# Technology, Human Capital, Growth and Institutional Development: lessons from endogenous growth theory?

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ABSTRACT: This paper provides a discursive review of seminal contributions to endogenous growth theory. It explains the source of the central findings to emerge from endogenous growth theory as well as the main policy implications of alternative new growth theories. The paper ends by considering the need for a reconsideration of the interaction of economic and political institutions in the light of the new growth theory.

# 1 Introduction

The resurgence of interest in the determinants of economic growth through the vehicle of endogenous growth theory has brought with it new understanding of what underlies long term economic prosperity. In particular, the role of human capital as an important driver of technological change and hence development has emerged as a key factor.

While endogenous growth theory has had a considerable impact on economics, the impact of the insights to emerge from this work in other social sciences is presently somewhat more limited. One reason for this is that the debate amongst economists has often been technically arcane, precluding ready access to non-initiates to the relevant mathematical technique.

Such a lack of interaction between endogenous growth theory and other social sciences, perhaps particularly political science, is unfortunate since the areas of potentially fruitful interaction are potentially of importance to our understanding of long term developmental prospects of social systems. Indeed, economic and political theory have already evidenced a very fruitful if controversial interaction in the form of modernization theory, positing the possibility of a link between economic and political development.[1] Given the new insights to emerge from endogenous growth theory it would seem that the possibility for a renewed period of possible interaction between political and economic theory presents itself. Traditional growth theory relied on exogenous technological advance. Political institutions can therefore dynamically interact only with the level of output of the economy - and indeed this is precisely what is to be found in "traditional" approaches to modernization theory. Allowing political dynamics to interact with either the level of output or with the nature of the technology of production leads to the potential of a richer depiction of the process of development - see Fedderke (2001) for a fuller discussion.[2] The new departures in growth theory, by endogenizing technological progress thus holds the possibility of a range of new insights.

Toward this end, the present paper has two objectives. The first is to make some of the seminal contributions to new growth theory accessible in a non-technical discursive discussion of its core features and implications. The second is to conclude with a set of deliberations on what the implications for a possible interaction between political and economic theory might be.

[1] For a more extensive discussion of aspects of this literature, see Fedderke (1997).

[2] Fedderke, De Kadt and Luiz (2001b) offers an empirical application of the approach to the case of South Africa.

The objective of the first section of the present paper is therefore to consider alternative conceptions of the source of technological progress propounded by economists. In the second section we consider some possible implications for further work, though the discussion in this paper can be no more than indicative of possible lines of further enquiry.

# 2 Core Explanations of a Growth-Technology Nexus

## 2.1 Endogenous technological change: the perfect university view

We begin with the most "obvious" hypothesis, that technological change depends on the magnitude of resources devoted to it. In Shell (1966) technological progress depends on the amount of resources devoted to inventive activity. Shell argues that the change in technology per unit of time will be positively affected by the resources devoted to knowledge creation, while knowledge is subject to "depreciation", as old forms of technology face obsolescence. Thus technological change can be represented by a differential equation given by:

$$\frac{dA}{dt} = \sigma\alpha(t)Y(t) - \beta A(t) \tag{1}$$

where $A$ denotes the level of technology, $\sigma$ denotes a "research success" coefficient (i.e. how likely it is that research will result in useable technological advance), $\alpha$ the proportion of output devoted to research and development (R&D), $Y$ output, and $\beta$ the rate of decay of technology. Thus the suggestion is that technological progress will depend explicitly on the resources devoted to the advance of knowledge. One might think of this as the resources devoted to R&D, and the more resources devoted to R&D the faster knowledge will advance, subject to the research success coefficient.

An alternative proposition to the one formulated above would be to suggest that the change in knowledge is related not to the resources devoted to it, but to the level of knowledge that we have already attained. The more we know, the more we are able to add to the stock of knowledge. This is effectively the principle that motivates the formation of institutions such as universities. Agglomerating individuals with superior access to knowledge, and providing resources such as libraries which store the accumulated knowledge from the past is meant to improve the process of transmitting already existing knowledge to new initiates, and to accelerate the augmentation of technology by making it easier to research. Thus we would have:

$$\frac{dA}{dt} = \sigma\alpha(t) A(t) - \beta A(t) \tag{2}$$

with the same notation as before.

It turns out that the simple distinction drawn between these two alternative knowledge creating processes carries with it profound differences. Most salient is that within the context of standard growth models the first knowledge creating process will eventually cease to generate new knowledge. By contrast, under the second specification knowledge will increase indefinitely, and this perpetual knowledge growth will be a source of unbounded growth in output.

The point of significance that emerges from this approach to technological change is that the *source* of technological change may not be neutral in terms of its impact on long run steady state. While the proposition that technological change requires resources may be uncontroversial at this most generic of levels, the imprecation of the preceding exposition is that understanding the precise nature of such resources and their impact on growth lies at the heart of coming to understand economic growth.

## 2.2 Endogenous technological change: knowledge spillover effects, or learning by doing

New growth theory received perhaps its most often cited impetus through the work of Paul Romer, notably Romer (1986). The argument presented in Romer (1986) revived insights which Arrow (1962) had already formalized - the possibility that the very process of being engaged in a productive activity generates learning effects, allows those who are engaged in productive tasks to become more efficient at performing them. Romer (1986) makes the crucial assumption that the process of investing in physical capital has the effect of creating knowledge which the firm undertaking the investment cannot internalize: it becomes available to all firms in the industry.[3]

[3] For some useful reflections on some potential limitations that attach to Romer's twist on Arrow's approach, see Solow (1997). Solow extends the discussion to a case in which learning by doing is bounded. On a prior approach to bounded learning by doing see Young (1993).

The assumption has two important components: the process of learning-by-doing, and the view that such learning will be available to all firms in an industry. To the existence of learning-by-doing is added the additional presumption that any knowledge gains obtained from the process of production and investment cannot be internalized by the firm in which that knowledge-creation takes place. Thus the learning spills over to become available to all labour, and all producers in the economy.[4] With spill-over effects, the suggestion is that knowledge production is an inadvertent side-product of all production and investment activity, and would thus take place whether firms wish to undertake it or not, as long as they are engaged in their standard productive activity. While in the tradition of the Shell hypothesis of resource-driven technological change, the resources here are investments in physical capital which generate inadvertent technology spill-over.

In the Romer model the effect of knowledge spill-over is to ensure that the efficiency of the labour input at the social level will improve.[5] The consequence of this is that the production function comes to show increasing returns to scale at the social level, even though the production function of each firm remains homogeneous of degree one.

The crucial difference between the Romer "new" growth model and traditional growth models relates to the nature of the capital stock in the economy. Once social returns to scale in capital are constant, it immediately follows that the marginal product of capital becomes constant also. As a consequence, in the Romer model the incentive to invest does not change with a rising capital labour ratio, since the marginal product of capital and hence the profit rate are constant. As a consequence, there is no incentive for the economy to ever "slow down" once it has started to expand.

One advantage of the Romer model is that it is able to account for the failure of poor countries to catch up with rich countries. Since the incentive

[4] An illustration of the potential significance of spill-overs is given by Landes (2000). Contrast the strong attempts to control the dispersion of knowledge concerning the construction of time pieces in China (2000:30), and the effects of the strong guilds in much of Europe (France and Augsburg in particular) (2000:222ff), with the relatively free circulation of ideas and expertise in Britain (outside London) (2000:231f). Britain won the ensuing contest.

[5] The effect is essentially to increase the growth rate of the *effective* labour force - with echoes of Harrod-neutral technological change. What is explicit here is the *source* of this technical change. Note also that here the creation of human capital is *consonant* with technological change. In Romer (1990) we will see that technological change is the *consequence* of human capital.

to invest does not decline with rising per capita capital stock the growth rate of the capital labour ratio and of per capita output does not change either. As a consequence, there is no reason why countries which have high per capita output should grow any slower than countries which have low per capita output, such that there is no inherent tendency toward catch-up as is present in traditional growth models.

However, it is important to realize that the source of the non-declining incentive to invest here rests on the failure of the marginal productivity of capital to decline with a rising capital stock. The reason for the constant marginal product of capital is the knowledge spill-over effect which attaches to the process of adding to the capital stock. In the first instance, a necessary condition for this to be feasible is that knowledge have public good characteristics. That is the act of investment is automatically seen to increase the effective labour force throughout the economy. There is no labour hour whose productivity is not improved. This is clearly a very strong assumption to make. But not only is the assumption particularly strong, it is also critical to the result. As Dasgupta and Stiglitz (1988) demonstrate, even partial excludability of the knowledge spill-over effects has the effect of destroying the result. Moreover, not only are knowledge spill-overs within countries potentially imperfect, but Barro and Sala-i-Martin (1995) demonstrate that while capital and technology may move between regions, the rate of diffusion is not instantaneous, but takes time. Hence the public good characteristic of technology on which the result relies is questionable. While capable of accounting for the failure of poor countries to catch up with the rich, the result is sensitive to the characteristic underlying assumptions of the model.

To the extent that we accept the model, however, it carries with it clear policy implications. Since knowledge has pure public good characteristics, in the sense that spill-over effects are non-excludable, the consequence is that investors do not have the opportunity to internalize the full marginal benefits which attach to a piece of capital equipment. At least some of the benefit leaks away to increase labour efficiency throughout the economy. The consequence will be private sector under-investment in capital, such that investment will not reach the point where the social marginal product of capital is equal to the social marginal cost of capital. Investment will cease at a point where the private marginal product of capital equals the private marginal cost, such that the social marginal product remains above social marginal cost. The appropriate policy intervention is that government subsidize purchases of capital goods, or subsidize production, raising the return on investment, and hence the incentive to invest.

In effect, the objective would be to raise the private marginal product to the level of the social marginal product of capital through government intervention, thereby increasing the inducement to invest, until the point of equality between social marginal product and cost of capital is attained.

## 2.3 Endogenous technological change: the intentional creation of new knowledge through R&D[6]

Despite the attention that Romer (1986) has received in the literature, in one sense the contribution continues to have affinity with traditional growth theory. What is new is that technological change has an explicit origin (in investment in physical capital stock) as it does not in Solow (1957) say. But in another sense technological change continues to "just happen" as a by product of intentional activity directed not at technological change itself, but at a quite different productive activity. The expectation is of a reward not from technological change *per sê*, but from the act of investment in physical capital. Even the most cursory consideration devoted to the advancement and transmission of knowledge both by the public sector (see universities and the RAND corporation for instance) and the private sector (R&D expenditure of pharmaceutical and software companies for instance) is an indication of the fact that such an understanding of the source of technological progress must have strong limitations. Indeed, any pure public goods conception of knowledge will struggle to account for intentional private sector devotion of resources to the advancement of knowledge.

The obvious question to ask is why nobody treats the production of new technology as an intentional human activity- which is purposefully engaged in with the view of making a profit? In short, surely technology is the outcome of real people who decide to "just do it" rather than something that "just happens" to humans. And surely they "just do it" because rewards attach to the activity of invention.

The answer to this question is the theme of the Schumpeterian tradition in economic growth theory.[7] Perhaps the most famous modern instantiation

[6] One might cite the famous Newtonian statement of "If I have seen further it is by standing on the shoulders of giants." (Isaac Newton, letter to Robert Hooke, 5 February 1675/6) as a succint synopsis of the argument that follows in this section.

[7] See for example Schumpeter (1943: Chapter VII).

is the contribution by Romer (1990). The crucial move in the argument in terms of the economics of the model is that knowledge is no longer treated as a (pure) public good. Under the public goods knowledge spill-over approach it is impossible to explain why any rational agent would spend resources on developing new technology. Since no one can be excluded from accessing the newly developed technology, they cannot be charged for its use, and inventors of the new technology would thus not be rewarded for their trouble. In order to make it possible for rational agents to undertake *purposeful* innovation of technology, it is necessary to allow technology to be a private good. That is, at least to some extent inventors of new ways of doing things have to be able to exclude other economic agents from employing their inventions, or at least they have to be in a position to charge, be rewarded for what they do. It is this proposition that underpins contributions to the technological progress debate in the Schumpeterian tradition.

Romer (1990) proceeds by relaxing the assumption that knowledge be a public good. Instead he replaces it with the assumption that knowledge is a mixed good, with both public and private good characteristics. The assumption is now that technological change has Schumpeterian characteristics, in the sense that agents consciously engage in technological change and innovation, responding to market incentives as they do so, and the only reason they do so, is that they are now in a position to internalize positive net marginal benefits from undertaking innovative activity.

Technological progress now becomes a response to the promise of economic reward for innovation. On the other hand, knowledge is not held to be a pure private good either, in the sense that to some extent it will be non-rival. Once it exists, the marginal cost of allowing another agent to use that knowledge would be zero. However, since access to knowledge is excludable, agents who have control over knowledge will no longer be price-takers, but have monopoly power over the innovations they initiate. In effect we will have monopolistically competitive markets in the economy. The consequence is that the social marginal return to knowledge will exceed the social marginal cost of knowledge, and as in the case of knowledge spill-over effects the private sector of society will underinvest in knowledge. In contrast to the knowledge spill-over model though, where the policy prescription was for production and investment subsidies, here the policy implication will be for subsidies to the production of knowledge.

In order to understand why knowledge might have both private and public good characteristics, we can distinguish between two different forms of knowledge. The first, *human capital*, is both rival and excludable. Human capital also has a limited life: once the human bearer of that human capital dies, the human capital depreciates to a value of zero instantaneously. The second, *technological design*, is nonrival, since once created a design could be made available to other potential users at zero cost. On the other hand it is excludable, in the sense that private, profit-maximizing firms will seek to keep exclusive use of any design innovations they have funded. Such excludability may take the form of trade secrets guarded from industrial espionage, and more formally patents forcing any user of a design innovation to pay for its use. By contrast to human capital, design can be accumulated indefinitely - once a design is in existence, the rate of depreciation on the design is zero. In terms of this conception human capital is a pure private good, while technological design by contrast is a mixed good, with both public and private good characteristics.

In the full Romer (1990) model the economy produces research output, intermediate goods (capital) as well as final output for the purpose of consumption. For our present purposes we can focus on the relatively simple process governing the production of research output. Production of design output (new technology) uses simply human capital and the accumulated stock of human knowledge, the sum of all previous designs in existence. We can "know" patents, and in particular the principles and insights that they embody, even where we are excluded from actively using them in production. As such, the principles and insights embodied in patents are available to researchers to further their production of knowledge.

The production of knowledge is thus very simple:

$$\frac{dA}{dt} = \delta \cdot H_A \cdot A \tag{3}$$

where $H_A$ denotes the human capital employed in the production of knowledge (as opposed to employed in the production of final goods), $A$ denotes the accumulated stock of knowledge, and $\delta$ denotes a productivity (research success) factor.

We should note that there are two elements here: the use of human capital in knowledge creation, but explicitly devoted *to* knowledge creation. As the Romer model makes explicit, the human capital resources could equally well have been used for the purposes of producing final output. Knowledge accumulation depends *both* on agglomeration effects (in $A$) *and* on the resources (of the specific $H_A$ variety) devoted to knowledge accumulation.

Technological advance takes place not because of "money" being thrown at the problem.[8] The requirement is for focused deployment of the very specific resource of human capital being devoted to it.

The implications of this knowledge production function are important. Implicit within the above process is the view that the development of new designs or blue-prints is not subject to indivisibilities or uncertainty, such that an increase in the inputs into the production of designs will increase the number of designs continuously. Explicitly, as the human capital input into knowledge production rises so the production of knowledge will increase also. From equation 3 the proportional growth rate of knowledge is determined by $\delta \cdot H_A$. More human capital devoted to research will increase (permanently) the growth rate of technology in an economy. Further, as the stock of knowledge rises, so the time rate of knowledge production will rise also - effectively the more productive the research sector worker becomes.[9] Knowledge production is technology- and human-capital intensive, with no reliance on either capital or "unskilled" labour. As long as $\delta > 0$, technology will grow without bound.

We should note explicitly that the formulation of the knowledge production function is important. The linearity of the production of designs and technology in the already existing stock of knowledge is what makes unbounded growth possible. In effect, the assumption is analogous to the introduction of a constant marginal product of capital in the knowledge spill-over model we examined in the preceding subsection. Here the relevant marginal product attaches to the human capital employed in the production of knowledge, a new factor of production in the production function, but again the ultimate effect is that production becomes subject to increasing returns to scale, such that the growth of the economy will become unbounded. The fundamental implication is that opportunities for knowledge creation never die out.[10]

[8] By which is meant resources in a generic sense.

[9] Since $\frac{\partial\left(d\dot{A}/dt\right)}{\partial H_A} = \delta A$.

[10] In implying that the opportunities in research never die out, the introduction of the knowledge production function is crucial, and deserves some closer justification. Romer (1992) argues that virtually any production process may be improved virtually indefinitely. By way of example he notes that the horseshoe, a technology almost 2000 years old, was still having patents registered in 1920. Considering the nature of production processes this is not all that surprising. For instance, in a mixture with a total of N elements, the total number of different possible mixtures is given by $2^{N-1}$, leaving aside different

The model goes on to demonstrate that under these circumstances, the growth in output in the long run will come to equal the growth rate in technology, which we have already seen to be will come to be given by $\delta H_A$. Since human capital can be used either in the production of new technology or in the production of final output, this implies that the more human capital is employed in final goods production rather than "research" into the advancement of knowledge, the lower will be the long run growth rate of output in the economy. Moreover, it is also possible to show what drives the allocative decision of human capital between knowledge production and final goods production. In particular it turns out that:

$$\frac{\dot{Y}}{Y} = \delta H_A = \delta (H - H_Y) = \delta H - \Lambda r \tag{4}$$

where $H$ denotes the total economy wide stock of human capital, $H_Y$ is the human capital devoted to final goods production, $Y$ denotes output, and $r$ denotes the interest rate. The higher the interest rate the more human capital comes to be allocated to final goods rather than knowledge production.

The most immediate implication that follows from this finding is that the growth rate of output and the interest rate are inversely related. As the interest rate rises, so the present value of the future discounted revenue from research falls, such that less human capital comes to be allocated to research, and ultimately the growth rate of output falls.

Second, subsidies on physical capital do not serve to foster growth as they did in the Romer (1986) knowledge spill-over model type.[11] The reason for this is that while in the Romer (1986) model endogenous growth in technology

possible proportions. The implication is that for $N = 100$, the total number of mixtures approximates to $10^{30}$. To all practical intents and purposes this renders the total number of combinations inexhaustible, and allows for virtually unlimited innovation in the use of chemicals and other elements. This inherent unknowability of the universe finds expression in the "shake & bake" branch of chemistry, which proceeds less on the basis of exhaustive theoretical deliberation, and more by trial and error in the development of new materials. The reasoning extends to other production processes. For instance, in a factory with 52 production steps, the total number of sequences for the steps amounts to 52!, or approximately $10^{68}$, a "big" number even by comparison with $10^{30}$, again suggesting that the possibilities for innovation are certainly substantial even in relatively simple contexts.

[11] Neither the marginal cost of physical capital nor the labour input appears in the growth rate of output. The reason for this in the context of the present model, is that an increase in labour input, or a decrease in the marginal cost of physical capital serves to increase the equilibrium level of physical capital, in so doing increasing the return on human capital employed in both the production of final output and in the production

emerged from positive externalities which attached to investment in physical capital, in the Romer (1990) model endogenous growth in technology emerges from a separate research sector which draws on human capital rather than on physical capital. It is human capital, and specifically human capital engaged in the production of new knowledge, that is the source of increasing returns to scale. Investment in human capital employed in knowledge production not only serves to increase the production of knowledge, but in doing so expands the range of physical capital which is at the disposal of producers of final output.

A further result of this finding is that there exists a scale effect in human capital, due to the increasing returns that attach to research. The greater is the stock of human capital within the economy, and the greater is the proportion of total human capital employed in knowledge production, the higher the growth in output will be. This conclusion suggests a potential barrier to growth, which serves as a possible poverty trap for the economy. Where the stock of human capital employed in knowledge production is too small, the growth in knowledge may in turn be too small to justify the sacrifice in current output required for allocating human capital to knowledge production. In effect, human capital can simply not be spared from production in order to undertake research, thus limiting the most important single long term determinant of growth. We thus have a low-level trap in output, and one that may well be applicable particularly to the African context.

A further potential barrier to growth which emerges from the Romer (1990) model is that the private sector will systematically under-invest in knowledge production. Since knowledge production is non-rival but excludable, the private marginal costs of acquiring blue-prints will lie above the social marginal cost. The socially optimal level of research is thus higher than what the private market will deliver. Private markets will deliver less human capital, less production of knowledge than is socially optimal.

There is a second reason why we might anticipate market failure within the context of the present model. Research producers generate a new product in the form of new forms of physical capital which are purchased by a sector that acquires patent rights in the use of the new capital. In so doing they

of knowledge. In the present model these effects cancel, leaving the allocation of human capital across the two sectors unaffected (this result is sensitive to functional form). The most general conclusion as regards the effects of growth in the labour input, and changes in the marginal cost of capital, is thus that they are ambiguous within the context of the present model.

acquire monopoly power in the use of the physical capital, and hence engage in monopoly pricing. The consequence is that the market price of the output produced by means of the physical capital will lie above the marginal cost of production. Again, the result will be a socially sub-optimal allocation of resources, with an underproduction of output.

The policy prescription that emerges from these forms of market failure is that the underproduction of research below the socially optimal level must be counteracted. The prescription is not a subsidy on physical capital, but a subsidy on human capital, and particularly human capital engaged in research and development.

A last implication that emerges from the model, is that there are advantages to be realized from increased international integration. As economies begin to integrate, so the total stock of human capital at their disposal will increase also, generating a higher growth rate of output for the composite set of economies. Thus, in terms of the Romer (1990) model, it is not the size of the market in terms of labour that matters, but the human capital content of the market that is crucial to the long-term growth prospects of a set of markets.

## 2.4 A direct impact of human capital on economic growth?

In the endogenous growth models encountered thus far the introduction of technological change had the effect of generating increasing returns to scale, such that the growth process became such that the economy does not move to steady state, but instead experiences unbounded growth. In the case of the Romer (1990) model unbounded growth is the result of the role human capital plays, particularly in terms of adding to the physical capital stock through the innovative activity of the research sector of the economy.

But the introduction of human capital need not have unbounded growth as a consequence. On the contrary, human capital can be successfully introduced into a traditional growth model of the economy,[12] maintaining the salient features of a neo-classical growth model, particularly convergence to steady state. Mankiw, Romer and Weil (1992) suggest that the introduction of human capital into a Solow model is justifiable, indeed desirable, since by 1969 in excess of 50% of the capital stock of the USA took the form of

[12] Of the Solow (1956 and 1957) variants.

human rather than physical capital stock. Moreover, they argue that the introduction of human capital into the Solow model successfully enhances its explanatory power to such a degree as to preclude the necessity of resorting to endogenous growth models of either the Romer (1986) or (1990) variants.

In making this argument they suggest that all that is required is the introduction of human capital as an additional factor of production over and above physical capital and labour inputs. This renders the production function augmented to:

$$Y = F(K, L, H) \tag{5}$$

where $Y$ denotes output, $K$ capital, $L$ labour and $H$ human capital.[13] The implication is that output can grow due to augmentation of human capital stocks as well as augmentation of physical capital, labour and technology. In assessing the explanatory power of the hypothesis Mankiw, Weil and Romer (1992) consider:

$$\ln\left(\frac{Y}{L}\right) = \beta_1 \ln s + \beta_2 \ln h - \beta_3 \ln g_L \tag{6}$$

where $\frac{Y}{L}$ denotes per capita output, $s$ the savings rate in physical capital $\frac{S}{Y}$, $g_L$ the proportional growth rate of the labour force, and $h$ the per capita stock of human capital. The question of significance is the improvement of the explanatory power of the specification contained in equation 6 over a specification with a zero restriction on $\beta_2$.

The implication Mankiw et al draw from their empirical results is that the human capital augmented Solow-model, despite its simplicity, accounts for a significant proportion of cross-country variation in per capita output. They argue that the strength of the empirical evidence has to be accepted as forceful evidence in favour of the model - and that recourse to endogenous growth theory, given all the complexity it often introduces, may simply not be necessary.[14]

[13]The presumption is of $F_K > 0$, $F_{KK} < 0$, $F_L > 0$, $F_{LL} < 0$, $F_H > 0$, $F_{HH} < 0$. Note that while the standard presumption is of homogeneity of degree one, this need not be binding.

[14]Further tests for the direct impact of human capital can be found in Barro (1997,2001), Goldin and Katz (2001), for instance.

## 2.5 Further extensions: back to endogenous growth and some additional lessons

Emphasis on the role of human capital in growth is one of the innovative features of the new growth theory. It is worthwhile briefly to revisit contributions we might expect from human capital to economic growth through the endogenous growth framework. Partly, this is in order to remind ourselves of the differences between it and the proposal put forward by Mankiw et al., but also in order to add some nuance to our understanding of the impact of human capital on growth within the endogenous growth framework.

In the Romer (1986) spill-over type of endogenous growth models human capital creation is simply the consequence of the positive externality that is associated with the act of investment in physical capital stock. While learning-by-doing is the vehicle by which the learning effects that are attached to the act of investment in physical capital stock are transmitted amongst firms, the origin of the human capital remains rooted in physical investment. That was why the policy prescription that emerged from this approach to understanding technological progress was to recommend subsidies on physical capital, in order to counteract the fact that the social marginal rate of return lay above the private marginal rate of return to physical investment.

But in a further (though independent) extension of the spill-over approach to endogenous growth, Lucas (1988) proposed a production function for output that captures very similar ideas to those proposed by Romer, but capable of generating some important additional nuance. The production function suggested by Lucas can be represented by:

$$Y = AK^{\beta} \left[uhL\right]^{1-\beta} h_A^{\gamma} \tag{7}$$

where $Y$ denotes output, $A$ the state of technology, $K$ capital, $L$ labour, where the actual labour time at the disposal of the economy is now adjusted for the level of human capital it embodies, $h$, as well as the proportion of time $u$ it devotes to the production of current output. While production is constant returns to scale, the possibility of increasing returns (as in the Romer model) is introduced through the impact of the generally available human capital, $h_A$, to the economy. Indeed increasing returns are present as long as $\gamma > 0$. Two implications make this model particularly interesting. Lucas suggested that human capital growth in an economy could be represented by:

$$v = h\delta \left(1 - u\right) \tag{8}$$

where $v$ represents the growth rate, $\delta$ a success coefficient, and $[1-u]$ represents the portion of time the existing stock of human capital is allocated to the creation of additional human capital rather than being employed in the production of final output. The reason why this formulation turns out to be interesting is that one can show that the final growth rate of the economy will be determined by $v$, the rate of growth of human capital creation. Moreover, the growth will turn out to be unbounded, even in the absence of increasing returns to scale, because of the implied growth in the effective labour force of the economy. The result is analogous to the unbounded growth due to technological progress in traditional theories of economic growth, but now with an explicit recognition of the motor force behind this growth in the process of human capital formation.

The second reason for our interest is that where we also have increasing returns to scale in production ($\gamma > 0$), the implication is that the usual consequence of economic theory, that the rate of return to factors of production will be highest where they are scarcest, will be reversed. Instead, the implication is that the rate of return to human capital will prove to be the highest where it is most abundant. In the presence of labour mobility, the implication is that labour well endowed with human capital will migrate to centres already intensive in human capital, simply because the rewards of doing so are large.

If this is the case the policy implications for developing countries are profound. It implies that if a country is behind in the accumulation of human capital it is likely to remain forever behind. Countries ahead in the growth race will steadily out-accelerate any lagging country. But worse, if a developing country tries to rectify matters by improving investment in human capital, such human capital is simply likely to emigrate away. Already wealthy countries will stand to benefit from the hard investment undertaken by the poor country - and accelerate away even more rapidly thanks to the poor country's efforts.[15] The situation for poor countries is doubly perverse. They are poor because poorly endowed with human capital. But the policy intervention designed to rectify the situation, of saving in order to be able to invest in education, merely serves to benefit the already rich, enabling them

[15] On this view therefore openness of the economy may allow human capital to migrate away from developing to developed countries. Openness under this view carries serious dangers for developing countries. However, without ameliorating the danger for human capital accumulation, Barro and Sala-i-Martin (1995) demonstrate that greater openness may bring advantages to both technology innovating and imitating countries.

to accelerate their growth yet further.

Thus if human capital matters to growth, and if increasing returns to human capital are indeed present, poor countries face the tough task of having to keep the environment for skilled people at home even more attractive than otherwise would have been the case. Policy intervention must be conscious of the need to improve the incentive for human capital to stay, rather than leave.

The theory thus far has come to imply that increasing returns to scale in human capital may lead to perverse international allocation of human capital. But this unfortunate international allocation of human capital may well be exacerbated by further counterproductive intranational human capital allocation. Recall that the Romer (1990) conception of the interaction between growth and technology also generates a low income level trap. In this model we have a sector dedicated to the creation of knowledge using human capital as an input, but with human capital also used in the production of final output. The difficulty for developing countries is that at low levels of human capital accumulation, there may simply not be the critical mass of human capital to generate sufficient returns from the pursuit of new knowledge. As a consequence human capital will come to migrate to final goods production rather than new knowledge production, simply because the return there is higher. The consequence is that more developed nations, with their ability to create new knowledge will come to forge ever further ahead of developing nations.

Thus developing nations are potentially caught in two vicious cycles that result from the impact of human capital on long run economic performance. The one results in an unfavourable international allocation of human capital away from developing nations to developed nations. And the other ensures that what human capital remains in developing nations may not be allocated to where it has the most dramatic long term impact.

Either way policy makers face demanding challenges in ensuring that incentives in developing economies are such as to ensure that human capital not only remains at home, but that if it so remains, that it is most productively employed.

Two final points are worthy of emphasis in the context of endogenous growth theory and its view of human capital. First, if the increasing returns emphasized during the course of our discussion do indeed attach to the human capital dimension, then the implication is not only that human capital should be core to any developmental strategy. It also implies that potentially significant indivisibilities attach to the impact of human capital on long run growth. If returns to human capital are increasing, the return to ever higher levels of education and training should be increasing also. Again on the proviso that the increasing returns are indeed present, policy should then pay attention to its human capital creation strategy as a totality. It is no longer simply a question of sorting out primary and secondary education. Tertiary education must become part of the most basic developmental human capital creation programme. Thus the implication is that if countries concentrate only on a "partial" human capital creation strategy, the pay-off may be considerably less dramatic than if a more holistic approach is adopted. Indeed, in the limit there may be very small, perhaps even negative returns to human capital in a partial human capital creating approach, since critical mass levels of human capital are not breached.

But the second point is equally instructive. Given the presence of the two perverse traps pointed to above, care must be taken in interpreting evidence on human capital formation and its impact on economic growth. A negative association would in fact not serve to prove the absence of a positive impact of human capital creation on economic growth. Instead, it may simply be pointing to the presence of one or both of the two traps we have identified. Under these circumstances creation of human capital would simply come to represent a drain of resources on poor countries, with benefits that migrate to developed nations.

## 3 So are there *technological* limits to political development?

The preceding discussion has considered the means by which technological progress may come to be generated over time, and its impact on long run economic development. A common theme to the discussion has been that technological progress is resource-dependent - though different approaches posit different resources as relevant to technological change. We have also already remarked in the introductory section to this paper that modernization theory thus far implicitly has not been able to take into consideration the nuance that emerges from endogenous growth theory. Instead, the link between political and economic development is postulated as more brute and direct, between the level of per capita resources available to citizens and the nature of the political processes.[16] What the preceding discussion should alert us to is that the conception of technological progress can carry profound consequences for the form of political development that becomes feasible. One might be tempted to add that failure to consider this nuance might underlie at least some of the ambiguity that modernization theory has encountred in empirical application.

Space constraints dictate that the discussion here can be only indicative. But one can identify at least three distinct issues that would arise as the subject of more intensive research projects.

The first and most immediate concerns the likely impact of the alternative forms of endogenous evolution of technology identified above on institutional development. The question here is whether it is matter of indifference or not for purposes of political development whether technological progress is Shell, Romer-86, Lucasian, Schumpeterian, or Mankiwnian. One answer might be that the *source* of technological progress is a matter of indifference - what counts is the fact that technological progress and associated welfare improvements leads to the sort of political progress that Lipset (1959) might have argued for. But it is at least equally plausible that alternative sources of technological progress might have quite distinct political consequences. For instance, where technological advance is the outcome of inadvertent spillovers that emanate from processes of investment in physical capital stock, pressures for democratization might be hypothesized to attach to the formation of a working class associated with the process of industrialization. Pace and direction of political developments might therefore be dictated by the pace of physical capital formation in the economy. By contrast, one might hypothesize that political progress associated with technological progress that is human capital intensive might take somewhat different form (though whether Lucasian, Schumpeterian or Mankiwnian human capital intensive development would make a difference here, is not so clear). Here the pace and

[16] Of course this is an abstraction of a more complex debate. In Lipset (1959), for instance, the suggestion is that the demand for democratization has an income elasticity greater than unity (in effect on a Maslowian hierarchy of needs argument), meaning that rising per capita GDP will generate ever increasing demand for political rights. Moreover, economic development leads both to an expanding middle class and increased importance of activity in the private as opposed to the public sector, both of which are argued to increase pressure for democratization. The greater nuance does not alter the fundamental proposition that the links cited are between the expanding per capita resource base of the society and political development directly. Fedderke (1997) contains greater detail on these points.

direction of political development would be dictated by human capital investment, rather than physical capital investment. It is worth noting that the distinction between the two types of interaction between technological progress origins and political development are directly testable at least in principle. The question would be whether political development was linked statistically significantly to physical capital accumulation, or human capital investment.[17]

A second question that arises concerns whether the sort of political development is likely to be influenced by the nature of the technology augmenting process that prevails. In short, is the *qualitative* nature of political developments likely to be different under a physical capital rather than human capital intensive technological trajectory?[18] Since the one is likely to be reliant on the development of industrial working and middle classes, and the other on the development of a wide human capital base in society, it would seem plausible to suppose that the trajectories would differ. But how, and why precisely would seem to be questions that would be both of interest, and for which political scientists would be best placed to provide suitable answers.

Third on the list of issues is the question of how sensitive the interaction between human capital investment and political development is to the form of human capital investment? Does it matter for processes of political progress whether the investment in human capital focuses on human capital widening rather than deepening? Does it matter whether the investment targets primary, secondary and tertiary education sequentially or in concert? Or whether education is biased toward literary, social or scientific skills? Does the mix between academic and vocational training exercise any influence on processes of political development? I am not sure what the answers to these questions might be, nor of how they might best be tackled - again they seem best suited to the tool kit of the political scientist rather than those of economics. But it would again appear at least plausible that important differences might emerge between different forms of human capital investment, with potentially crucial consequences for the long term developmental

[17]The availability of data from Freedom House on political rights indexes for countries around the world makes this a feasible undertaking. For South Africa, Fedderke, De Kadt and Luiz (2001a) would supply suitable data over a much longer time run.

[18]By way of example, the discussion in Wood (2000) is suggestive of the possibility that the particular constellation of physical capital formation and the associated impacts on labour markets is crucial in understanding the South African democratic transition.

prospects for society.

Focus of the first three questions posed here has been on how alternative sources of technological progress might come to have differential impacts on political progress. Should the questions prove meaningful, the important implict implication is that the nature of technological progress may come to generate at least some degree of path dependency in political development. Unless the answer to all of the questions posed in the preceding paragraphs is negative, it would appear that one of the sources of the uniqueness of political development in any society is attributable to the particular mix of physical and human capital intensity of knowledge augmentation, as well as the particular form human capital investment takes.

A second set of questions relates to the possibility of feed-back from political and social institutions to the process of technological development. The work of Landes might be argued to represent a series of demonstrations of the importance of political and social institutions for the purposes of technological innovation. What emerges from Landes (1998) is that a series of institutional features are identifiable that are important for long run economic development. The fundamental point of these institutional features is that they regulate the form that a number of functional relationships crucial to long run development take. These functional relationships concern (a.) access to existing stocks of knowledge, (b.) transmission of knowledge to the future, (c.) incentive mechanisms based on merit, (d.) creating space for entrepreneurship, and (e.) defining sound property rights[19] to ensure that the fruit of innovation is internalized by the innovator. All of these relate to what I have elsewhere termed the institutionalized learning capacity of society.[20] The learning capacity of societies has seen a considerable improvement during the course of the last few centuries. Moreover, the improvement is not coincidental, but depends at least in part on an improvement of a number of institutions. Autonomy of intellectual enquiry, reliance on precise observation, description, replicability and verification that underpins scientific method in order to provide a means to challenge received authority and to settle debate, the routinization and generalization of learning and literacy, systematic means of storing and retrieving knowledge, sound property rights including intellectual property rights are all important institutional characteristics that account in part for our accelerating knowledge accumulation.

[19] On this see also the discussion in Rosenberg (1982:11f).

[20] See the discussion in Fedderke (1999) for more detail on this and the following points.

We now all too readily take for granted the existence of a stock of knowledge and of skilled, trained human capital on which knowledge accumulation depends (the $A$ and $H$ of the endogenous growth models). Yet history carries the useful warning signal that not only has the current scale of this phenomenon only recently emerged, but also that societies have often contrived to squander their lead over rivals by compromising the institutional foundations of their technological leadership outlined above.[21]

The questions of how, why and to what effect political and social institutions come to influence processes of technological innovation emerge from such concerns.

Fedderke (2001) represents one attempt to begin to address some of the questions posed here more formally. Two important conclusions emerge from the analysis. First, the nature of the steady state (if any) that emerges is very sensitive not only to the nature of the interaction between technology or output and the institutional structure of the society, but also to the precise strength of any such association. It is possible either for there to be a steady state for both economic and institutional development, or for unbounded growth to emerge in both dimensions. Moreover, the possibility of low-level poverty trap steady states lurks also. Second, a consideration of the international evidence reveals that considerable heterogeniety emerges between countries in terms of the nature of the link between economic development and political institutions. Societies are not all on the same developmental trajectory - the evolution and interaction of political institutions and economic activity differs between countries.

## 4 Conclusions and Evaluation

The development of endogenous growth theory has led to a more varied and deeper depiction of the processes that issue in technological progress. This paper has provided an overview of some of the seminal contributions to the endogeneous growth literature, and drawn out some of the central implications that emerge for development.

We have seen that technological progress itself depends on resources - though the literature has emphasized that different factors of knowledge production may play a role. Human capital devoted to knowledge creation, accumulated stocks of knowledge, spill-overs from physical capital augmen-

[21]See for instance Landes' (1998) discussion of the Chinese and Iberian experiences.

tation, all receive attention as potential sources of innovation. We have seen that these distinct sources of innovation carry distinct policy implications. Specifically in the case of human capital driven technological progress we saw the emergence of a danger of low level equilibrium traps that allocate human capital intra- and internationally so as to impair developmental prospects.

An important additional consequence of the new growth in growth theory is that some old questions surrounding the interaction between political and economic development are rekindled. The greater nuance that emerges for our understanding of processes underlying economic growth forces reconsideration of how evolutionary trajectories in political institutions might thereby come to be affected. But equally, how political and social institutions in their own right might come to shape the shoulders on which stand current attempts to advance the frontiers of knowledge.

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