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Technology, Human Capital and Growth

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Abstract

ABSTRACT: The paper examines whether endogenous growth processes can be found in middle income country contexts. Estimation proceeds by means of dynamic heterogeneous panel analysis. Empirical evidence finds in favour of positive impacts on total factor productivty growth by Schumpeterian innovative activity. A crucial finding is that it is the quality of human capital rather than the quantity of human capital that is important for TFP growth. We also find that human capital is both influenced by, and determines the institutions of society that serve to determine the long run productivity of all factors of production.

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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 potential explanation of economic growth.

Economic theory has pointed to two potential channels through which human capital may influence growth. The first is an indirect channel, by which human capital enables technological progress. On this view, without dedicated activity devoted to the process of generating new ideas in the anticipation of economic reward, innovation will not take place, or at least take place at a much slower rate. In addition, human capital is viewed as vital in being able to absorb technological advance that may take place elsewhere. Given that technological progress may come to be the most important long-run driver of economic growth, especially as economies reach the developmental frontier, in the long-run this source of human capital's impact on growth is the most invariant, and potentially the largest impact human capital can have on economic development. The second channel by which human capital impacts on development is more straightforward. Here human capital is a direct factor of production, that is capable of contributing positively to output generation much like physical capital, or labour hours. On this view there is no mystery to the positive impact of human capital - it is simply a good thing to have around in order to be able to produce more effectively.

Both propositions are of course presented with considerable variation and nuance in the literature. But the fundamental propositions have immediate intuitive appeal, and hence it is not surprising that the importance of human capital has become a central tenet of the debate on the determinants of economic development. Yet the empirical literature on the impact of human capital on growth is mixed. On the one hand, there is almost universal acceptance of microeconomic findings that there are strong economic returns to education at the level of individuals. Surprisingly therefore, the macro-evidence delivers divergent results. While early cross-country studies showed a positive, statistically significant, and often strong impact from school enrollment rates on economic growth, a second wave of studies, often focussing on stocks of human capital rather than flows, reported empirical results that suggested that the impact of human capital on growth was zero at best - potentially even negative. A third class of empirical investigations has begun to investigate the relative robustness of these two sets of findings. While supporting a positive impact of human capital on growth (in some instances tentatively so), this literature has also pointed to three crucial methodological considerations for studies examining the human capital - growth nexus.

The first methodological point suggests that the rate of return to education at the macro level may not coincide with private rates of return, since education may be serving as a signalling device for some underlying unobservable characteristic of agents, rather than imparting improved skills to the recipients of the education.[1] Under these circumstances, social returns to education would lie below private returns, explaining the divergence between macro- and micro-level findings. A second set of concerns has arisen with respect to the consistency with which educational attainment is measured across countries. A number of studies have suggested that measurement error in this dimension is both severe, and pervasive. Correction for such error reverses the finding of macro insignificance of education for economic growth, and confirms a positive impact according to these studies. Finally, some studies have suggested that failure to distinguish between the quantity and the quality of human capital will again serve to bias the impact of human capital downward.

In a related but distinct class of studies, emphasis has been placed on the institutional grounding not only of investment in physical capital, but for investment in human capital also. An influential study[2] points to the importance of "social infrastructure" not only in determining the productivity of physical and human capital in growth, but in dominating the determination of growth directly. Subsequent work has suggested that "social infrastructure" is itself not exogenous to the process of economic development, and that human capital and education themselves play a central role in determining the form and efficiency of the "social infrastructure" of an economy.[3] From a crucial determinant of technological innovation, human capital in effect comes to be postulated as a determinant of the most fundamental institutions of society, which in turn determine the productivity of all factors used in production.

Given this context, the present paper undertakes three tasks.

In the first, we provide a broad overview of the international theoretical and empirical literature concerning the impact of human capital on growth. Considerations of space and parsimony necessarily dictate that the review is incomplete, though the intention is to identify the main channels of influence of human capital, and associated empirical findings.

Second, we present new empirical findings on the impact of human capital on technological innovation, paying close emphasis to the distinction between quantity and quality of human capital by employing a new data set.

Third, we examine in greater detail the possibility of an interaction between social institutions and human capital investment, taking seriously the possibility of simultaneity between the two.

An innovation of the paper is that it employs long time runs in all relevant dimensions from a specific middle income country, South Africa, using both industry panel

[1] Human capital is of course a more inclusive concept than simply education. However, most empirical studies are restricted to the measurement of education, so that education and human capital are often conflated and used interchangeably in the literature. This paper transgresses similarly.

[2] Hall and Jones (1999).

[3] See Glaeser et al (2004) and Djankov et al (2003).

data and aggregate time series data. This approach has two advantages.[4] First, it avoids in substantial measure the concern about cross-country differences in the measurement of educational attainment. Second, our interest is of course in general principles governing the impact of human capital on development. Using an individual country case study may seem a strange place to look for confirmation of general results. But where general laws genuinely hold they must be evident not only in aggregate, but in particular instances also. Study of particular cases are useful since they allow for circumstances and factors that may be idiosyncratic to the specific instance under study to be controlled for with a degree of precision that is not feasible for aggregate cross country studies. As a consequence, the threat of parameter heterogeneity that plagues cross-country studies,[5] dissipates, and the fundamental relationship of interest (growth-human capital say) may emerge with greater precision than in cross-country studies.[6]

The paper begins with an overview of the relevant theoretical background. Section three reviews the related international empirical evidence. In section four, the empirical model employed in the tests for human capital impacts on technological progress is developed. Section five reviews the data and econometric methodology, while section six presents the estimation results on the endogenous growth model. In section seven we explore the possible existence of an interaction between human capital and institutions. Section eight concludes.

2. Theoretical Background

Postulating a link between economic growth and technology is not new. Adam Smith's example of the production of pins under different degrees of labour specialization, demonstrates the growth potential associated with improvements in the technology of production. Better techniques of production lead to more output under the same input of capital and labour into the production process. Economists have

[4] Use of South African data is useful for a third reason. The literature has disputed whether economic growth can be primarily attributed to capital accumulation or growth in total factor productivity. For South Africa the evidence suggests that the transition from capital accumulation to TFP-efficiency gains had taken place by the 1990's, by which point TFP was the single most important contributor to South African growth. See Fedderke (2002). Investigating the determinants of TFP-based growth is thus of clear relevance to South Africa, allowing us to avoid the controversy of the relative importance of TFP and investment in machinery and equipment.

[5] For a technical discussion of the consequences of heterogeneity in the context of panel studies, see Pesaran et al (1999).

[6] An analogy may be helpful here. Both feathers and boulders are subject to the laws of gravity. But dropping them anywhere but in a vacuum would generate motion that is widely divergent, sufficiently so to render the derivation of the law of gravity difficult from associated "panel" evidence, since all relevant factors determining the objects' motion are difficult to control for exhaustively. Since in the social sciences we cannot, in general, conduct experiments which control for all factors affecting economic growth, a useful way to isolate general principles is to pay close attention to the unique features of the object under study, in order to isolate the general principles.

long recognized the link in their formulation of production functions, which make output (denoted by Y) depend on capital (K) and labour (L) inputs, as well as on technology (A):

$$Y = F(A, K, L) \tag{1}$$

Such a formulation allows us to detail the impact of technological change.[7] But equally, detailing the impact of technological change does not explain its source.

The most "obvious" hypothesis is that technological change depends on the magnitude of resources devoted to it. Under this conception, technological advance is effectively a "good" like any other, that can be produced by allocating the appropriate inputs to inventive activity (research and development or R&D for short). In place of a mysterious creative black box, we have mundane production lines for producing new ways of doing things - ideas if you will. Again, the link between the production of ideas and the resources devoted to their generation has been present in economic theory for some time.[8] A simple representation of the link might be given by:

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

where σ denotes a "success" coefficient, X denotes the resource employed for R&D purposes, α the proportion of the resource base devoted to R&D, and β 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 (R&D). The more resources devoted to R&D (i.e. the greater is α) the faster knowledge will advance, the final rate of advance being determined by the magnitude of the research success coefficient (σ).

Which raises the crucial question of what the fundamental resource base relevant to technological advance might be. Two generic answers, which we will encounter in various guises and in various modulations in what follows, is that the X-factor is either the general command over resources (such as, but not restricted to output) or the stock of accumulated knowledge itself.[9]

In what is one of the most often cited origins of new growth theory, Romer (1986), the hypothesis is that the very process of being engaged in a productive activity generates learning effects, which allows those who are engaged in productive tasks to become more efficient at performing them.[10] This is combined with the assumption

[7]Neoclassical growth theory specified in detail the impact of neutral, capital- and labour-augmenting technological change from the outset. See for instance Solow (1957). Allowing for vintage effects on capital stock followed soon after. See for instance Solow (1960) and Nelson (1964), and the discussion in Hulten (1992).

[8]The simple formal representation below is essentially that of Shell (1966), but there may well be antecedents.

[9]The distinction is important. For instance, Shell (1966) demonstrated that the distinction in the framework provided by (2) leads to either existence (where $X = A$) or non-existence (where $X = Y$) of steady state for the economy.

[10]This revives insights which Arrow (1962) had already formalized.

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.[11] Thus the learning-by-doing spills over to become available to all labour, and hence all producers in the economy.[12] With spill-over effects, the suggestion is effectively that knowledge production is an inadvertent side-product of production and investment activity, and is embodied in the human capital of the workers engaged in production. Technological advance through the human capital accumulation of the workforce thus takes place whether firms wish to undertake it or not, as long as they are engaged in their standard productive activity. While in the spirit of resource-driven technological change, the resources here are investments in physical capital which generate inadvertent technology spill-over.[13]

While the Romer (1986) conception of technological change does identify an explicit origin (investment in physical capital stock) of technological change, strictly speaking 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 (universities 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 be incomplete at best, and potentially misleading at worst. There is simply no means by which we can account for any *intentional* devotion of resources to the process of advancing knowledge in the expectation of economic reward.

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[11] 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).

[12] The consequence is that the production function shows increasing returns to scale at the social level, even though the production function of each firm remains homogeneous of degree one. Once social returns to scale in capital alone are constant, it follows that the marginal product of capital becomes constant also. As a consequence, the social (as opposed to private) incentive to invest does not decline with a rising capital labour ratio, since the marginal product of capital and profit rates are constant. Given only the appropriate policy intervention (subsidies to investment in physical capital stock), the prospect of unbounded growth emerges. Dasgupta and Stiglitz (1988) emphasise the sensitivity of the result to the public goods nature of the learning.

[13] An alternative formulation of the spill-over approach to endogenous growth is given by Lucas (1988), which proposes a production function represented by:

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

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. β, $1-\beta$, and γ are coefficients. While the model generates some important nuance to the Romer model, here we note only the explicit recognition of the motor force behind growth in the process of human capital formation.

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 here is how to treat the production of new technology as an intentional human activity- which is purposefully engaged in with the view of realising a rate of return.

The answer to this question is the theme of the Schumpeterian tradition in economic growth theory. There exist a number of important contributions within this approach, seminally including Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992). While here we follow Romer (1990), the principles illustrated are generic to the Schumpeterian approach, and henceforth we refer to this type of model as the RGHAH class of models. The crucial aspect 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 *qua* 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 have private good characteristics, so as to allow innovators to internalize the pay-off from innovation. Accordingly, in Romer (1990) knowledge is a mixed good, is constituted by both human capital inputs, which are both rival and excludable, and the stock of knowledge, which is non-rival but excludable due to the existence of intellectual property rights in blue-print designs. In Romer (1990) the production of design output (new technology) uses simply human capital and the accumulated stock of knowledge, the sum of all previous designs in existence, such that:

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

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 δ denotes a productivity (research success) factor.[14] 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 given by $\delta \cdot H_A$, so that 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.[15] Knowledge production is technology- and human-capital intensive, with no reliance on either capital

[14]Thus (3) is effectively (2) with the resource base given by both knowledge, and human capital. Implicit within the 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.

[15]Since $\frac{\partial(dA/dt)}{\partial H_A} = \delta A$.

or "unskilled" labour.[16] Finally, it is worth noting that as long as $\delta > 0$, technology will grow without bound.[17]

A further result of RGHAH-type models is that there exists a scale effect in human capital. 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. Jones (1995) and Kremer (1993) dismiss this scale effect as incompatible with the empirical evidence. They suggest that the RGHAH class of models is unnecessarily restrictive in an ad hoc sense, because in:

$$\frac{dA}{dt} = \delta \cdot H_A^{\lambda} \cdot A^{\phi} \tag{4}$$

they impose $\lambda = \phi = 1$ with little justification, implying a rate of return on previous knowledge and human capital devoted to innovation that is not only very specific, but empirically unjustifiable.[18] More plausible, they argue, is both $\lambda < 1$, and $\phi < 1$, with the consequence that balanced growth paths for the economy reemerge.[19] Nevertheless, while the Jones-Kremer modulation lowers the rate of return on human capital and knowledge in knowledge production, the resource base from which knowledge production proceeds remains unchanged from the RGHAH class of models, and remains in the broadly Schumpeterian mould of identifying knowledge and human capital as the source of innovation.

[16]The appropriate policy response here is again related to market failure. A potential barrier to growth is that the private sector will systematically under-invest in knowledge production, since the private marginal cost 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. 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 second potential barrier to growth arises where the stock of human capital employed in knowledge production is so small, that 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. We thus have a low-level trap in output, and one that may well be applicable particularly to the African context.

[17]We should note explicitly that the linear specification of the knowledge production function, and the implied constant marginal product of human capital in knowledge production ($\partial \left(\frac{dA}{dt}/A\right)/\partial H_A = \delta$, $\partial^2 \left(\frac{dA}{dt}/A\right)/\partial H_A^2 = 0$), is crucial to the unbounded growth implication that follows from the model. The linearity assumption is analogous to the introduction of a constant marginal product of capital in the knowledge spill-over model, again with the effect of production subject to increasing returns to scale. The fundamental implication is that opportunities for knowledge creation never die out. While some authors, for instance Jones (1995) and Kremer (1993) find this implication implausible, Romer (1992) argues that virtually any production process may be improved virtually indefinitely - citing examples from horseshoe technology, shake-and-bake chemistry and production steps in factories.

[18]In the developed countries the post-World War 2 period has seen a rising proportion of the labour froce devoted to R&D activity, without comparable increases in TFP growth.

[19]The policy prescription of wage subsidies to labour engaged in knowledge production is robust to the changed specification, however.

But the recognition of the importance of human capital need not be restricted to a role in endogenous knowledge production, in either of its Romer (1986) or RGHAH class variants. Instead, human capital can be successfully introduced into a traditional neoclassical growth model of the economy as an additional factor of production. This approach simply recognizes that human capital is itself a productive factor of production, which should therefore be recognized as a driver of growth. Thus Mankiw, Romer and Weil (1992) suggest that the introduction of human capital into a Solow model is justifiable, indeed necessary, since by 1969 in excess of 50% of the capital stock of the USA took the form of human rather than physical capital stock. This renders the production function augmented to:[20]

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

The implication is that output can grow directly due to augmentation of human capital stocks as well as augmentation of physical capital, labour and technology. This stands in marked contrast to the indirect effect of human capital that we have encountered thus far through the augmentation of the effective labour force in spillover models through investment in physical capital, or the growth in technology due to human capital devoted to research.

Economic theory has thus recognized two explicit channels that allow human capital to influence economic development. A direct channel, in which human capital is a direct factor of production, contributing directly to output, and an indirect channel, in which human capital serves as a stimulus to technological change.

3. Reviewing the International Empirical Evidence

The hypothesis that human capital is a potential determinant of economic growth has received considerable attention from researchers examining the empirical evidence on growth.

With mixed results.

The evidence can be separated into four distinct classes.[21]

The rapid proliferation of empirical growth studies during the course of the 1990's generated a wide range of cross-country studies that found a relatively strong association between school enrollment (as a proxy for human capital investment) and long-run economic growth performance. Barro (1991) found significance for both primary and secondary school enrollment rates. Mankiw et al (1992) conclude from their evidence that the human capital augmented Solow-model, accounts for up to 80% of cross-country variation in real per capita GDP. These results have been replicated many times, including in Barro (1997, 2001), Barro and Sala-i-Martin (1995), and

[20] 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.

[21] In most of these classes there exist many studies generating evidence similar to that reported below. For the sake of parsimony, only a few typical studies are cited.

Goldin and Katz (2001) to cite a few examples. Given that cross-country growth studies gained some notoriety in terms of the lack of robustness of their results, the fact that Levine and Renelt (1992) found the human capital variables they employed (school enrollment rates) to be second only to investment in physical capital in robustness, was often cited as further confirmation of the role of human capital in economic growth.

The second class of studies provides countervailing evidence. Despite wide-spread acceptance of microeconomic evidence demonstrating a strong rate of return to education in terms of earnings in developing countries, a range of studies found that the evidence at the macro-level was weak, absent, or even pointed to a negative impact of human capital accumulation on economic growth. Examples here include Benhabib and Spiegel (1994), Bils and Klenow (2000), Pritchett (2001), Easterly and Levine (2001) Easterly (2001), and Temple (1999).

An obvious question is then how such divergent results can be accounted for.

In a third class of empirical papers, the approach provides a sort of meta-analysis, assessing the contribution of a wide range of potential growth determinants, including their robustness to alternative specifications of the growth equation, and sample period. Sala-i-Martin et al (2004) employ a Bayesian averaging of classical estimates approach to assess the impact of 67 potential growth determinants the literature has identified.[22] Of these 18 are found to be significantly and robustly related to growth, three weakly so, and the remainder (46) are found to be insignificant determinants of growth. Of the significant and robust determinants, primary schooling is found to be the second most important.

Bosworth and Collins (2003), in examining the impact of human capital on growth, point to three possible reasons for the divergence of the micro- and macro-evidence. The first, is that social and private returns to education may diverge where education is primarily a signal for unobservable characteristics, rather than a process of skills-enhancement for the recipients of education.[23] Second, data measurement issues arise due to the large variation in the classification of educational attainment, even across the OECD, and all the more so across wide ranges of economic development. De La Fuente and Domenéch (2001) show that the impact of education on growth is considerably strengthened when data is adjusted so as to standardize attainment across countries. Finally, and crucially for Bosworth and Collins, macro-evidence may diverge from micro-findings since cross national variation in education quality is likely to be considerably greater than intra-national variation, implying that educational quality must be controlled for in growth studies. Thus Hanushek and Kimko (2000), controlling for a cross-country quality index based on international tests in maths and

[22] This work represents an extension of the earlier extreme bounds analysis of Sala-i-Martin (1997).

[23] This is also one of the reasons Pritchett (2001) advances for his findings. He adds the possibility that the marginal returns to education may fall where demand for educated workers is stagnant, and that under perverse institutional environments human capital may be attracted to socially unproductive uses, such as rent-seeking.

science find a strong impact on economic growth emerging from educational quality. Bosworth and Collins (2003) confirm the impact of the quality of human capital - though the impact dissipates where the quality of government institutions is also controlled for, suggesting that educational quality may simply be a proxy for the quality of wider public institutions, rather than that of human capital *per sê*.

In the fourth and final class of models, institutions are explicitly modelled as the ultimate long-run determinants of capital accumulation, human capital efficiency and productivity. In Hall and Jones (1999), the fundamental role is attributed to social infrastructure.[24] They find that output per worker in the five richest nations to be 31.7 times higher than output per worker in the five poorest countries in their sample. Differences in the capital-output ratio contribute a factor of only 1.8 to this difference, since investment rates are only 2.9 times higher in the rich countries. Differences in human capital per worker contributes a factor of 2.2 to the rich-poor difference, since education is only 8.1 years greater in the rich than in the poor nations. Even accounting for differences in the capital-output and per capita human capital endowments between rich and poor countries, therefore still leaves the citizens in the richest countries 4 times better off than those of the poorest nations. Productivity differences between the countries therefore contribute a factor of 8.3 to the rich-poor differential. In their empirical findings, their index of social infrastructure proves a significant determinant not only of physical capital accumulation, and of human capital accumulation, but of productivity differences between countries directly. Their claim is that once measurement error is corrected for, differences in social infrastructure account for a 25.2 fold difference in the output per worker between rich and poor nations. New evidence further suggests that the quality of social infrastructure itself may come to be determined by human capital, thus deepening the potential impact of human capital on long-run economic development. The empirical findings of Glaeser et al (2004), echoing the theoretical propositions advanced by Djankov et al (2003), confirm that both the institutional and productive capacities of societies are shaped by human and social capital endowments. Causality may thus be multidirectional between human capital creation and institutional structure.[25]

While results for the impact of human capital are therefore subject to some divergence, the implications of the meta-evidence, as well as findings that locate human

[24] "By social infrastructure we mean the institutions and government policies that determine the economic environment within which individuals accumulate skills, and firms accumulate capital and produce output. A social infrastructure favourable to high levels of output per worker ... gets the prices right, so that ... individuals capture the social returns to their actions as private returns." (Hall and Jones, 1999: 84).

"By social infrastructure we mean the institutions and government policies that provide the incentives for individuals and firms in an economy. These incentives can encourage productive activities such as the accumulation of skills or the development of new goods and production techniques, or those incentives can encourage predatory behaviour such as rent-seeking, corruption, and theft." (Hall and Jones, 1999: 95).

[25] Hall and Jones (1999) estimate under instrumental variables, in part to avoid this trap.

capital investment within a wider institutional context, suggest that education does matter for economic growth, though the relevant channel of influence may have to distinguish between different qualities of human capital.

4. Testing for Endogenous Growth Effects

Since endogenous growth theory posits that human capital exercises its influence on the efficiency gains associated with technological innovation, the first step of analysis must be the measurement of these efficiency improvements. This is often accomplished by means of the computation of total factor productivity growth (TFP). A useful overview of the computation of TFP growth is provided by Barro (1998). While there are undoubtedly a number of limitations that attach to growth accounting as a means of isolating technological change, the approach remains in wide-spread use due to the simplicity and consistency of its internal structure.[26]

Perhaps the most significant limitation of the simple decomposition approach for present purposes attaches to its assumption of constant returns to scale. Since endogenous growth theory directs its most fundamental challenge against traditional growth theory on this very assumption, this constitutes a fundamental limitation. Fortunately the limitation can be addressed for estimation purposes. We outline three alternatives corresponding to three alternative conceptions of endogenous growth.

Where we have increasing returns due to spill-over effects, it follows that:[27]

$$
\begin{aligned}
TFP &= \frac{\dot{Y}}{Y} - \alpha\frac{\dot{K}}{K} - (1-\alpha)\frac{\dot{L}}{L} \\
&= \frac{\dot{A}}{A} + \beta\frac{\dot{K}}{K} \qquad (6)
\end{aligned}
$$

where $\frac{\dot{A}}{A}$ captures exogenous technological progress, and $\beta\frac{\dot{K}}{K}$ captures the spill-over effect due to the factor of production with a weight greater than that implied by its income share (here given by α). An early example of this approach is given by Grilliches (1979), who proxied for $\frac{\dot{K}}{K}$ by means of R&D activity. Under the now more

[26]The literature on growth accounting, its strengths and weaknesses, has come to be vast since the contributions of Denison (1962, 1967, 1974). The first crucial limitation of simple decomposition approaches is that it factor inputs are not disaggregated by quality classes, with resultant upward bias in TFP measures. See for instance Jorgenson and Griliches (1967) and Jorgenson, Griliches and Fraumeni (1987). Our empirical results reflect further on this. A second limitation attaches to the assumption that factor social marginal products coincide with observable factor prices. One response to this difficulty is provided by recourse to a regression approach, in order to obtain direct evidence on factor elasticities. However, the regression approach is subject to its own, and severe limitations, since factor input growth rates are likely endogenous, and factor input growth rates are likely to be subject to considerable measurement error. Both Hulten (2001) and Bosworth and Collins (2003) confirm the continued usefulness of TFP computations.

[27]For a fuller discussion of this and the following derivations see Barro (1998).

conventional approach of Romer (1986), the appropriate growth rate is in terms of physical capital stock, while the Lucas (1988) specification would require additional augmentation with investment in human capital through which the spill-over channel runs in the Lucas specification.

Under a Schumpeterian approach with an increasing variety of intermediate (capital) goods (denoted X),[28] we have instead:

$$\begin{aligned} TFP &= \frac{\dot{Y}}{Y} - s_L \frac{\dot{L}}{L} - s_X \frac{\dot{X}}{X} \\ &= \frac{\dot{A}}{A} + b \frac{\dot{N}}{N} \end{aligned} \tag{7}$$

where terms are as defined above, s_i denotes the income share of factor i, and $\frac{\dot{N}}{N}$ denotes the endogenous expansion of intermediate (capital) good varieties (i.e. technological progress). Under the alternative Schumpeterian quality ladders conception[29] a symmetrical derivation follows, with the $\frac{\dot{N}}{N}$ term coming to denote the overall quality growth rate instead of the variety growth rate. The only remaining difference between the two Schumpeterian conceptions relates to the b coefficient. Under the varieties approach, b can be shown to equal $(1 - \alpha)$ where α has the usual elasticity interpretation with respect to intermediate inputs, while under the quality ladder interpretation $0 < b < 1$, with $b \rightarrow 1$ associated with "high", and $b \rightarrow 0$ denoting "small" quality differentials.

The usual proxy for the $\frac{\dot{N}}{N}$ term under both Schumpeterian approaches is given by the ratio of the flow of R&D to the market value of the stock of past R&D. While the flow measure is generally readily available, the stock measure is not. Fortunately, from the relationship given by equation 7 it can be readily demonstrated that TFP growth is linear in the ratio of the R&D flow measure to per capita output, easing the requirements of empirical specification.[30]

A remaining problem with the empirical specification is that a danger of simultaneity bias continues to lurk in the above specifications. Where R&D proves successful in stimulating TFP growth, firms have an incentive to respond by raising R&D expenditure further. There is thus no reason to suppose that R&D activity would not respond to changes in productivity growth. In order to obtain reliable estimation results it is thus important to instrument the R&D measure. The most generic instruments relate to government policies toward R&D, the registration of patents, and other variables relating to the general enabling environment for private sector R&D activity.

[28] In the Romer (1990) or Grossman and Helpman (1991: ch3) vein.

[29] See the discussion in Aghion and Howitt (1992) and Grossman and Helpman (1991: ch4).

[30] Thus we can replace $\frac{R\&D\ Flow}{Market\ Value\ of\ Past\ R\&D}$ with $\frac{R\&D\ Flow}{Y/L}$.

R&D has found empirical support as a determinant of productivity growth.[31] Of course, innovation is unlikely to be determined by a single dimension such as R&D activity, however that is conceived. The empirical and theoretical literature has identified a range of other relevant conditioning variables,[32] including industrial bargaining characteristics,[33] product market characteristics (essentially industry concentration),[34] labour quality and human capital,[35] trade, international competition or openness of the economy,[36] foreign direct investment,[37] financial liberalization, and exchange rate overvaluation.[38]

We proceed with an application to South African data.

5. The Econometric Methodology and the Data Employed

5.1. The Data

The empirical work of this paper employs both aggregate data for South Africa and manufacturing sector data for South Africa. Choice of the manufacturing data is determined by data reliability, in order to explore in detail the relative impact of the quantity and quality dimensions of human capital. Aggregate data is employed in the context of identifying the interaction of "social infrastructure" and human capital in gorwth processes.

In the empirical section employing the manufacturing sector data, we employ a panel data set for purposes of estimation, with observations from 1970 through 1997. The panel employs data for 22 three-digit SIC version 5 manufacturing sectors in the South African economy for which data is available. The list of sectors included in the panel is that specified in Table 1. This provides a 22×28 panel with a total of 616

[31] See for instance Lichtenberg and Siegel (1991), and Hall and Mairesse (1995).

[32] In addition to the conditioning variables specified, the literature has also identified the regulatory environment as relevant. See for instance the discussion in Pakes and McGuire (1994), Hopenhayn and Rogerson (1993) and Olley and Pakes (1996). Since we have data only on financial liberalization for South Africa, we do not pursue this line of enquiry further in this paper.

[33] See for instance Nickell (1996), Freeman and Medoff (1981).

[34] See Nickell (1996), Haskel (1991) and Haskel and Slaughter (2001), Baily, Hulten and Campbell (1992), Lichtenberg (1992), McGuckin and Sang (1995), and Jovanovic (1982).

[35] See for example the findings in Doms, Dunne and Troske (1997), and Entorff and Kramarz (1998). In a somewhat different tradition, see Nelson and Wright (1992) and Fagerberg (1994).

[36] See Grossman and Helpman (1991), Rivera-Batiz and Romer (1991), Coe and Helpman (1995), Coe, Helpman and Hoffmaister (1997), Keller (1998), Benhabib and Spiegel (1994), Haskel and Slaughter (2001), Mayer (2001), Sala-i-Martin et al (2004), Bosworth and Collins (2003), Sachs and Warner (1995). See also the discussion in Tybout (2000) with respect to developing country manufacturing sectors, and Bernard and Jensen (1995), Clerides, Lach and Tybout (1998), Doms and Jensen (1998), and Bernard and Jensen (1999).

[37] See De Mello (1997) and Ramirez (2000), and Fedderke and Romm (2005) for an application to South Africa.

[38] See Rajan and Subramanian (2005).

Manufacturing Sectors of South Africa included in Panel.	
Food	Plastics
Beverages	Glass & Glass Products
Textiles & Knitting	Other Non-metallic Minerals
Wearing Apparel	Basic Iron & Steel
Leather & Tanning	Basic Non-ferrous Metals
Footwear	Fabricated Metals
Wood	Machinery & Apparatus
Paper	Electrical Machinery
Publishing & Printing	Motor Vehicles & Accessories
Basic Chemicals	Transport Equipment
Other Chemicals & Fibres	Furniture
Rubber	Other Manufacturing & Recycling

Table 1: Manufacturing Sectors

observations.[39] For data on TFP growth in South African manufacturing, we rely on Fedderke (2002).

Variables for the manufacturing sector include the output, capital stock, and labour force variables and their associated growth rates.

In addition we also incorporate a range of variables measuring investment in human capital at both the secondary and primary schooling as well as tertiary educational levels in South Africa. In doing so we control for both the quantity and the quality of human capital investment. The variables controlling for investment in primary and secondary human capital incorporated into the present study are:[40]

- The school enrolment rate, for the "white" racial group in South Africa.[41] The schooling variables are all specified as the enrolment rate of the relevant age cohort, obtained from census data. For whites, since the schooling pupil data covers both primary and secondary schooling, the age cohort is the 5-19 age

[39] In general South Africa reports data on 28 3-digit manufacturing sectors. Some of these had to be excluded from the analysis for reasons of data availability. Television, radio & communications equipment and Professional & scientific equipment did not have data on R&D expenditure, while Tobacco, Plastic products, Television, radio & communications equipment and Other transport equipment lacked data on labour force skills levels. Petroleum products lacked consistent information on industry concentration.

[40] See Bosworth and Collins (2003) and De La Fuente and Doménech (2001) on the importance of data quality in panel and cross country studies employing productivity growth and human capital variables. Use of single country data at least considerably raises the *consistency* of the outcomes measures employed. We do the best we can in the current context. Solow (1997:85) offers a further reminder of the intrinsic difficulties associated with the measurement of human capital.

[41] Both the "white", and the "total" enrolment rate below are constructed from the base data contained in Fedderke, de Kadt and Luiz (2000). For ease of reference we employ the historical Apartheid racial designations in the discussion that follows.

group. Readers should note that the variable is likely to result in downward bias, since a significant proportion of pupils in the white schooling system are likely to complete schooling no later than at age 17. We denote the variable WENROL.

- The total school enrolment rate, for all racial groups in South Africa. The variable is given by the ratio of pupils enrolled in primary and secondary schooling as a proportion of the total age cohort eligible for schooling. We denote the variable TOTENROL.

- The proportion of pupils sitting for mathematics in their matriculation examination in white schooling.[42] We denote the variable MATHPRP.

The reason for controlling for the two schooling enrollment rates separately is that the quality differential between the schooling provided for the different racial groups in South Africa was large.[43] Simple incorporation of the aggregate school enrolment rate may thus fail to distinguish adequately substantial quality gradients in South African schooling that may render the aggregate enrolment rate insignificant or perverse. The school enrolment rates are here employed as proxies for the *quantity* of primary and secondary human capital investment. Figure 1 illustrates the white and black enrolment rates as WENROL and TOTENROL respectively. Finally, the proportion of matriculation students reading mathematics is incorporated as a means of controlling as strictly as possible for the quality of schooling. Fedderke, de Kadt and Luiz (2000) argue that the mathematics proportion in the matriculation year provides a proxy for the quality of schooling being offered. Since the evidence of that study indicates that the white schooling system in South Africa offered the best available schooling as measured by the quality of inputs into the schooling production process, controlling for the mathematics *quality* dimension in the best part of the South African schooling system represents as unalloyed a proxy for the quality dimension of schooling as is available to us.

In terms of the tertiary human capital investment variables the study incorporates:[44]

- The total number of degrees issued by South African universities. We denote the variable DEGREE.

- The total number of degrees issued by South African universities in the mathematical, natural and engineering (NES) sciences. We denote the variable NESDEG.

[42] The proportion is constructed from the base data contained in Fedderke, de Kadt and Luiz (2000).

[43] Fedderke, de Kadt and Luiz (2000) provides extensive detail, while Fedderke and Luiz (2002) provides confirmation of the quality differential in the context of a schooling production function.

[44] For details on the construction of all of these variables see Fedderke, de Kadt and Luiz (2003).

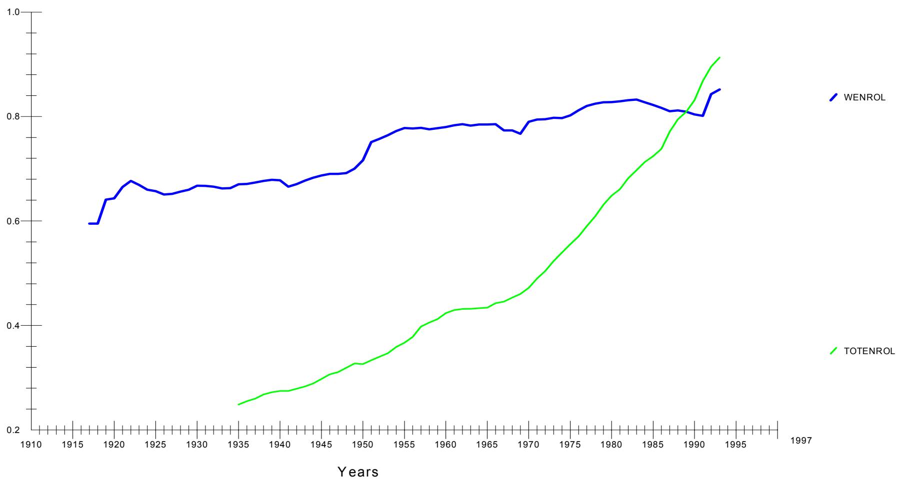

Figure 1: White and Total Enrolment Rates

- The ratio of mathematical, natural and engineering science (NES) degrees to the total degrees issued by the university system in South Africa. We denote the variable NESPRP.

Again, the number of degrees issued serves as a measure of the quantity of tertiary human capital produced in South Africa. By contrast, the number of NES degrees, and the proportion of NES degrees variables both serve as alternative proxies for the quality dimension of tertiary human capital creation.

Further, we introduce a number of additional variables that proxy for the general "enabling" environment for innovative activity:

- The total number of patents registered in South Africa, in order to serve as a proxy for the quality of intellectual property rights.[45] We employ the variable in log transform, denoted as lnPAT.
- An index of property rights in South Africa, as a second proxy for the quality of the property rights environment. The hypothesis is that the general quality of property rights may impact on the quality of intellectual property rights.[46] We employ the variable in log transform, denoted as lnPROP.
- The skills mix of the labour force in each manufacturing sector. The ratio is of high and medium skill levels to unskilled labour. We denote the variable as SKRAT. Since TFP decompositions in South Africa do not control for changing

[45] For details on the construction of this variable see Fedderke, de Kadt and Luiz (2001).
[46] For details on the construction of this variable see Fedderke, de Kadt and Luiz (2001).

skills composition of the labour force, it is vital to control for the skills ratio in any determination of TFP, in order to correct for the resultant upward bias in the TFP measure.[47]

- The net export ratio of each manufacturing sector,[48] incorporated on the hypothesis encountered in the literature that export competitiveness may require strong innovative capacity. We denote the variable as NX.
- An index of openness of the South African economy, denoted OPEN, obtained from Aron and Muellbauer (2002).
- An index of financial liberalization in the South African economy, denoted FINLIB, obtained from Aron and Muellbauer (2000).
- A measure of exchange rate overvaluation obtained in terms of the methodology outlined by Rajan and Subramainan (2005).[49] We denote the variable OVERVAL.
- Real foreign direct investment from Fedderke and Romm (2005). We denote the variable FDI.
- R&D expenditure by manufacturing sector is compiled from published survey data on R&D expenditure. Data is collected for private sector R&D expenditure, public sector R&D expenditure, and expenditure by tertiary educational institutions earmarked for each of the 28 manufacturing sectors.[50] All expenditure is real. Fuller detail is provided in the data appendix to the paper.

Finally, we control for conditions in the output and labour markets faced by firms:

- Two measure of industry concentration, given by the Gini index and Rosenbluth index computed for each industry in each year over the sample period. Data is obtained from Fedderke and Szalontai (2005). We denote the variables GINI and ROSEN respectively.
- Three measures of intensity of industrial action, given by the number of strikes, the number of labour days lost due to industrial action, and the number of workers involved in strikes. Data is published by the South African Reserve Bank. We employ the variables in log transform, and denote them lnSTR, lnDAYL and lnLABS respectively.

[47] See the more detailed discussion of this point in Fedderke (2002).
[48] Computed as $\frac{X}{X+IM}$ where X denotes exports, and IM imports.
[49] This in turn follows earlier methodologies due to Dollar and Frankel.
[50] The surveys are the *Resources for R&D* surveys undertaken by the Office of the Scientific Adviser to the Prime Minister/President and the Council for Scientific and Industrial Research (CSIR).

- Given the often close association between industrial action and political opposition to Apartheid governments over substantial within-sample periods for this study, we also control for the level of political instability in South Africa. We employ the index compiled in Fedderke, de Kadt and Luiz (2001), denoted INSTAB.

We turn now to issues arising from estimation.

5.2. *The Econometric Methodology*

For the panel data analysis, we employ the Pooled Mean Group (PMG) estimator of Pesaran, Shin and Smith (1999).

Consider the unrestricted error correction ARDL(p, q) representation:

$$\Delta y_{it} = \phi_i y_{i,t-1} + \boldsymbol{\beta}_i' \mathbf{x}_{i,t-1} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \boldsymbol{\delta}_{ij}' \Delta \mathbf{x}_{i,t-j} + \mu_i + \varepsilon_{it}, \tag{8}$$

where $i = 1, 2, ..., N$, $t = 1, 2, ..., T$, denote the cross section units and time periods respectively. Here y_{it} is a scalar dependent variable, $\mathbf{x}_{it}$ $(k \times 1)$ a vector of (weakly exogenous) regressors for group i, and μ_i represents fixed effects. Allow the disturbances ε_{it}'s to be independently distributed across i and t, with zero means and variances $\sigma_i^2 > 0$, and assume that $\phi_i < 0$ for all i. Then there exists a long-run relationship between y_{it} and $\mathbf{x}_{it}$:

$$y_{it} = \boldsymbol{\theta}_i' \mathbf{x}_{it} + \eta_{it}, \; i = 1, 2, ..., N, \; t = 1, 2, ..., T, \tag{9}$$

where $\boldsymbol{\theta}_i = -\boldsymbol{\beta}_i'/\phi_i$ is the $k \times 1$ vector of the long-run coefficients, and η_{it}'s are stationary with possibly non-zero means (including fixed effects). This allows (8) to be written as:

$$\Delta y_{it} = \phi_i \eta_{i,t-1} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \boldsymbol{\delta}_{ij}' \Delta \mathbf{x}_{i,t-j} + \mu_i + \varepsilon_{it}, \tag{10}$$

where $\eta_{i,t-1}$ is the error correction term given by (9), and thus ϕ_i is the error correction coefficient measuring the speed of adjustment towards the long-run equilibrium.

This general framework allows the formulation of the PMG estimator, which allows the intercepts, short-run coefficients and error variances to differ freely across groups, but the long-run coefficients to be homogenous; i.e. $\boldsymbol{\theta}_i = \boldsymbol{\theta} \; \forall \; i$. Group-specific short-run coefficients and the common long-run coefficients are computed by the pooled maximum likelihood estimation. Denoting these estimators by $\tilde{\phi}_i$, $\tilde{\boldsymbol{\beta}}_i$, $\tilde{\lambda}_{ij}$, $\tilde{\boldsymbol{\delta}}_{ij}$ and $\tilde{\boldsymbol{\theta}}$, we obtain the PMG estimators by $\hat{\phi}_{PMG} = \frac{\sum_{i=1}^{N} \tilde{\phi}_i}{N}$, $\hat{\boldsymbol{\beta}}_{PMG} = \frac{\sum_{i=1}^{N} \tilde{\boldsymbol{\beta}}_i}{N}$, $\hat{\lambda}_{jPMG} = \frac{\sum_{i=1}^{N} \tilde{\lambda}_{ij}}{N}$, $j = 1, ..., p-1$, and $\hat{\boldsymbol{\delta}}_{jPMG} = \frac{\sum_{i=1}^{N} \tilde{\boldsymbol{\delta}}_{ij}}{N}$, $j = 0, ..., q-1$, $\hat{\boldsymbol{\theta}}_{PMG} = \tilde{\boldsymbol{\theta}}$.

PMG estimation provides an intermediate case between the dynamic fixed effects (DFE) estimator which imposes the homogeneity assumption for all parameters except for the fixed effects, and the mean group (MG) estimator proposed by Pesaran and Smith (1995), which allows for heterogeneity of all parameters. It exploits the statistical power offered by the panel through long-run homogeneity, while still admitting short-run heterogeneity. As long as sector-homogeneity is assured, the PMG estimator offers efficiency gains over the MG estimator, while granting the possibility of dynamic heterogeneity across sectors unlike the DFE estimator. In the presence of long-run homogeneity, therefore, our preference is for the use of the PMG estimator.

The crucial question is whether the assumption of long-run homogeneity is justified, given the threat of inefficiency and inconsistency noted by Pesaran and Smith (1995). We employ a Hausman (1978) test (hereafter h test) on the difference between MG and PMG estimates of long-run coefficients to test for long-run heterogeneity.[51] Note that as long as the homogeneity Hausman test is passed in our estimations, we report only PMG estimation results.[52]

Finally, it is worth pointing out that a crucial advantage of the estimation approach of the present paper, is that the dynamics generally argued to be inherent in growth processes are explicitly modelled, while recognizing the presence of a long-run equilibrium relationship underlying the dynamics. This is particularly important given the recurrent debate in the context of growth studies concerning the appropriate length of the time window used in averaging data for cross country studies. Justification for averaging rests on the need to remove short run fluctuations in growth studies. Choice of any window is in the final instance arbitrary.[53] Thus the justification for the use of the PMG estimator is that it is consistent both with the underlying theory of an homogenous long-run relationship, while allowing for the explicit modelling of short run dynamics around the long run relationship and the possibly heterogeneous dynamic time series nature of the data in the dynamics of adjustment.

6. The Results: Schumpeterian R&D Impacts

In our empirical investigation of the presence of Schumpeterian endogenous growth effects in South African manufacturing, we proceed with an estimation of the empirical specification provided by equation 7. As discussed above, this requires regression of growth in total factor productivity on the ratio of R&D expenditure to per capita output.[54] The literature also suggests a range of additional factors relevant to the de-

[51] An alternative is offered by Log-Likelihood Ratio tests. However, the finite sample performance of such tests are generally unknown and thus unreliable. We therfore employ the h-test instead.

[52] The author thanks Yongcheol Shin for the provision of the appropriate GAUSS code for estimation purposes.

[53] Indeed, some panel studies do not average at all. Unfortunately the estimators used in turn are generally not dynamic, so that the results obtained may also be driven by short-term fluctuations.

[54] There is some debate about whether the appropriate productivity measure is provided by labour productivity or total factor productivity. The TFP measure is generally preferred since Y/L may

termination of productivity gains,[55] including labour market conditions, labour quality and human capital, industry concentration, exposure to international competition, foreign direct investment, financial liberalization, and exchange rate overvaluation.

We therefore estimate a baseline specification given by:

$$TFP_{it} = \alpha + \beta_1 \left(\frac{R\&D}{Y/L}\right)_{it} + \beta_2 SKRAT_{it} + \beta_3 NX_{it} + \beta_4 GINI_{it} + \beta_5 Z_t + \varepsilon_{it} \qquad (11)$$

where Z_t denotes a vector of the various additional conditioning dimensions identified above, including a range of human capital measures (WENROL, TOTENROL, MATHPRP, DEGREE, NESDEG, NESPRP), institutional measures covering intellectual property rights conditions (lnPAT, lnPROP), measures of labour market and general political turmoil (lnSTR, lnDAYL, lnLABS, INSTAB), as well as foreign direct investment (FDI), an additional openness measure (OPEN), a measure of financial liberalization (FINLIB), and a measure of exchange rate overvaluation (OVERVAL).[56]

A final estimation issue concerns the possibility of simultaneity bias attaching to the $\frac{R\&D}{Y/L}$ variable identified in the theoretical discussion. To address this problem we instrument the $\frac{R\&D}{Y/L}$ variable.[57] While the regressor in equation 11 is constructed with private sector R&D expenditure, we employ SURE estimations[58] in order to instrument the private sector R&D expenditure ratio on public sector R&D activity and tertiary educational institutions' R&D activity within each manufacturing sector.[59] We report the results of the SURE estimations in Table 2. Reported χ^2 test statistics based on equation and system log likelihoods confirm the presence of non-diagonal error covariance matrices throughout, confirming the appropriateness of SURE estimation.

As a final step we now turn to the estimation of equation 11. We report results in Tables 3 through 6.

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increase due to a rising K/L, without technology changes. TFP growth provides more direct information on growth due to technological change, and is the measure employed here.

[55] Bartelsman and Doms (2000) provides a useful overview of the issues beyond the literature already cited above.

[56] Note that all of these dimensions are generic to the economy, rather than industry-specific.

[57] Adequate instruments should be correlated with the private sector R&D variable, but not the TFP term. Public and tertiary R&D is employed in the current study, since they are likely to show association with the R&D activity of the private sector, but would not be associated with the innovation in production of the private sector. Correlation of government and tertiary R&D with private sector R&D is 0.44 and 0.31 respectively; correlation of the two instruments with TFP is 0.01 and 0.02 respectively, confirming our prior.

[58] SURE estimation is appropriate on the assumption that contemporaneous correlation of disturbances attaching to growth in total factor productivity across manufacturing sectors may be non-zero - a reasonable assumption confirmed by relevant diagnostics. Given that we have separate R&D expenditure figures for private, public and tertiary sectors across manufacturing sectors, SURE promises efficiency gains over single equation estimation.

[59] Note, some sectors did not have data on public or tertiary sector R&D expenditure data available. For these we instrumented on either PATENT (marked †) or PROPERTY (marked ‡).

Dependent Variable: Private Sector R&D			
Sector	**Public R&D**	**Tertiary R&D**	χ^2 $\{d.f\}$
Food	1.68 (0.12)	1.26 (0.50)	260.71* {15}
Beverages	1.20 (0.55)	0.38 (0.50)	260.71* {15}
Textiles	0.25 (0.03)	−12.02 (2.74)	260.71* {15}
Wearing Apparel	-	−0.11 (0.06)	260.71* {15}
Leather	-	−0.19 (0.05)	260.71* {15}
Footwear‡	3917.8 (1354.2)		1837.60* {20}
Wood	0.14 (0.13)	0.76 (0.57)	260.71* {15}
Paper‡	2658.1 (1156)		1837.60* {20}
Print & Publish†		6.96 (2.28)	1837.60* {20}
Basic Chemicals	1.92 (0.21)	11.26 (0.31)	279.81* {15}
Other Chemicals	0.36 (0.02)	4.93 (0.17)	279.81* {15}
Rubber	−1.43 (0.52)	-	279.81* {15}
Plastics	−0.02 (0.06)	10.95 (1.08)	279.81* {15}
Glass	5.58 (0.58)	1.41 (0.20)	279.81* {15}
Non-Metallic	0.43 (0.20)	1.94 (0.59)	131.40* {6}
Basic Iron & Steel	5.36 (0.90)	17.81 (3.49)	131.40* {6}
Basic Non-Ferrous	0.10 (0.03)	0.60 (0.40)	131.40* {6}
Metal Products	10.26 (1.49)	−7.89 (5.08)	131.40* {6}
Machinery	0.61×10^{-7} (0.86×10^{-7})	0.38×10^{-5} (0.49×10^{-6})	188.50* {20}
Electr. Machinery	-0.55×10^{-8} (0.26×10^{-7})	0.41×10^{-6} (0.38×10^{-7})	188.50* {20}
Motor Vehicles	−0.16 (0.38)	14.74 (1.94)	188.50* {20}
Furniture	-0.14×10^{-4} (0.38×10^{-5})	0.14×10^{-4} (0.38×10^{-5})	1837.60* {20}
Other Industry	0.86×10^{-6} (0.15×10^{-6})	0.27×10^{-5} (0.43×10^{-6})	188.50* {20}

Table 2: Results of SURE instrumenting estimation, Figures in round parentheses represent standard errors

Dependent Variable: Growth in Total Factor Productivity				
	1	2	3	4
ARDL:	3,3,2,1,3	3,3,2,1,3	3,3,2,1,3	3,3,2,1,2
$\ln\left(\frac{R\&D}{Y/L}\right)$	0.049^* (0.012) [3.26]	0.036^* (0.008) [1.19]	0.168^* (0.004) [0.09]	0.080^* (0.010) [0.87]
SKRAT	-0.045^* (0.016) [2.20]	-0.112^* (0.018) [0.02]	-0.088^* (0.024) [0.37]	-0.049^* (0.022) [2.58]
NX	0.041^* (0.018) [2.03]	0.029^* (0.016) [0.78]	0.00 (0.02) [0.75]	0.182^* (0.028) [0.12]
GINI	-0.329^* (0.128) [1.74]		-0.92^* (0.03) [0.21]	-0.219 (0.175) [0.17]
ROSEN		-0.983^* (0.514) [1.38]		
WENROL			-0.46^* (0.04) [0.45]	
TOTENROL				-0.468^* (0.056) [5.80]
ECM	-1.10^* (0.12)	-1.01^* (0.14)	-0.97^* (0.19)	-0.98^* (0.14)
h-test	5.38 [0.25]	8.64 [0.07]	2.99 [0.70]	6.74 [0.24]
RLL	602.63	609.87	709.14	642.55
ULL	820.71	827.14	1467.68	1042.59
LR: χ^2	436.16^*	434.53^*	1517.08^*	800.09^*

Table 3: Schumpeterian Results I, Figures in round parentheses are standard errors, Square parentheses below coefficients are Hausman tests, Other square parentheses are probability levels, Figures in curly parentheses are degrees of freedom, * denotes significance

Dependent Variable: Growth in Total Factor Productivity				
	5	6	7	8
ARDL:	3,3,2,1,3	3,3,2,1,3	3,3,2,1,3	3,3,2,1,2
$\ln\left(\frac{R\&D}{Y/L}\right)$	0.079* (0.016) [0.52]	0.047* (0.012) [1.82]	0.047* (0.012) [1.83]	0.032* (0.019) [0.00]
SKRAT	−0.056* (0.019) [1.69]	−0.045* (0.017) [3.37]	−0.045* (0.017) [3.37]	−0.088* (0.018) [0.85]
NX	0.036 (0.025) [1.07]	0.041* (0.019) [1.09]	0.041* (0.019) [1.09]	0.115* (0.020) [0.58]
GINI	−2.31* (0.115) [1.15]	−0.331* (0.129) [0.61]	−0.331* (0.129) [0.61]	0.164 (0.196) [0.04]
MATHPRP	0.188* (0.025) [0.13]			
DEGREE		0.003 (0.013) [0.95]		
NESDEG			0.003 (0.013) [0.96]	
NESPRP				2.926* (0.44) [1.13]
ECM	−0.90* (0.14)	−1.12* (0.13)	−1.12* (0.13)	−0.89* (0.09)
h-test	3.45 [0.63]	5.75 [0.33]	5.76 [0.33]	4.93 [0.42]
RLL	669.92	588.52	588.52	629.36
ULL	1354.53	854.88	854.89	1267.05
LR: χ^2	1369.20*	532.73*	532.74*	1275.37*

Table 4: Schumpeterian Results II, Figures in round parentheses are standard errors, Square parentheses below coefficients are Hausman tests, Other square parentheses are probability levels, Figures in curly parentheses are degrees of freedom, * denotes significance

Dependent Variable: Growth in Total Factor Productivity						
	9	10	11	12	13	14
ARDL:	3,3,2,1,3	3,3,2,1,3	3,3,2,1,3	3,3,2,1,3	3,3,2,1,3	3,3,2,1,3
$\ln\left(\frac{R\&D}{Y/L}\right)$	0.111* (0.013) [0.36]	0.047* (0.012) [0.84]	0.013 (0.01) [0.92]	0.047* (0.012) [0.01]	0.045* (0.012) [3.18]	0.049* (0.013) [5.04]
SKRAT	−0.014* (0.017) [2.45]	−0.048* (0.018) [0.99]	−0.074* (0.017) [0.33]	−0.048* (0.017) [0.63]	−0.050* (0.016) [3.55]	−0.044* (0.017) [2.79]
NX	0.078* (0.016) [0.91]	0.030 (0.023) [0.76]	0.010 (0.018) [1.34]	0.046* (0.019) [0.72]	0.045* (0.018) [0.19]	0.042* (0.018) [0.45]
GINI	−0.068* (0.083) [0.81]	−0.380* (0.149) [0.86]	−0.292* (0.104) [1.42]	−0.319* (0.125) [0.18]	−0.327* (0.138) [3.42]	−0.331* (0.130) [1.51]
lnPAT	−0.220* (0.026) [1.29]					
lnPROP		0.015 (0.017) [0.69]				
INSTAB			0.002* (0.000) [1.06]			
lnSTR				0.001 (0.001) [1.05]		
lnDAYL					0.002 (0.001) [2.22]	
lnLABS						0.000 (0.001) [4.10]
ECM	−1.13* (0.157)	−1.12* (0.13)	−1.16* (0.13)	−1.14* (0.13)	−1.12* (0.13)	−1.12* (0.13)
h-test	7.39 [0.19]	4.64 [0.46]	4.15 [0.53]	4.12 [0.53]	8.34 [0.14]	8.59 [0.13]
RLL	608.83	588.72	599.62	588.93	589.40	588.56
ULL	872.44	856.32	876.45	854.64	839.39	833.60
LR: χ^2	527.21*	535.20*	553.66*	531.41*	499.99*	490.09*

Table 5: Schumpeterian Results III, Figures in round parentheses are standard errors, Square parentheses below below coefficients Hausman tests, Other square parentheses are probability levels, Figures in curly parentheses are degrees of freedom, * denotes significance

Dependent Variable: Growth in Total Factor Productivity				
	15	16	17	18
ARDL:	3,3,2,1,3	3,3,2,1,3	3,3,2,1,3	3,3,2,1,3
$\ln\left(\frac{R\&D}{Y/L}\right)$	0.052* (0.013)	0.054* (0.013) [0.08]	0.054* (0.013) [2.60]	0.010 (0.008) [0.20]
SKRAT	−0.043* (0.016)	−0.064* (0.013) [1.55]	−0.043* (0.016) [2.09]	−0.042* (0.018) [1.25]
NX	0.048* (0.022)	0.042* (0.017) [3.72]	0.046* (0.021) [5.76]	0.226* (0.018) [0.01]
GINI	−0.307* (0.139)	−1.018* (0.162) [0.25]	−0.313* (0.133) [0.01]	0.107 (0.084) [0.10]
FDI	0.010 (0.019)			
OPEN		−0.039 (0.066) [0.06]		
FINLIB			−0.012 (0.022) [0.00]	
OVERVAL				0.030* (0.015) [0.11]
ECM	−1.11* (0.13)	−1.10* (0.13)	−1.11* (0.13)	−1.34* (0.31)
h-test	11.85 [0.04]	6.38 [0.27]	9.04 [0.11]	4.93 [0.42]
RLL	588.67	604.70	588.69	596.79
ULL	848.09	892.57	921.06	1268.19
LR: χ^2	518.82*	575.74*	664.73*	1342.80*

Table 6: Schumpeterian Results IV, Figures in round parentheses are standard errors, Square parentheses below coefficients are Hausman tests, Other square parentheses are probability levels, Figures in curly parentheses are degrees of freedom, * denotes significance

For all specifications estimation results confirm not only adjustment to equilibrium, but rapid adjustment (see the *ECM*-parameters, which correspond to the ϕ-paramters of equation 8). Moreover, in general the Hausman tests (denote *h*-tests) confirm the legitimacy of the PMG estimator by failing to reject the homogeneity restriction on the long-run coefficients for South African manufacturing sectors at conventional levels of significance (with only one exception at the 5% level of significance - in the specification in which we control for FDI - and a further exception at the 10% level -in the specification controlling for the Rosenbluth concentration index). Given the unknown finite sample properties of the LR test statistic, we thus proceed on the assumption of long-run parameter homogeneity.

The results confirm the presence of a positive impact of R&D expenditure on growth in total factor productivity, as postulated by Schumpeterian theory. The coefficient on the instrumented R&D measure is consistently positive, and is statistically significant in all but two specifications.[60] In general the R&D coefficient proves robust to alternative specifications,[61] and in most specifications lies in the range from 0.04 to 0.05. Thus the findings confirm the presence of a positive, and consistent impact on output growth of innovative R&D activity undertaken by the private sector. Indeed, the only concern with this set of results is that the impact of the R&D activity is potentially too strong to be plausible, since the stable coefficient range implies a more than proportional impact of R&D on TFP growth. Given the well-documented uncertainties surrounding R&D success, this is surprising, and likely implausibly large.

The variable controlling for the skills composition of the labour force, SKRAT, corrects the TFP measure for its upward bias that results from not correcting the underlying decomposition for improving skills levels.[62] Accordingly, the impact of the SKRAT variable proves to be consistently negative, as well as statistically significant in all estimations. What is more, parameter-values are consistently in the -0.04 to -0.05 range.[63] The inference is that the TFP decomposition does serve to bias upward the measure of technological progress, with at least some of the efficiency gain in production proving attributable to increasing skills levels in the labour force.

Net exports consistently have a *positive* impact on the innovative activity of the manufacturing sectors in South Africa, though in four of the estimated specifications the measure of exposure to international competitive forces proves to be statistically insignificant.[64] Parameter stability across the estimated specifications holds in general, with estimated coefficients of approximately 0.05.[65] The NX measure spans the

[60] Those controlling for INSTAB and OVERVAL.

[61] There are four exceptions, in the specifications controlling for WENROL, TOTENROL, MATHPRP, and lnPAT.

[62] For South African data this is not feasible, due to missing earnings shares by skills categories.

[63] There are five exceptions: for the specifications controlling for lnPAT, INSTAB, NESPRP, WENROL, and ROSEN.

[64] In the specifications controlling for WENROL, MATHPRP, lnPROP and INSTAB.

[65] There are four relative outliers, associated with the specifications controlling for TOTENROL,

range from -0.97 to 0.84 in the study sample. Thus an increase of 0.1 in the NX measure constitutes an increase of approximately 5% in the net export ratio within sample. For a parameter value of 0.05, the implication is that output growth would improve by 0.5% per annum through the TFP channel due to the 5% improvement in the net export ratio, suggesting a fairly sensitive response to international exposure of the South African manufacturing sectors. Learning opportunities from exposure to international markets thus appear to be significant for South African manufacturing. But such learning effects appear to relatively sectorally specific. In column (16) of Table 6 we control for the Aron-Muellbauer aggregate openness index for the South African economy, in addition to sectoral net export ratio. It proves statistically insignificant, suggesting that what learning effects there are, are associated with the international exposure of individual industries, rather than the general openness of the economy.

Industry concentration proves to have the opposite effect on TFP growth from that found for net exports. Increased concentration proves to lower TFP growth, regardless of whether the concentration measure is the GINI or the ROSEN. Columns (1) and (2) of Table 3 report. For remaining specifications we therefore report only the specifications controlling for GINI. The impact of industry concentration is consistently negative and statistically significant for all specifications, with only two specifications reporting a statistically insignificant impact.[66] Again, parameter stability is generally present across specifications, with estimated coefficients of approximately -0.3.[67] The within sample range of the GINI variable is from 0.69 to 0.99, such that for the parameter value of -0.3 the implication of a reduction of the concentration measure of 0.1 (1/3 of the in-sample range of the GINI measure), would generate 3% more output growth per annum through the TFP channel. Again, the impact is notable for its strength, and suggests that competition policy in South Africa is one means by which output growth might be stimulated by triggering efficiency improvements in production.

The impact of the various human capital variables we controlled for in estimation falls into two sharply distinct categories. All of the human capital measures that are associated with the *quantity* of human capital investment, are either negatively or statistically insignificantly associated with TFP growth. The statistically significant negative associations emerge for the school enrolment rates (WENROL, TOTENROL, columns 3 and 4 of Table 3), and the insignificant associations for the tertiary measure (DEGREE column 6 of Table 4). By contrast, the measures that capture the *quality* of human capital investment, (MATHPRP and NESPRP in columns 5 and 8 of Table 4) are statistically significantly and positively associated with TFP growth, with the one exception of the absolute number of NES degrees which is sta-

NESPRP, lnPAT, and OVERVAL.

[66] Those controlling for NESPRP and OVERVAL.

[67] In four specifications there is some deviation from this value: those controling for MATHPRP, WENROL, lnPAT, and OPEN.

tistically insignificant (NESDEG column 7 of Table 4). The finding thus confirms the distinction drawn in the literature between quantity and quality of human capital investment, and in particular confirms the strong positive impact of quality human capital investment.[68] The only real puzzle that requires attention here is why the quantity of human capital investment might generate a negative (rather than a zero) impact on TFP and hence output growth. Given the sample period of the present study (1970-1997), the finding is less surprising than might appear at first sight. Considerable evidence has accumulated that confirms the presence of considerable resource misallocation and inefficiencies in the South African schooling and tertiary educational system over the sample period.[69] The negative coefficient on the quantity of human capital investment thus is likely to represent the efficiency loss that would result from any resource misallocation. While the results from the human capital indicators thus point to a positive impact of human on productivity growth, the results equally highlight that in the presence of inefficient resource use in the education sector, efficiency losses may also be present.[70]

These findings suggest that the divergent findings to emerge from cross-national studies on the impact of human capital investment on economic growth may be due both to inadequate focus on divergent quality of education across countries, as well as to the absence of attention being paid to the efficiency of resource use across educational sectors within, and across countries.

Most of the additional regressors employed in estimation proved to be statistically insignificant. Noteworthy here are the measures of industrial bargaining (lnSTR, lnDAYL, lnLABS), which while positive are consistently statistically insignificant. They thus provide only weak support for the 'voice' model hypothesis. Since the industrial bargaining measures are aggregate measures for South Africa as a whole, it must be pointed out that more sectorally disaggregated industrial bargaining data might

[68]This finding accords well with that of Hanushek and Kim (1995) and Hanushek and Kimko (2000) on an international sample of countries, in which schooling in mathematics and science had a growth impact considerably larger than general education. Thus the implication is that while education in general helps, it also matters what sort of training is being undertaking. The growth payoff from training in science and engineering appears to exceed that of general training.

[69]See the discussions in Fedderke, De Kadt and Luiz (2000), Fedderke and Luiz (2002) and Fedderke, De Kadt and Luiz (2003).

[70]In estimation, we also estimated the empirical specification provided by equation 6 to allow for Romer (1986)-type spill-over effects. The coefficient on the growth rate of the capital stock is consistently negative and statistically significant, rejecting Romer 1986 spill-over effects. Where equation 6 is augmented to incorporate human capital dimensions, as explicitly required by the Lucas (1988) variant of the spill-over model, human capital investment variables prove to have positive and significant coefficients. Again, however, this is restricted to the quality dimensions of human capital investment, MATHPRP and NESPRP. By contrast, the total school enrollment rate, and the total number of degrees issued by South African universities while significant, contribute negatively to total factor productivity growth, while the white school enrollment rate, and the total number of NES degrees are insignificant. The findings in favour of quality human capital creation, and the negative impact of inefficient resource use in human capital creation for growth purposes thus are robust between the Schumpeterian and spill-over versions of endogenous growth models.

serve to improve the accuracy of results for labour market conditions. By contrast the aggregate measure of political instability (INSTAB) proves statistically significant and positive, suggesting that manufacturing firms in periods of political turmoil have sought output growth through efficiency gains rather than factor accumulation.[71] Similarly, the positive and statistically significant impact of exchange rate overvaluation can be similarly interpreted as reflecting pressure on firms to resort to innovation under conditions that increase competitive pressure on domestic producers.

Estimation suggests FDI, financial liberalization and property rights to be statistically insignificant in TFP growth - while the negative sign on patents is the one coefficient amongst those estimated that is not easy to explain.

In summary, the empirical evidence from South African manufacturing industry thus appears to point to a positive impact on TFP from R&D activity within a Schumpeterian framework, as well as from human capital. However, crucial to the latter finding is the need to distinguish between the quality and the quantity of human capital investment, with the quality of human capital having the strong positive impact on TFP growth that we would anticipate from economic theory. By contrast, resource misallocation in education is likely to carry negative growth consequences.

7. Testing for the direct impact of human capital creation on long-run economic growth in South Africa

As a final step in this paper we turn our attention to the possibility of a direct impact of human capital on long-run economic growth rather than the indirect channel provided by its impact on TFP growth examined in the previous section of the paper.[72]

Mankiw, Romer and Weil (1992) provide one approach to the estimation of a direct impact of human capital on growth. However, and particularly so in a time series context, problems of endogeneity in estimation are likely to be severe in Mankiw-Romer-Weil-specifications. In the newer literature, such as Hall and Jones (1999), which emphasizes the impact of institutions in driving differences in physical and human capital investment as well as productivity differences between countries, the problem compounds. Djankov et al (2003) suggest that both the institutional and productive capacities of societies are shaped by human and social capital endowments, theoretical propositions supported by the empirical findings of Glaeser et al (2004). Causality may thus be multidirectional between human capital creation and

[71] This finding would be consistent with the result that the political instability variable has a significant negative impact on investment in physical capital - see Fedderke (2004).

[72] This section of the paper draws substantially on Fedderke and Luiz (2005) in which more extensive results are presented. My thanks to John Luiz for allowing the use of one core analytical result from the paper in this context.

Variable	~I(0)	~I(1)	~I(2)	Critical Value
INSTAB	-3.43	-7.66*	-	-3.49
RACE	1.25	-1.12	-6.01*	-2.90
LYPC	-2.18	-4.86*	-	-2.90
POL	-033	-4.61*	-	-2.92
PROP	1.39	-6.69*	-	-2.93
IY	-0.74	-5.56*	-	-2.93
TOTENROL	0.46	-4.56*	-	-2.92
NESPRP	-2.75	-8.16*	-	-2.90
UC	-2.02	-5.78*		-2.93

Table 7: The Univariate Structure of the Data ADF Statistics on Stationarity

the institutional structures of society, providing a structure such as:

$$\begin{aligned} Y &= F(K, L, H, R, Z_1) \\ R &= R(H, Y, Z_2) \\ H &= H(R, Y, Z_3) \end{aligned} \tag{12}$$

where R denotes the relevant institutional dimension (Hall and Jones' "social infrastructure"), and the Z_i denote vectors of additional relevant variables.

We formulate a structural system that incorporates the most general formulation of the base-line proposition of a linkage between social infrastructure and productivity growth and human capital accumulation, as well as the literature suggesting that social fragmentation impacts on the long-run growth potential of countries, particularly in Africa.[73] Core to this approach is the proposition that the social fractionalization at the root of distributional conflict, has an impact not only on instability, but directly on the quality of policy formulation relevant to economic growth.[74] In the current context, therefore, as a starting position we postulate a possible impact of fractionalization on political instability, on output directly (due to poor growth-related policy formulation), and on human capital investment.[75] In South Africa, the social cleavage at the heart of distributional conflict has been race, and hence we employ racial fractionalization as the appropriate measure in our structural equation model.

The univariate time series structure of the data employed in the study is reported in Table 7. The evidence confirms the presence of level, first difference and second difference stationary variables. Estimation of the structural system is by standard

[73]Perhaps the most famous contribution here is by Easterly and Levine (1997), though the article spawned a substantial literature, characterised by considerable controversy.

[74]See Easterly and Levine (1997), Alesina and Perotti (1993), and Persson and Tabellini (1994).

[75]That South African human capital formation has been adversely affected by the pursuit of racially motivated policy formulation is standard in the literature. See for instance Fedderke and Luiz (2002), Fedderke et al (2000, 2003), as well as Case and Deaton, (1999).

time series techniques, with variables that are first-difference stationary. Johansen[76] techniques of estimation are now standard, so that discussion of estimation methodology here can be brief. We employ a vector error-correction mechanism (VECM) framework, for which, in the case of a set of k variables, we may have cointegrating relationships denoted r, such that $0 \leq r \leq k-1$. This gives us a k-dimensional VAR:

$$z_t = A_1 z_{t-1} + \cdots + A_m z_{t-m} + \mu + \delta_t \tag{13}$$

where m denotes lag length, a μ set of deterministic components and δ a Gaussian error term. Reparameterization provides the VECM specification:

$$\Delta z_t = \sum_{i=1}^{k-1} \Gamma_i \Delta z_{t-i} + \Pi z_{t-k+1} + \mu + \delta_t \tag{14}$$

The existence of r cointegrating relationships amounts to the hypothesis that:

$$H_1 (r) : \Pi = \alpha\beta' \tag{15}$$

where Π is $p\ x\ p$, and α,β are $p\ x\ r$ matrices of full rank. $H_1\ (r)$ is thus the hypothesis of reduced rank of Π. Where $r > 1$, issues of identification arise.[77] Estimation is by VECM cointegration.

We postulate a labour intensive output (denoted LYPC) equation which loads on the investment rate (IY), the user cost of capital (UC), political instability (INSTAB), math and science degree proportions (NESPRP), as well as the change in racial fractionalization (DRACE).[78] Second, we postulate that political instability (INSTAB) in turn is driven by the change in racial fractionalization (DRACE), per capita output (LYPC), property rights (PROP) and human capital investment in both quality and quantity dimensions (NESPRP, TOTENROL). Finally, we postulate that the quality dimension of human capital investment (NESPRP) is determined by the change in racial fractionalization (DRACE), per capita output (LYPC), political rights (POL), and the quantity of human capital production (TOTENROL). Hence:

[76] See Johansen (1991) and Johansen and Juselius (1990).

[77] See Wickens (1996), Johansen and Juselius (1990, 1992), Pesaran and Shin (1995a, 1995b), Pesaran, Shin and Smith (1996).

[78] The first difference specification is driven by the iI(2) structure of racial fractionalization in South Africa. Inclusion into the Johansen VECM framework thus requires the first difference transformation.

$$\Pi z_{t-k+1} = \alpha\beta z_{t-k+1} \tag{16}$$

where

$$\alpha = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \\ \alpha_{41} & \alpha_{42} & \alpha_{43} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \\ \alpha_{61} & \alpha_{62} & \alpha_{63} \\ \alpha_{71} & \alpha_{72} & \alpha_{73} \\ \alpha_{81} & \alpha_{82} & \alpha_{83} \\ \alpha_{91} & \alpha_{92} & \alpha_{93} \\ \alpha_{10.1} & \alpha_{10.2} & \alpha_{\cdot 10.3} \end{bmatrix}$$

$$\beta = \begin{bmatrix} \beta_{11} & \beta_{12} & 1 & \beta_{14} & \beta_{15} & \beta_{16} & \beta_{17} & \beta_{18} & \beta_{19} & \beta_{1.10} \\ \beta_{21} & 1 & \beta_{23} & \beta_{24} & \beta_{25} & \beta_{26} & \beta_{27} & \beta_{28} & \beta_{29} & \beta_{2.10} \\ \beta_{31} & \beta_{32} & \beta_{33} & \beta_{34} & \beta_{35} & \beta_{36} & \beta_{37} & \beta_{38} & 1 & \beta_{3.10} \end{bmatrix}$$

$$z'_{t-k+1} = \begin{bmatrix} DRACE, LNYPC, INSTAB, POL, PROP, IY, \\ UC, NESPRP, TOTENROL, T \end{bmatrix}$$

in which T denotes a time trend, and identification proceeds by $\beta_{14} = \beta_{16} = \beta_{17} = 0$; $\beta_{21} = \beta_{24} = \beta_{25} = \beta_{2,9} = 0$; $\beta_{31} = \beta_{35} = \beta_{36} = \beta_{37} = 0$. In addition, we impose weak-exogeneity restrictions on racial fractionalization and the property rights dimension, such that, $\alpha_{11} = \alpha_{12} = \alpha_{13} = \alpha_{51} = \alpha_{52} = \alpha_{53} = 0$.[79] Given space constraints, in the discussion of the empirical results which follows, we focus primarily on the characteristics of the β-cointegrating vectors, though we note the stability characteristics of the structural model that we investigate.[80]

Note that the specification of the structural model is such as to capture the theoretical structure postulated by equations (12). Human capital creation is granted both a direct impact on growth, through the quality dimension, and an mpact on instability through both quantity and quality dimensions.[81] The model also explicitly allows for feedback from institutions to human capital formation - with output, social

[79] The exogeneity restrictions were extensively tested. Results that justify the restrictions under which estimation proceeds here have been presented more extensively elsewhere - see Fedderke and Luiz (2005). Exogeneity of the racial composition of a population has immediate intuitive purchase. While property rights exogeneity may be more controversial, note that the restriction is merely on contemporaneous feedback effects. Moreover, that property rights might lead political rights has additional support in the literature (Sened, 1997; Weimer, 1997; Schultz, 1992), and is justifiable on the grounds that rights over property might be granted in an attempt to lower the danger of political change that might widen access to rights over setting the fundamental rules of the game.

[80] Full details of the α-loading matrix are available from the author on request.

[81] There are a number of possible justifications for this link. One is that rising human capital leads to rising political aspirations, and hence increased pressure to change repressive political systems.

Null	Alternative	Eigenvalue Statistic	95% Critical Value	Trace Statistic	95% Critical Value
$r = 0$	r=1	107.17*	61.22	310.14*	215.79
$r \leq 1$	r=2	63.61*	55.83	202.97*	177.79
$r \leq 2$	r=3	39.20	50.10	139.36**	141.73
$r \leq 3$	r=4	34.04	43.72	100.16	108.90
$r \leq 4$	r=5	22.35	37.85	66.12	81.20
$r \leq 5$	r=6	19.31	31.68	43.77	56.43
$r \leq 6$	r=7	15.60	24.88	24.46	35.37
$r \leq 7$	r=8	8.66	18.08	8.86	18.08

Table 8: Structural Equation Estimation Results

fragmentation and distributional (instability) conflict being afforded the opportunity to impact on human capital investment.

Table 8 reports the maximal eigenvalue and trace statistics on the number of cointegrating vectors present in the data.

Both tests reveal the presence of at least two cointegrating vectors - and in the case of the trace statistic of up to three CV's at the 10% level of significance. Given that the trace statistic has better power characteristics in small samples, and given the theoretical priors of equation (12), we proceed on the assumption of three CV's.

Estimation results are reported in column (1) of Table 9.

Error correction is present for the long-run relationships estimated in the three cointegrating vectors, and all variable signs correspond to theoretical priors. Rising per capita GDP, and improving property rights serve to lower political instability,[82] while rising racial fractionalization (DRACE) serves to raise political instability. Both the quantity and the quality of human capital investment proxies serve to increase the level of instability, though the implied human capital quality elasticity in the instability equation is unusually high. Per capita output responds positively to investment and quality human capital (NESPRP), and negatively to political instability. The only potential surprise arises with respect to the positive association between the user cost of capital and output. Nevertheless, the finding is consistent both with a Romer (1990)-type framework, in which final goods production rises in real interest rate since the sustainable rate of return on capital increases, and (more directly for the current context) with the finding that stringent macroeconomic stabilization policy is growth enhancing.[83] In the third cointegrating vector, the quality of human capital investment rises in the quantity of human capital investment, real per capita GDP, political instability, and political rights.

Impulse response functions confirm the presence of error correction behaviour for

[82] Confirming the findings of Fedderke and Luiz (2005).

[83] The finding has considerable empirical provenance - see for example Barro (1991), Fischer (1993) for early evidence on this link. For the South African time series context the result is strongly confirmed by Mariotti (2002). For a dissenting view Rodrick (2005).

	(1)		
	CV1	CV2	CV3
DRACE	−1273.0 (150.19)	0.00	0.00
LYPC	43.88 (5.28)	1.00	−0.55 (−0.04)
INSTB	1.00	0.002 (0.0003)	−0.003 (0.0002)
POL	0.00	0.00	−0.002 (0.0002)
PROP	0.01 (0.02)	0.00	0.00
IY	0.00	−0.34 (0.09)	0.00
UC	0.00	−0.004 (0.001)	0.00
NESPRP	−500.06 (32.27)	−8.13 (0.49)	1.00
TOTENROL	−27.62 (10.01)	0.00	−0.39 (0.07)
T	−1.74 (0.25)	−0.04 (0.002)	0.01 (0.002)
	Elasticities at Means		
DRACE	−0.61		
LYPC	13.91		−2.89
INSTAB		0.05	−0.05
POL			−0.27
PROP	0.16		
INVRAT		−0.07	
UC		−0.05	
CRIM			
NESPR	−30.28	−1.55	
TENROL	−4.17		−0.97

Table 9: Structural Equation Estimation Results, figues in round parentheses denote standard errors

all three structural relationships.

A number of core implications follow from the estimation.

First, human capital exercises both a direct impact on output (via the quality dimension of human capital investment), and an indirect impact through its impact on political instability. Importantly, while human capital investment serves to raise output through its direct impact, the estimation findings are consistent with the possibility that human capital investment raises political aspirations, and hence political instability under conditions of poor political rights dispensations. The human capital impact on growth thus has two countervailing features. The direct impact on output is positive; but since human capital also serves to raise instability and since instability lowers output, it exercises a negative impact on output also. The net effect of a one percent increase in human capital on the estimated elasticities at variable mean values is marginally negative - though very small (elasticity of 0.06). In the context of developing and middle income countries that often find themselves in political transition, the potential dual impact of human capital may provide at least a partial explanation of why the international literature on the growth impact of human capital finds an unstable, sometimes negative sometimes positive, or ambiguous empirical impact of human capital variables.[84]

Second, human capital itself comes to depend not only on the level of economic development (as measured by per capital GDP), but on the institutional dispensation under which economic agents accumulate human capital. Political instability as well as improving political rights are found to fuel investment in quality human capital. Since political instability is likely present precisely under conditions under which pressure for political reform and hence improving rights are high, such findings are consistent with increased incentives on the part of agents to increase investment in mobile capital (rather than irreversible investment in physical capital), of as high a quality as is feasible. The implied objective is to maximize the accumulation of capital that is maximally mobile in international terms.

The results of Glaeser et al (2004) who find an impact of human capital on institutions finds confirmation from both our structural models.[85] Human capital formation does indeed lead to institutional transformation by stimulating the political instability that finally led to the political transformation of South Africa. The nuance to emerge from the findings reported here is that the institutional context also exercises an influence on human capital formation. Both instability and the level of rights appears to impact on human capital investment decisions also.

Third, the results suggest that the primary channel of influence of social cleavage is through raising the level of (distributional) conflict - in our study measured by political instability.[86] In broad terms our results are thus consistent with the implica-

[84]See Pritchett (2001).

[85]Similar findings are also reported by Djankov et al (2003).

[86]In Fedderke and Luiz (2005) racial fractionalization was also allowed to influence both output and human capital investment directly. While there is some evidence to suggest that there may

tions of for instance Easterly and Levine (1997) [87]- but our findings add the important caveat that the channel of influence through which fractionalization exercises its influence may simply be conflict. Controlling for both conflict (properly measured) and fractionalization in growth specifications may be an unnecessary overspecification of the requisite model.

8. Conclusions and Evaluation

The empirical findings of this paper confirm the presence of endogenous growth processes in the South African economy. Growth in total factor productivity has assumed increasing importance in South Africa's growth performance. Schumpeterian direct impacts from innovative (R&D) activity appear to exert a positive impact on total factor productivity growth in the South African manufacturing industry. In addition, human capital also exerts a statistically significant and potentially strong impact on efficiency gains in the South African manufacturing sector. Crucially, however, the positive impact from human capital attaches to quality human capital, rather than the quantity of human capital.

Endogenous growth processes thus do find support for a middle income country context. We caution that the results presented in the paper point to the presence of endogenous growth processes. They do not necessarily quantify the aggregate magnitude of such effects. Since the focus is on the manufacturing sector of the South African economy, in order to isolate sectors that are most likely to have quality data available, the paper can only draw inference on whether the endogenous growth processes hypothesized in the literature are present in a middle income country context, not how large the effects are likely to be for the economy as a whole.

Some immediate implications follow from these findings. The first is that policy on education cannot focus simply on a quantity dimension. South African education has been successful in widening access - with the very considerable post-1994 achievements being particularly notable in this regard. Concern for the deepening of quality has been of secondary importance. Particularly given the impact of high quality tertiary educational output, it is important that attention begin to turn to the improvement of both primary and secondary preparatory education, as well as to the provision of quality-uncompromised tertiary education. Finally, at one level the evidence that we have presented is reassuring. Investment in human capital offers a means of improving growth performance, provided that we recognize that the impact is one that is manifest in the long-run, and that requires close attention to quality education as well as widening access to education.

Our structural model examining the existence of a direct impact of human cap-

be a direct impact of racial fractionalization on output (perhaps due to poor policy choices), such evidence is weakened by the dynamic instable of such specifications.

[87] Though studies that employ fractionalization either affirming the Easterly and Levine (1997) result, or critical of it, are myriad. See for instance Sachs and Warner (1997); and Englebert (2000).

ital on economic growth within the institutional context, finds that human capital comes to influence not only growth, but distributional conflict also. In particular the structural model found that the quality of human capital raises growth, while both the quality and quantity of human capital raises political instability. Middle income countries often find themselves in circumstances of substantial social and political upheaval. Our findings suggest that under such circumstances, human capital investment potentially is a crucial component of such dynamics, by raising political aspirations and hence the motivation for social and political transformation. Since human capital does not stand alone, but itself comes to respond to economic (as well as institutional) development, embarking on a positive growth path may endogenously lead to social and political transformation.

Pointing to the possibility that social, institutional and political dimensions may be important to growth is helpful in widening our understanding of long-run economic prospects, and the mechanisms through which human capital exercises its influence - but the central finding that human capital, particularly in its quality dimension, is an important driver of long-run growth remains unchallenged by the detailed middle income country specific evidence considered in this paper.

Appendix1 : The R&D Expenditure Data

The R&D expenditure data is collected from the CSIR and Scientific Adviser to the Prime Minister/President survey results on R&D activity in South Africa by economic sector. Expenditure figures are real. Survey dates are 1969/70, 1973/74, 1975/76, 1977/78, 1979/80, 1981/82, 1983/84, 1985/86, 1987/88, 1989/90, 1991/92, 1993/94. A further survey was available for 1997, but unfortunately data were not comparable to earlier samples. Two further samples, 1977/78 and 1981/82, gave outlier values that were implausible, and thus required interpolation. In samples after 1979/80 survey data is presented in aggregated manufacturing "clusters". Decomposition of the "clustered" data was undertaken according to average compositions of R&D expenditure over the 1970-79 period. The Coke & refined petroleum products series is not defined for the 1973/74 and 1975/76 surveys. The relative contribution of this sector could thus only be calculated on the 1969/70 survey results. Since this survey predates the impact of SASOL, the Coke & refined petroleum products R&D series is thus likely to be biased downward.

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