market and political-economy

[10] This benefit is emphasized by McCain and Mustard (1999).
[11] See Aghion and Howitt (1996 and 1998, ch.6).

channels through which this might work. For example, unions whose members have an especially hard time coping with new technologies will be especially prone to bargain for featherbedding contracts that make it difficult for a firm to implement new processes; such contracts obviously discourage process innovations. Likewise voters who lack coping skills will tend to support politicians promising to protect such unions and promising to use other means of blocking disruptive technological progress.

Taking these effects into account implies that an improvement in health that raises the coping skills of a population will affect a country's growth path by raising the research-intensity ρ. This would reinforce the effects of improved coping skills that work through productive efficiency. For as we saw above under *C* above the long-run effect of increased research intensity would also be an increase in relative per-capita GDP for a country in group 1, an increase in growth for a country in group 2, and a shift of some countries from group 2 to group 1.

F. Inequality

Empirically there is a strong negative correlation between various indicators of population health and measures of income inequality.[12] Although the causal interpretation of this correlation is still an open research question, many measures that increase population health will also result in reduced inequality because their main impact will be on the least privileged members of society and on those for whom poor health would otherwise make them relatively less well off.

Reduced income inequality is likely to have a positive impact on a country's growth path. The main effect that has been analyzed extensively in the growth literature

[12] The evidence is surveyed critically by Deaton (2003).

works through credit-market imperfections and school attendance.[13] That is, in some countries even though there might be a high rate of return to education many people are unable to take advantage of this high rate because of financial constraints. A reduction in inequality, even if it leaves average income unchanged, will raise the fraction of people able to finance an education and will lengthen the years of schooling of those able to afford some. This effect works even in countries with widely available public education systems involving no tuition costs, because for many parents the main economic cost of sending a child to school is the income that the child would otherwise have earned for the family.

Thus by reducing income inequality an improvement in population health will impact on the above formal model through an increase in the school attendance parameter ε. As we saw in *C* above, the long-run effect of increased school attendance would also be an increase in relative per-capita GDP for a country in group 1, an increase in growth for a country in group 2, and a shift of some countries from group 2 to group 1.

Moreover, according to much sociological and epidemiological research on the health effects of SES gradients,[14] there is likely to be a positive feedback effect of reduced inequality on health. This effect has been challenged on empirical grounds by Deaton (2003), but there is no reason to think that there will be a negative feedback effect. Thus if there is any feedback at all it will probably serve to amplify all of the positive effects of improved health on growth and relative income identified under headings *A* through *E* above.

[13] Galor and Zeira (1993); Aghion, Caroli and García-Peñalosa (1999).
[14] Wilkinson (1996 and 2000).

5. Conclusion

In summary, we have laid out a simple version of recent Schumpeterian growth theory that allows us to identify and analyze six different channels through which an improvement in a country's population health will impact on its long-run growth performance. With one possible exception these effects all work in the same direction. Specifically, they will raise the productivity and per-capita GDP (both relative to the world technology leaders) of a country that is sufficiently well off to be growing at the same rate as the world technology leaders, they will raise the growth rate of per-capita GDP in a country whose growth rate is below that of the technology leaders, and they will allow some countries finally to stabilize the relative gap in living standards that separates them from the technology leaders. The one possible exception is an increase in life expectancy, which can work so as to reduce average skill levels in the population if it operates mainly by reducing the rate of infant mortality.

The main effects that Schumpeterian theory brings out and which were not present in either neoclassical growth theory or the earlier (AK) version of endogenous growth theory are those that work through the equilibrium rate of innovation. The effects on creativity and coping skills are especially important. In this respect, Schumpeterian theory underscores the importance of recent research showing the beneficial effects that early childhood health and maternal health have on these critical dimensions of human capital.

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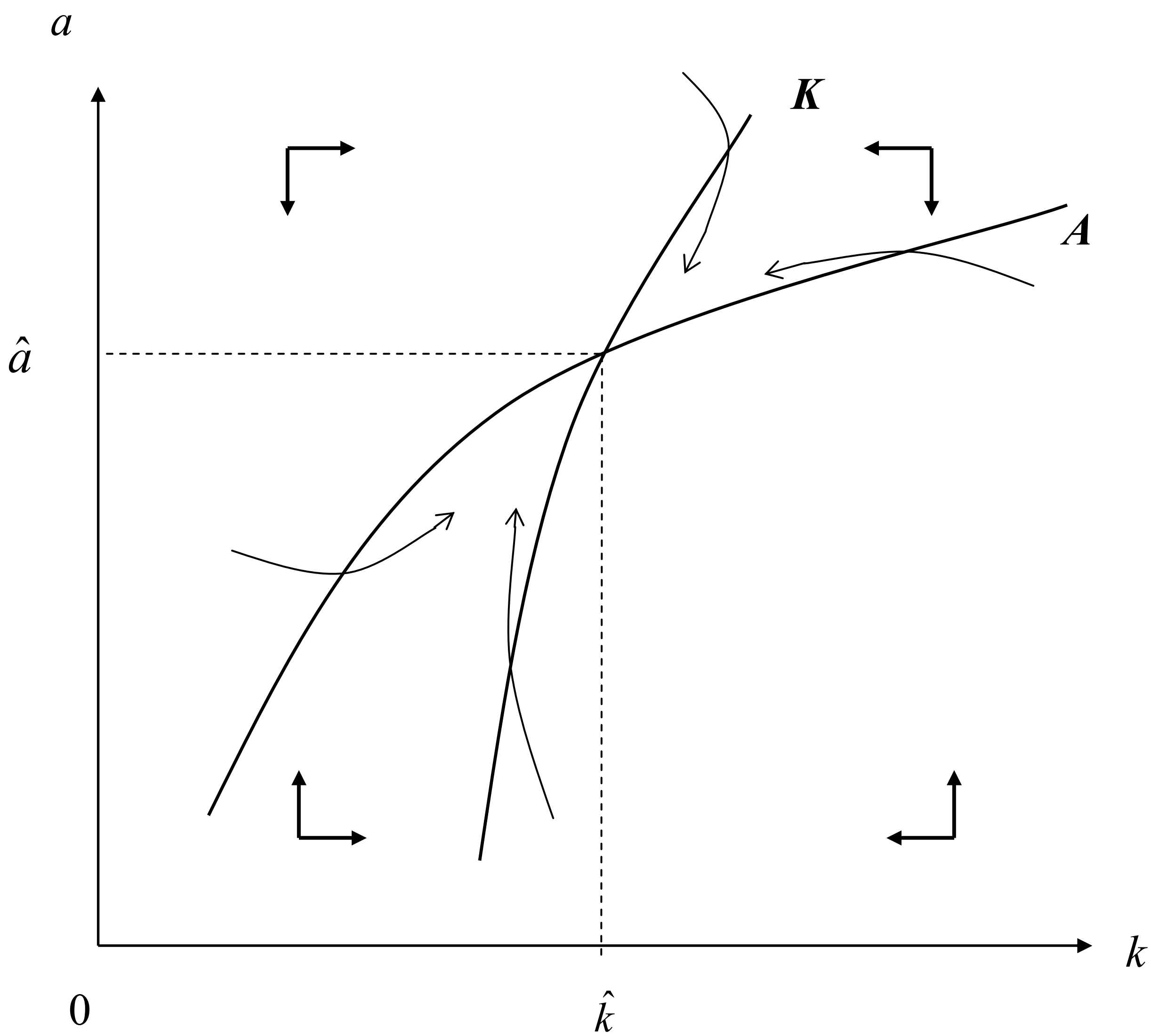

Figure 1: The dynamics of a country in the first convergence group, with a steady-state growth rate equal to g^*, the growth rate of the global technology frontier.

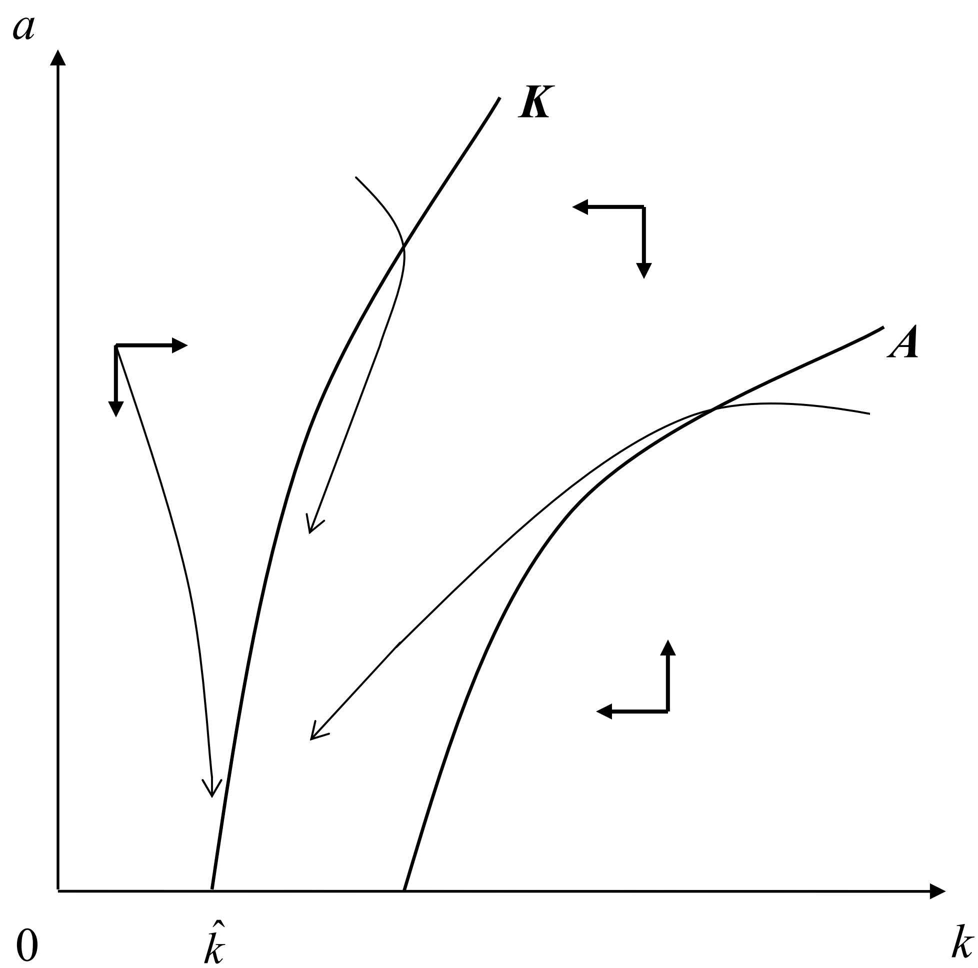

Figure 2: The dynamics of a country in the second convergence group, with an endogenous steady-state growth rate strictly less than g^*, the growth rate of the global technology frontier.

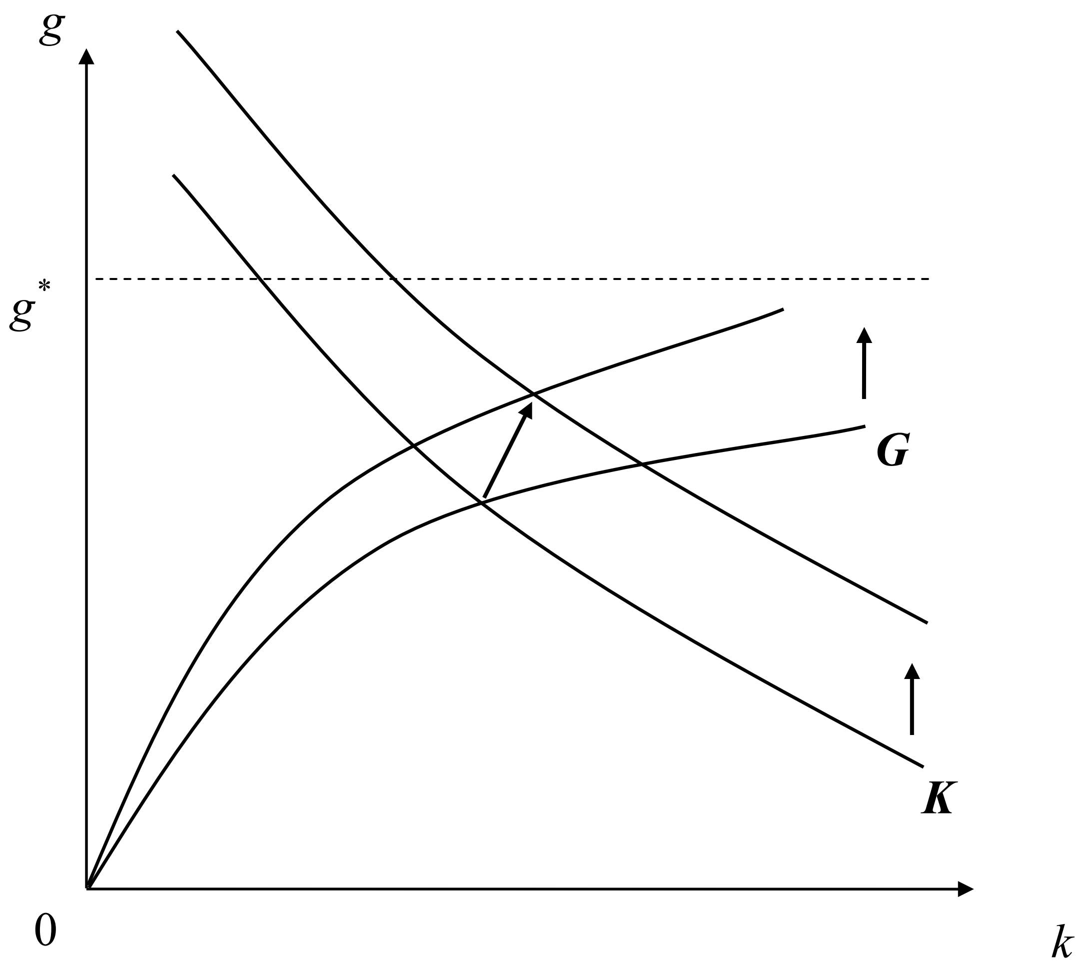

Figure 3: The effects of an improvement in health, working through enhanced productive efficiency, on a country in the second convergence group.