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Technology, Human Capital and Growth: Evidence from a Middle Income Country Case Study Applying Dynamic Heterogeneous Panel Analysis

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ABSTRACT: This 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 both knowledge spill-over effects, and of positive impacts on total factor productivty growth by Schumpeterian innovative activity. A crucial finding is that spill-over effects emerge from investment in human rather than physical capital, and that the quality dimension in human capital investment is vital in generating innovation.
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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 factor.

In this paper we are concerned with two crucial questions that emerge from the endogenous growth literature. In the first instance, while some attention has been paid to the question of evidence in favour of endogenous growth processes in the context of cross-sectional studies, the dynamic evidence is more limited. The first contribution of the present paper is to examine the possibility of endogenous growth processes in the manufacturing sectors of a specific country, employing dynamic heterogeneous panel analysis. While work has been undertaken in the application of panel analysis to growth evidence, the application of the new advances represented by dynamic heterogeneous panel analysis holds out the promise of additional insight.

The second question is a deeper conceptual one. A range of empirical evidence has emerged that suggests that growth in less developed and middle income countries is generally capital-intensive, with relatively little scope for contributions from growth in total factor productivity.[1] By contrast, it has long been established that total factor productivity growth plays a very significant role in the growth experience of developed economies.[2] The implication would appear to be that endogenous growth processes could only be relevant to developed, and not developing countries. If these findings are correct, some important dynamic puzzles arise. How, and at what stage do economies move from a growth process that is purely capital intensive, to one that is knowledge intensive? What is the nature of the transition in which the role of total factor productivity growth becomes of increased importance? More fundamentally, one should note that the source of endogenous growth processes would become obscure on at least some accounts provided by the literature. Learning-by-doing and associated postulated spill-over effects would be difficult to isolate only to developed country contexts. The positive impact of intentional innovative (R&D) activity under Schumpeterian approaches similarly would be difficult to exclude in developing country contexts.

[1] See for instance the discussion in Lim (1994).

[2] Some classic references are Abramovitz (1956), Denison (1967) and Maddison (1987), and see the discussion in Fagerberg (1994).

For these reasons an understanding of whether or not endogenous growth processes are present in middle income countries carries general theoretical as well as empirical interest. In addition, for policy makers it is vital that the precise nature of the endogenous growth process be identified, since the nature of the appropriate policy intervention varies with the form of endogenous growth postulated.

We note at the outset that the undertaking is not one without promise for South Africa. In particular, Fedderke (2001b) demonstrates that growth in the South African economy, and the manufacturing sector in particular over the 1970-97 period has been characterized by potentially strong total factor productivity growth. There is thus at least a question to be asked concerning the potential presence of endogenous growth processes. In section 2 of the paper we outline the estimation methodology to be employed in testing for endogenous growth. Section 3 outlines the econometric methodology and the data deployed in the study. Section 4 presents results, and section 5 concludes.

2 Testing for Endogenous Growth Effects

Computation of Total Factor Productivity (TFP) growth is generally by means of the standard primal estimate given by:

$$TFP = \frac{\dot{Y}}{Y} - s_K \frac{\dot{K}}{K} - s_L \frac{\dot{L}}{L} \tag{1}$$

where s_K and s_L denote the shares of capital and labour in output respectively, Y denotes output, K capital, and L labour. However, it is vital to realize that evidence to emerge from the simple growth accounting decomposition can only be understood to be broadly indicative. The literature on growth accounting since the contributions of Denison (1962, 1967, 1974) has provided further sophistication to the decomposition, and further extensions have emerged due to the developments in endogenous growth theory discussed above (for a useful overview of the developments see Barro 1998).[3]

The first crucial limitation of the simple decomposition approach outlined above is that it does not disaggregate factor inputs by quality classes.

[3] An alternative methodology, combining the insights from new growth and new trade theory, is given by Anderton (1999). Unfortunately data limitations for South Africa preclude its use. Findings support the conclusion that relative R&D and patenting activity influence import penetration and hence long term growth prospects.

The work of Jorgenson and Grilliches (1967) and Jorgenson, Griliches and Fraumeni (1987) demonstrates the potentially substantial impact this carries for the conclusions to be drawn from the decomposition. Given the extent of segmentation in South African labour markets, the impact of factor input quality is potentially of considerable significance. Unfortunately data limitations preclude the possibility of pursuing this line of enquiry further.

A second limitation of the simple growth decomposition 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. Both factor input growth rates are unlikely to prove exogenous with respect to output growth rates, raising the prospect of bias and inconsistency in parameter estimates due to simultaneity. Moreover, both factor input growth rates are likely to be subject to considerable measurement error, once again raising the prospect of inconsistent parameter estimates. The problem is of particular significance for the capital growth rate, for which capacity utilization carries important implications, and the likelihood of an *under*estimation of the contribution of growth in the capital stock to output growth. For these reasons, while regression approaches are not unheard of, the predominant approach in the literature remains rooted in growth accounting decomposition approaches. The present study follows suit.

But the most significant limitation of the simple decomposition approach attaches to its assumption of constant returns to scale. Since endogenous growth theory directs its most fundamental challenge against traditional growth theory against this very assumption, this constitutes a fundamental limitation.[4] Fortunately the limitation is also fairly readily addressed. 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:[5]

$$\begin{aligned} TFP &= \frac{\dot{Y}}{Y} - \alpha\frac{\dot{K}}{K} - (1-\alpha)\frac{\dot{L}}{L} \\ &= \frac{\dot{A}}{A} + \beta\frac{\dot{K}}{K} \end{aligned} \tag{2}$$

[4] For an overview of some central endogenous growth contributions, see Fedderke (2001a).

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

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 conventional approach of Romer (1986), the appropriate growth rate is in terms of physical capital stock, or under the Lucas (1988) specification in terms of investment in human capital. One should note immediately that a significant limitation of the approach will remain the potential of bias and inconsistency in estimation due to the possibility of simultaneity.

Under a Schumpeterian approach with an increasing variety of intermediate (capital) goods (denoted X),[6] we have instead:

$$\begin{aligned} TFP &= \frac{\dot{Y}}{Y} - s_L\frac{\dot{L}}{L} - s_X\frac{\dot{X}}{X} \\ &= \frac{\dot{A}}{A} + b\frac{\dot{N}}{N} \end{aligned} \tag{3}$$

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[7] 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 $b \to 1$ associated with "high", and $b \to 0$ 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 3 it can be readily demonstrated that TFP growth is linear in the ratio of the

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

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

R&D flow measure to per capita output, easing the requirements of empirical specification.[8] The only remaining problem with the empirical specification is that the danger of simultaneity bias continues to lurk. In particular, there is no reason to suppose that R&D activity would not respond to exogenous 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.

We now proceed with an application to South African data.

3 The Econometric Methodology and the Data Employed

3.1 The Data

The focus of the empirical work in this section is on the manufacturing sector of the economy. The reason for the choice is determined predominantly by data reliability and availability considerations.

We employ a panel data set for purposes of estimation, with observations from 1970 through 1997. The panel employs data for the 28 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 28×28 panel with a total of 784 observations, though for some estimations some sectors did not have the requisite data available.[9] For data on TFP growth in South African manufacturing, we rely on Fedderke (2001b)

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

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

[9] 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.

1	Food
2	Beverages
3	Tobacco
4	Textiles
5	Wearing apparel
6	Leather & leather products
7	Footwear
8	Wood & wood products
9	Paper & paper products
10	Printing, publishing & recorded media
11	Coke & refined petroleum products
12	Basic chemicals
13	Other chemicals & man-made fibres
14	Rubber products
15	Plastic products
16	Glass & glass products
17	Non-metallic minerals
18	Basic iron & steel
19	Basic non-ferrous metals
20	Metal products excluding machinery
21	Machinery & equipment
22	Electrical machinery
23	Television, radio & communications equipment
24	Professional & scientific equipment
25	Motor vehicles, parts & accessories
26	Other transpor equipment
27	Furniture
28	Other industries

Table 1: Key to sectoral numbers

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:[10]

- The school enrolment rate, for the "white" racial group in South Africa.[11] 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 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 school enrolment rate, for the "black" (African) racial group in South Africa. For blacks the age cohort is the 5-24 age group since a significant proportion of pupils in the black schooling system are likely to complete schooling into their mid-20's.[12] We denote the variable BENROL.

- 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.[13] We denote the variable MATHPRP.

[10] See 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. We do the best we can in the current context. Solow (1997:85) offers a reminder of the intrinsic difficulties associated with the measurement of human capital.

[11] Both the "white", the "black" 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.

[12] See the discussion in Wittenberg (1999). Completion of schooling takes longer in South Africa's black population groups. The inequalities in resourcing detailed by the studies from which the data is sourced suggests many reasons why this might be the case - none of which implies fault on the part of the pupils themselves. But this is not our current concern.

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

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.[14] 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 BENROL 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:[15]

- 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.
- 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.
- Apprenticeship contracts issued per capita. We denote the variable APPCAP.

[14] Fedderke, de Kadt and Luiz (2000) provides extensive detail, while Fedderke and Luiz (1999) provides confirmation of the quality differential in the context of a schooling production function.

[15] For details on the construction of all of these variables see Fedderke, de Kadt and Luiz (2001b).

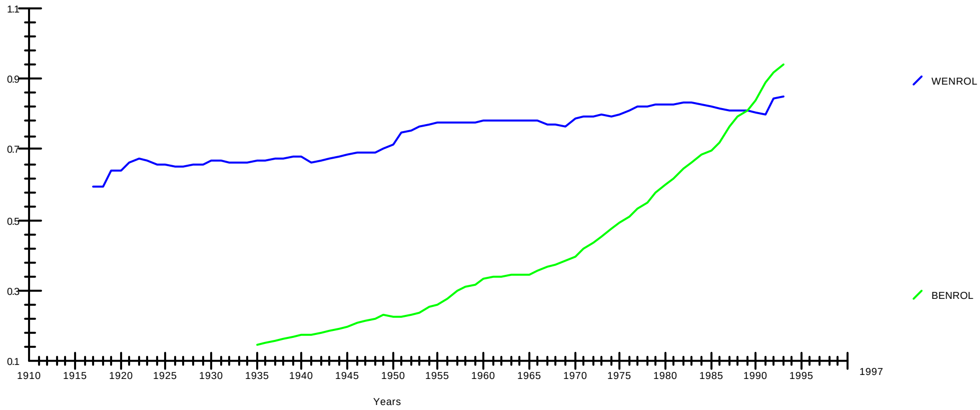

Figure 1: "White" and "Black" school enrolment rates.

Again, the degrees and apprenticeship contracts issued both serve as measures 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.

Finally, we also introduce a number of additional variables that proxy either 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.[16] We denote the variable as PATENT.
- 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.[17] We denote the variable as PROPERTY.
- The skills mix of the labour force in each manufacturing sector. The

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

ratio is of high and medium skill levels to unskilled labour. We denote the variable as SKRAT.

- The net export ratio of each manufacturing sector,[18] incorporated on the hypothesis encountered in the literature that export competitiveness may require strong innovative capacity. We denote the variable as NX.

- 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.[19] All expenditure is real. Fuller detail is provided in the data appendix to the paper.

We turn now to issues arising from estimation.

3.2 The Econometric Methodology

The estimator is provided by the Pooled Mean Group Estimator Methodology provided by Pesaran, Shin and Smith (1999).

Following Pesaran, Shin and Smith (1999), we base our panel analysis on the unrestricted error correction ARDL(p, q) representation:

$$\Delta y_{it} = \phi_i y_{i,t-1} + \boldsymbol{\beta}_i' \mathbf{x}_{i,t-1} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \boldsymbol{\delta}_{ij}' \Delta \mathbf{x}_{i,t-j} + \mu_i + \varepsilon_{it}, \quad (4)$$

$i = 1, 2, ..., N$, stand for the cross-section units, and $t = 1, 2, ..., T$, indicate time periods. Here y_{it} is a scalar dependent variable, $\mathbf{x}_{it}$ $(k \times 1)$ is the vector of (weakly exogenous) regressors for group i, μ_i represent the fixed effects, ϕ_i is a scalar coefficient on the lagged dependent variable, $\boldsymbol{\beta}_i$ is the $k \times 1$ vector of coefficients on explanatory variables, λ_{ij}'s are scalar coefficients on lagged first-differences of dependent variables, and $\boldsymbol{\delta}_{ij}$'s are $k \times 1$ coefficient vectors on first-difference of explanatory variables and their lagged values. We assume that the disturbances ε_{it}'s are independently distributed across i

[18] Computed as $\frac{X}{X+IM}$ where X denotes exports, and IM imports.

[19] 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).

and t, with zero means and variances $\sigma_i^2 > 0$. We also make the assumption that $\phi_i < 0$ for all i and thus there exists a long-run relationship between y_{it} and $\mathbf{x}_{it}$:

$$y_{it} = \boldsymbol{\theta}_i'\mathbf{x}_{it} + \eta_{it}, \ i = 1, 2, ..., N, \ t = 1, 2, ..., T, \tag{5}$$

where $\boldsymbol{\theta}_i = -\boldsymbol{\beta}_i'/\phi_i$ is the $k \times 1$ vector of the long-run coefficient, and η_{it}'s are stationary with possibly non-zero means (including fixed effects). Then, equation 4 can be written as

$$\Delta y_{it} = \phi_i \eta_{i,t-1} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \boldsymbol{\delta}_{ij}' \Delta \mathbf{x}_{i,t-j} + \mu_i + \varepsilon_{it}, \tag{6}$$

where $\eta_{i,t-1}$ is the error correction term given by (5), and thus ϕ_i is the error correction coefficient measuring the speed of adjustment towards the long-run equilibrium.

Under this general framework we will consider the following three approaches: *First*, the dynamic fixed effects (DFE) model which imposes the homogeneity assumption for all of the parameters except for the fixed effects: *viz.* for $i = 1, ..., N$,

$$\begin{aligned} \phi_i &= \phi; \ \boldsymbol{\beta}_i = \boldsymbol{\beta}; \ \lambda_{ij} = \lambda_j, \ j = 1, ..., p-1; \\ \boldsymbol{\delta}_{ij} &= \boldsymbol{\delta}_j, \ j = 1, ..., q-1; \ \sigma_i^2 = \sigma^2. \end{aligned} \tag{7}$$

The fixed effects estimates of all the short-run parameters are obtained by pooling and denoted by $\hat{\phi}_{DFE}$, $\hat{\boldsymbol{\beta}}_{DFE}$, $\hat{\lambda}_{jDFE}$, $\hat{\boldsymbol{\delta}}_{jDFE}$, and $\hat{\sigma}^2_{DFE}$. The estimate of the long-run coefficient is then obtained by

$$\hat{\boldsymbol{\theta}}_{DFE} = -(\hat{\boldsymbol{\beta}}_{DFE}/\hat{\phi}_{DFE}). \tag{8}$$

Secondly, the mean group (MG) estimates proposed by Pesaran and Smith (1995), which allows for heterogeneity of all the parameters and gives the following MG estimates of short-run and long-run parameters:

$$\begin{aligned} \hat{\phi}_{MG} &= \frac{\sum_{i=1}^N \hat{\phi}_i}{N}; \ \hat{\boldsymbol{\beta}}_{MG} = \frac{\sum_{i=1}^N \hat{\boldsymbol{\beta}}_i}{N}; \\ \hat{\lambda}_{jMG} &= \frac{\sum_{i=1}^N \hat{\lambda}_{ij}}{N}, j = 1, ..., p-1; \hat{\boldsymbol{\delta}}_{jMG} = \frac{\sum_{i=1}^N \hat{\boldsymbol{\delta}}_{ij}}{N}, j = 1, ..., q-1, \end{aligned} \tag{9}$$

where $\hat{\phi}_i$, $\hat{\boldsymbol{\beta}}_i$, $\hat{\lambda}_{ij}$ and $\hat{\boldsymbol{\delta}}_{ij}$ are the OLS estimates obtained individually from (6), and

$$\hat{\boldsymbol{\theta}}_{MG} = N^{-1}\sum_{i=1}^{N} -(\hat{\boldsymbol{\beta}}_i/\hat{\phi}_i). \tag{10}$$

Finally, we consider the Pooled Mean Group (PMG) estimator advanced by Pesaran, Shin and Smith (1999), which provides an intermediate case between the above two extreme cases. This estimator allows the intercepts, short-run coefficients and error variances to differ freely across groups, but the long-run coefficients are constrained to be the same; that is,

$$\boldsymbol{\theta}_i = \boldsymbol{\theta},\ i = 1, 2, ..., N. \tag{11}$$

The common long-run coefficients and the group-specific short-run coefficients are computed by the pooled maximum likelihood (PML) estimation. These PML estimators are denoted by $\tilde{\phi}_i$, $\tilde{\boldsymbol{\beta}}_i$, $\tilde{\lambda}_{ij}$, $\tilde{\boldsymbol{\delta}}_{ij}$ and $\tilde{\boldsymbol{\theta}}$. We then obtain the PMG estimators as follows:

$$\begin{aligned} \hat{\phi}_{PMG} &= \frac{\sum_{i=1}^{N}\tilde{\phi}_i}{N};\ \hat{\boldsymbol{\beta}}_{PMG} = \frac{\sum_{i=1}^{N}\tilde{\boldsymbol{\beta}}_i}{N}; \\ \hat{\lambda}_{jPMG} &= \frac{\sum_{i=1}^{N}\tilde{\lambda}_{ij}}{N}, j = 1, ..., p-1; \hat{\boldsymbol{\delta}}_{jPMG} = \frac{\sum_{i=1}^{N}\tilde{\boldsymbol{\delta}}_{ij}}{N}, j = 1, ..., q-1, \\ \hat{\boldsymbol{\theta}}_{PMG} &= \tilde{\boldsymbol{\theta}}. \end{aligned} \tag{12}$$

This clearly highlights both the pooling implied by the homogeneity restrictions on the long-run coefficients and the averaging across groups used to obtain means of the estimated error-correction coefficients and other short-run parameters.

We briefly discuss one important modelling issue. In principle, we need to choose between the alternative specifications. Tests of homogeneity of error variances and/or short- or long-run slope coefficients can be easily carried out using Log-Likelihood Ratio tests, since the PMG and DFE estimators are restricted versions of (possibly heterogeneous) individual group equations. It is worth noting, however, that for most cross-country studies the Likelihood Ratio tests usually reject equality of error variances and/or slopes (short-run or long-run) at conventional significance levels. We note in passing that the finite sample performance of such tests are generally unknown and thus unreliable. An alternative would be to use Hausman (1978) type tests. The MG estimator provides consistent estimates of the mean of the long-run coefficients, though these will be inefficient if slope homogeneity holds. For example, under long-run slope homogeneity the PMG estimators are consistent and efficient. Therefore, the effect of both long-run and short-run heterogeneity on the means of the coefficients can be determined by the Hausman test (hereafter h test) applied to the difference between MG and PMG or DFE estimators.

This paper will examine the extent of panel heterogeneity mainly in terms of difference between MG and PMG estimates of long-run coefficients using the Hausman test. A significant test result (in combination with the Log-Likelihood Ratio test results) suggests the adoption of a more pragmatic approach: division of the total group of samples into sub-group samples. However, in what follows we will only report the results of estimations across the full sample.

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.

Finally, it is worth pointing out once again that a crucial advantage of the estimation approach of the present paper, is that dynamics are explicitly modelled.

4 The Results

4.1 Spill-Over Effects

In Table 2 we report the results from dynamic heterogenous panel estimation of the empirical specification provided by equation 2 for South Africa's 28 manufacturing sectors. In estimation we allow for both the Romer (1986) specification and the Lucas (1988) specification. We thus regress growth in total factor productivity on capital stock growth, as well as a range of alternative indicators of human capital investment introduced in the data section above.[20] In line with our prior indication of preference for the Pooled

[20]We also allowed for joint Romer-Lucas effects, by incorporating both capital stock growth as well as the alternative human capital measures. None of the findings here re-

Mean Group estimator we report only the PMGE results in Table 2.[21]

We note immediately that for all specifications estimation results confirm not only adjustment to equilibrium, but rapid adjustment (see the estimated ϕ terms). Moreover, both the Hausman as well as the Log-Likelihood Ratio 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.

Further, while the results confirm the presence of spill-over effects for South African manufacturing, it is important to note that the confirmation is not unconditional. In the first instance we should note that to the extent that spill-over effects are corroborated, they take the form suggested by Lucas (1988) rather than Romer (1986). The coefficient on the growth rate of the capital stock is consistently negative (even where we control for investment in human as well as physical capital) and statistically significant. Since the coefficient of the capital growth rate should control for the positive contribution of capital stock over and above that implied by its income share due to spill-overs, this constitutes a rejection of Romer-type spill-over effects in South African manufacturing industry.

On the other hand, Lucas-type spill-over effects do find some support, in the sense that at least some of the human capital investment variables prove to have positive and significant coefficients. However, even here the support for Lucas spill-overs is circumscribed. In particular, only very specific types of investment in human capital contribute positively to productivity growth. The proportion of matriculation students sitting mathematics, and the proportion of NES degrees in total degrees are the only two human capital variables that provide a positive and significant contribution to productivity growth in South African manufacturing industry over the 1970-97 period.

By contrast, the total school enrollment rate, and the total number of degrees issued by South African universities while significant, contributed negatively to total factor productivity growth, while the white school enrollment rate, the total number of NES degrees, and the number of apprenticeship contracts per capita prove to be insignificant.

These findings are consistent with those of Fedderke, De Kadt and Luiz (2000), Fedderke and Luiz (1999) and Fedderke, De Kadt and Luiz (2001b),

ported was altered under the joint specification, and hence we do not report them explicitly. They are available from the author on request.

[21] Full DFE and MGE results are available from the author on request.

Dependent Variable: Growth in Total Factor Productivity				
Regressors		$ECM\ \phi$	h-test	LR: $\chi^2_{\{d.f.\}}$
$\frac{\dot{K}}{K}$	-0.004^* (.000)	-0.95^* (0.04)	1.17 [0.28]	49.59 {27}
WENROL	-0.03 (0.34)	-0.91^* (0.05)	0.03 [0.85]	24.49 {27}
TOTENROL	-0.12^* (0.04)	-0.93^* (0.05)	0.71 [0.40]	23.95 {27}
MATHPRP	0.11^* (0.04)	-0.93^* (0.05)	0.08 [0.78]	26.66 {27}
DEGREE	$-0.1 \times 10^{-4*}$ (0.1×10^{-5})	-0.95^* (0.05)		18.96 {27}
NESDEG	0.00 (0.00)	-0.95^* (0.05)		19.34 {27}
NESDEGPRP	0.79^* (0.32)	-0.93^* (0.05)	0.66 [0.42]	28.62 {27}
APPCAP	13.82 (15.13)	-0.91^* (0.05)	0.70 [0.40]	22.14 {27}
lnPATENT	0.01^* (0.004)	-0.90^* (0.05)	0.57 [0.45]	19.53 {27}

Table 2: Testing for Spill Over Effects, Figures in round parentheses denote standard errors, in square parentheses probability values, and curly parentheses degrees of freedom, * denotes significance

which all point to the very significant inefficiency of educational production in South African schooling and tertiary educational systems. It appears that the inefficient use of resources pointed out in the earlier work in primary, secondary and tertiary education in South Africa was costly not only for the educational system directly, but also proves harmful for the innovative capacity of the real economy.

What counts for purposes of the innovative activity that is coupled to long run output growth in South African manufacturing, is not so much the production of human capital *per sê*, but the production of quality human capital, as proxied by the math and NES degree proportions. And there are at least two good reasons that make this finding plausible. The first is that quality human capital is simply more likely to have the positive spill-over effects identified by Lucas (1988), while poor quality human capital does not. A second interpretation of the evidence might point to an improved quality of screening by the educational system (both primary and secondary, and tertiary) with rising math and NES degree proportions. This is turn might be hypothesized to reduce the risk faced by producers wishing to hire human capital for purposes of innovative activity.

However, subject to these caveats, we note that endogenous growth processes find support from the evidence from South African manufacturing. The crucial distinctions are that the spill-overs appear to attach to human rather than physical capital, and that it is quality human capital rather than generalized human capital that generates the spill-over.

4.2 Schumpeterian R&D Impacts

In our second empirical investigation surrounding the presence of endogenous growth effects in South African manufacturing, we proceed with an estimation of the empirical specification provided by equation 3. As discussed above, we thus regress growth in total factor productivity on the ratio of R&D expenditure to per capita output. The literature also suggests a range of additional factors relevant to the determination of productivity gains.[22] Both choices by firms (innovative activity, input choices, product output), as well as market interactions (competition type, market share), and indeed the interaction of market structure and firm choices can come to influence

[22] Bartelsman and Doms (2000) provides a useful overview of the issues.

growth in total factor productivity.[23] The factors advanced in the literature as relevant to total factor productivity growth are:

- *R&D:* we have already introduced the importance of R&D in a number of contexts above. Here we note merely that R&D finds empirical support as a determinant of productivity growth.[24]

- *Labour quality and human capital:* since the quality of the labour force may determine the technology that may feasibly be employed by firms,[25] while human capital investment by the society as a whole may improve the capacity to absorb technological advance.[26]

- *International Exposure*: export performance and productivity growth appear to be related. Possible reasons for this may be that export-activity selects in productive firms, that export activity may increase the exposure of firms to more productive firms and other learning opportunities, and the opportunity to exploit more efficient scales of production.[27]

- *Managerial Ability and Ownership Structure*: both the quality of management[28] and ownership structure[29] (being owned by a productive firm will lead to technology transfer and productivity gains) has been advanced as having an impact on innovation.

[23] 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 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.

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

[25] See for example the findings in Doms, Dunne and Troske (1997), and Entorff and Kramarz (1998).

[26] See for example the discussion in Nelson and Wright (1992) and Fagerberg (1994). Landes (2000:277-8) provides an illustration with respect to the Jura valley in Switzerland and its take-off into clock making.

[27] See 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).

[28] See for instance Jovanovic (1982).

[29] See for instance Baily, Hulten and Campbell (1992), Lichtenberg (1992), and McGuckin and Sang (1995).

- *Regulation*: regulatory changes are seen as affecting productivity growth through a number of possible channels. Regulation is capable of affecting barriers of entry, hence market structure including in terms of the degree of vertical integration of markets, and market share and the degree of competitive pressure in industries.[30]

Given data limitations, we cannot control for managerial ability, ownership structure and regulation at the level of aggregation determined by the data set of this study. We do however control for the skills ratio in production, the net export ratio of the manufacturing sector, and a range of indicators of human capital investment. Thus we estimate:

$$TFP = \alpha + \beta_1 \left(\frac{R\&D}{Y/L} \right) + \beta_2 SKRAT + \beta_3 NX + \beta_4 H \tag{13}$$

where H denotes the various human capital investment proxies introduced above.

A final consideration concerns the possibility of simultaneity bias attaching to the $\frac{R\&D}{Y/L}$ variable identified in the discussion above. To address this problem we instrument the $\frac{R\&D}{Y/L}$ variable.[31] While the regressor in equation 13 is constructed with private sector R&D expenditure, we employ SURE estimations[32] 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.[33] We report the results of the SURE estimations in Table 3. Reported χ^2 test statistics based on equation and system log likelihoods establish the presence of non-diagonal error covariance matrices throughout, confirming the appropriateness of SURE estimation.

[30] See for instance the discussion in Pakes and McGuire (1994), Hopenhayn and Rogerson (1993) and Olley and Pakes (1996).

[31] 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.

[32] 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. 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.

[33] 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}
Tobacco†		49.80 (40.40)	1837.60* {20}
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}
Coke & Petroleum	1.07 (1.00)	17.40 (0.58)	279.81* {15}
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}
TV, Comms etc	-	-	-
Professional, Scientific, etc	-	-	-
Motor Vehicles	−0.16 (0.38)	14.74 (1.94)	188.50* {20}
Other Transport	0.02 (0.01)	2.30 (0.21)	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 3: Results of SURE instrumenting estimation, Figures in round parentheses represent standard errors

Dependent Variable: Growth in Total Factor Productivity					
	1	2	3	4	5
$\ln\left(\frac{R\&D}{Y/L}\right)$	0.009 (0.005)	0.02* (0.01) [0.36]	0.03* (0.01) [0.07]	0.02* (0.01) [3.56]	0.02* (0.01) [–]
SKRAT		−0.14* (0.04) [0.01]	−0.11* (0.04) [1.18]	−0.13* (0.04) [1.93]	−0.13* (0.04) [–]
NX		0.01 (0.03) [3.44*]	0.02 (0.03) [4.85*]	0.004 (0.03) [3.82]	0.004 (0.03) [–]
WENROL		−0.67* (0.30) [0.70]			
TOTENROL			−0.09 (0.05) [2.17]		
MATHPRP				0.02 (0.04) [6.42*]	
DEGREE					-0.1×10^{-5} (0.1×10^{-5}) [–]
$ECM\ \phi$	−1.065* (0.05)	−0.81* (0.07)	−0.80* (0.07)	−0.79* (0.07)	−0.83* (0.07)
h-test	0.11 [0.74]	4.00 [0.41]	6.70 [0.15]	15.95 [0.00]	–
LR: χ^2 $\{d.f.\}$	26.24 {25}	235.84* {88}	267.81* {88}	256.08* {88}	246.13* {88}

Table 4: 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

As a final step we now turn to the estimation of equation 13. We report results in Tables 4 and 5.

Again, for all specifications estimation results confirm not only adjustment to equilibrium, but rapid adjustment (see again the ϕ-parameters). Moreover, the Hausman tests continue to confirm the legitimacy of the PMG estimator by failing to reject the homogeneity restriction on the long run coefficients for South African manufacturing sectors (with only two exceptions). Given the unknown finite sample properties of the LR test statistic, we thus proceed on the assumption of long run parameter homogeneity.

The results otherwise confirm the presence of a positive impact of R&D expenditure on growth in total factor productivity, as postulated by Schumpeterian theory. Patent registrations could be argued to carry much the same information (see regression 9). Thus the findings confirm the presence of the positive impact on output growth of innovative R&D activity undertaken by

Dependent Variable: Growth in Total Factor Productivity					
	6	7	8	9	10
$\ln\left(\frac{R\&D}{Y/L}\right)$	0.02^* (0.01) [–]	0.02^* (0.01) [1.53]	0.01 (0.01) [0.06]	−0.01 (0.01) [0.33]	0.002 (0.01) [0.00]
SKRAT	-0.14^* (0.04) [–]	-0.12^* (0.04) [1.13]	-0.11^* (0.04) [0.18]	-0.07^* (0.03) [0.23]	-0.06^* (0.03) [4.11*]
NX	0.03 (0.03) [–]	0.05 (0.03) [4.47*]	−0.02 (0.03) [6.10*]	0.03 (0.02) [2.47]	0.02 (0.03) [2.80]
NESDEG	-0.1×10^{-5} (0.1×10^{-5}) [–]				
NESDEGPRP		1.00^* (0.39) [0.05]			
APPCAP			-50.75^* (19.52) [0.30]		
lnPATENT				0.02^* (0.00) [0.24]	
lnPROPERTY					0.01 (0.02) [0.98]
$ECM\ \phi$	-0.83^* (0.07)	-0.81^* (0.06)	-0.90^* (0.06)	-0.89^* (0.06)	-0.92^* (0.05)
h-test	–	8.10 [0.09]	11.87 [0.02]	–	–
LR: $\chi^2_{\{d.f.\}}$	261.32^* {88}	210.32^* {88}	239.39^* {88}	160.01^* {88}	196.09^* {88}

Table 5: Schumpeterian Results II, 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

the private sector. We note further that the coefficient on the R & D variable $\longrightarrow 0$ rather than $\longrightarrow 1$. On the varieties interpretation this suggests a low elasticity with respect to intermediate imports. On the quality bidders interpretation, it suggests "small" quality differentials. It should be noted however that this positive effect on output growth emerges only after appropriate instrumenting, in order to account for the feedback from productivity growth on R&D. In the absence of instrumenting, the impact of private sector R&D expenditure remains significant but carries a negative sign. The implication is that the simultaneity noted as potentially relevant in estimation is indeed present and of significance, biasing the non-instrumented coefficient.

Perhaps equally significantly, net exports of manufacturing sectors had *no* net impact on the innovative activity of the manufacturing sectors in South Africa in any of the models tested. By contrast, the skills ratio was consistently negative, and significant. The implication is that in South African manufacturing efficiency gains were more likely in unskilled intensive sectors than in skilled intensive sectors. Given that South Africa's major trading partners over the past three decades have been developed economies, and since relative to these economies South Africa is relatively unskilled labour intensive in production, one interpretation of this result is that it reflects South African comparative advantage.[34] Perhaps a more likely explanation is provided by the fact that unskilled labour intensive sectors in the South African economy have been shedding labour to a significant extent due to a mispricing of unskilled labour.[35] Thus unskilled labour intensive sectors of the economy may have been experiencing productivity gains simply due to reductions in labour inputs.

Finally, the range of human capital indicators again point to the possibility of a positive impact of human capital spill-overs on productivity growth, or of the general enabling environment for innovation indicated by the human capital dimension. However, just as for the spill-over discussion above, the particular dimension of human capital investment controlled for proves to be crucial. The positive impact on productivity growth emerges from the NES degree proportion variable (as it did for the spill-over discussion), while a number of human capital variables prove to be negative and significant (WENROL, APPCAP) or insignificant. The interpretation of this evidence

[34] For instance, Fedderke, Shin and Vaze (2000) find evidence consistent with Stolper-Samuelson effects for South Africa.

[35] See for instance the discussion in Fedderke, Shin and Vaze (2000), Fedderke, Henderson, Mariotti and Vaze (2000), and Fedderke and Pirouz (2000).

remains much the same as for the spill-over section. While the human capital dimension can legitimately be argued to have a positive impact on long run productivity growth, it is above all the *quality* dimension of human capital that exercises this effect rather than the quantity of human capital.

The empirical evidence from South African manufacturing industry thus appears to point to a positive impact from both explicit R&D activity, as well as the human capital dimension, particularly the quality dimension of the latter.

5 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 the direct impact of human capital on long run economic growth noted by Mankiw, Romer and Weil (1992).

Descriptive analyses of the human capital creation process in South Africa are now readily available, providing relatively long time series. The implication of this descriptive evidence is that matters are not as sound as we might like them to be.[36] However, in the context of interest in long run economic development the question must be whether there is evidence to suggest that this really matters in hard growth terms?

In this final section we therefore examine the impact of the human capital dimension on the long run economic performance of South Africa. In the preceding section we have already established that at least for the manufacturing sector, investment in human capital in a number of distinct dimensions does appear to be adding to total factor productivity growth. In this section our focus is on the impact of human capital on long run growth performance for the economy in aggregate. In order to examine this question we employ a standard growth equation, incorporating investment in both physical and human capital as potential determinants of economic growth.

The specification employed is given by:[37]

$$\ln Y = F\left(\frac{I}{Y}, H\right) \tag{14}$$

[36] The reader is referred to Fedderke, De Kadt and Luiz (2000, 2001b) for exhaustive descriptive accounts of the empirical evidence. Space considerations preclude a revisitation at this point.

[37] This mirrors the specification employed by Mankiw et al (1992).

where $\ln Y$ denotes the natural log of real per capita output (GDP) of the economy, $\frac{I}{Y}$ denotes the investment rate given by the ratio of real gross domestic fixed investment to real GDP, and H denotes a vector of human capital variables.

As empirical methodology we employ the vector error correction methodology of Johansen, incorporating the cointegration techniques appropriate to nonstationary time series data. Johansen[38] techniques of estimation employ a vector error-correction (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:

$$z_t = A_1 z_{t-1} + ... + A_m z_{t-m} + \mu + \delta_t \tag{15}$$

where m denotes lag length, and δ a Gaussian error term. While in general z_t may contain $I(0)$ elements, as long as non-stationary variables are present as in the present case, we are exclusively restricted to $I(1)$ elements. Reparametrization provides the VECM specification:

$$\Delta z_t = \sum_{i=1}^{k-1} \Gamma_i \Delta z_{t-i} + \Pi z_{t-k+1} + \mu + \delta_t \tag{16}$$

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

$$H_1(r) : \Pi = \alpha\beta' \tag{17}$$

where Π is $p \times p$, and α, β are $p \times r$ matrices of full rank. $H_1(r)$ is thus the hypothesis of reduced rank of Π. Where $r > 1$, issues of identification arise.[39]

Augmented Dickey-Fuller test statistics confirm all variables to be $I(1)$ - see Table 6.

We examine two specifications, employing the two alternative tertiary education variables, DEGREES and NSDEGREES, and we report trace and maximal eigenvalue statistics in Tables 7 and 8, and the results of estimation for the long run equilibrium relationships in Table 9.

The quality of the two sets of results is strongly differentiated. First, note that the long run relationship that included *total* degrees issued (DEGREES) has none of the human capital variables statistically significant. The only significant determinant of the output variable is the investment rate. Thus on

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

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

Variable	$\mathbf{I}(0)$	$\mathbf{I}(1)$
$\ln Y$	-2.44	-4.85^*
$\frac{I}{Y}$	-1.52	-5.52^*
$WENROL$	-0.22	-6.49^*
$\ln BENROL$	0.70	-3.82^*
$DEGREE$	9.24	-4.32^*
$NESDEG$	3.92	-5.05^*

Table 6: Augmented Dickey-Fuller Statistics, * denotes significance, Note that DEGREE is subject to a structural break in 1973-7

Null	*Alternative*	*Eigenvalue Statistic*	95%*Critical Value*	*Trace Statistic*	95%*Critical Value*
$r = 0$	$r = 1$	47.41*	33.64	116.05*	70.49
$r \leq 1$	$r = 2$	28.81*	27.42	68.64*	48.88

Table 7: Cointegration Based on Maximal Eigenvalue of the Stochastic Matrix: * denotes statistical significance; 43 annual observations; VAR order =4; list of variables included in cointegrating vector: lnY, IY, WENROL, lnBENROL, DEGREE; List of eigenvalues is descending order: 0.67, 0.49, 0.38, 0.35, 0.02,

Null	*Alternative*	*Eigenvalue Statistic*	95%*Critical Value*	*Trace Statistic*	95%*Critical Value*
$r = 0$	$r = 1$	50.51*	33.64	107.51*	70.49
$r \leq 1$	$r = 2$	23.90	27.42	57.00*	48.88

Table 8: Cointegration Based on Maximal Eigenvalue of the Stochastic Matrix: * denotes statistical significance; 43 annual observations; VAR order =4; list of variables included in cointegrating vector: lnY, IY, WENROL, lnBENROL, NESDEG; List of eigenvalues is descending order: 0.69, .43, .36, .27, .01,

	$\ln Y$	$\ln Y$
$\frac{I}{Y}$	2.59^* (35.11) [0.22]	0.23^* (32.71) [0.02]
$WENROL$	-0.27 (.03) [-0.05]	11.06^* (10.69) [1.96]
$\ln BENROL$	0.34 (.36) [0.47]	-3.14^* (7.02) [-4.34]
$DEGREE$	-0.00001 (.69) [-0.28]	
$NESDEG$		0.001^* () [4.15]
$ECM\,(-1)$	-0.10 {.06}	-0.05^* {.02}
$adj-R^2$	0.03	0.35

Table 9: Aggregate Human Capital Impact, Figures in round parentheses are chi-squared test statistics on over-identifying zero restrictions, Figures in round parentheses are standardized coefficients, Figures in curly parentheses are standard errors, * denotes significance

this specification there would appear to be little more to be said on the impact of human capital creation on long run growth.[40] By contrast, the specification that loads on the natural and engineering science degrees, generates results that are both statistically and theoretically sound. In particular we note that the estimation unambiguously has a unique cointegrating vector present in the data. All of the human capital variables are now statistically significant in addition to the investment rate. The implication is that investment in both physical and human capital is a significant determinant of long run output values in the South African economy. The error correction mechanism confirms the presence of a long run equilibrium relationship in the data, as implied by the cointegrating vector.

What is particularly startling about the estimation results is that once the estimated coefficients are standardized, the impact of the human capital variables come to demonstrate a very strong impact on output.

[40] In fact, the maximal eigenvalue and trace statistics also indicate that there may be problems with this specification, since there is evidence of a number of cointegrating vectors present in the data. Thus imposing a single cointegrating vector on the data may produce misleading results, with estimated coefficients being linear combinations of the cointegrating vectors that are present. While we examined a number of alternative just identifying restrictions on a system of equations, none produced theoretically or statistically congruent results.

The implication of these findings is that the human capital variables carry their significance jointly, rather than singly.[41] Results are consistent with the Romer (1990) or Lucas (1988) implication of increasing returns to human capital. The impact of human capital emerges once the synergies between primary and secondary, and tertiary education come to be recognized. It is not enough to have only some parts of the educational system contributing to output - one needs to recognize the contribution of all components of the educational process to the generation of output. It is the educational system as a vertically integrated whole rather than components of it that are important for economic growth.

A number of the features of the estimations demand further comment, and in turn carry significant policy implications.

The first point to note is that it is the natural and engineering science degrees that appear to generate the strong impact on economic output, rather than degrees in general. 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 undertaken. The growth payoff from training in science and engineering appears to exceed that of general training. Again this finding conforms to those already noted in earlier sections.

The second point concerns the negative impact of the enrolment rate in black schooling which seems counterintuitive, and therefore questionable. But this is so only at first sight. In the descriptive evidence of Fedderke, De Kadt and Luiz (2000, 2001b) and the schooling production function for South Africa of Fedderke and Luiz (1999) two fundamental insights with regard to South Africa's black schooling system emerge. First, we noted that the quality of inputs into black schooling over the 1910-93 period was far inferior to the inputs into white schooling. The estimated production function showed that the quality of inputs matters in determining the quality of output from schooling. In addition, the educational production function evidence suggested that over and above the poor quality of inputs given to

[41] A zero restriction on the human capital variables jointly is rejected at the 1% level. The Chi square statistic is 10.72 for 3 degrees of freedom. We also estimated the specification with only the school enrolment variables included in the estimation, and found the school enrolment rate on its own to be insignificant. Again, the implication is that the human capital variables appear to be significant only in concert.

black schooling, the institutions governing black schooling in South Africa limited the users of the black schooling system from ensuring that what resources were deployed to black schooling, were used productively. The consequence was that not only were poor inputs provided to black schooling, but such inputs were also frequently used inefficiently.

This provides us with a coherent interpretation of the evidence we are obtaining from our estimation. The implication of the results is not that rising enrolment of black pupils lowers long run output in South Africa *per sê*. Rather, the implication is that a mere quantitative expansion of educational opportunities, which does not pay any attention to the quality of the education that is taking place, is not particularly helpful for purposes of generating output growth.

Our evidence thus tells us that human capital matters directly for growth. But it does so only if deployed wisely. Not all education and training delivers the same rate of return - and tertiary level science and engineering appears to offer particularly strong returns (see the standardized coefficient). But even for the generalized education offered by schooling quality matters. The South African legacy of apartheid, with its strong investment in the human capital of one part of its population, and the systematic under-investment in the rest of the population, provides a useful if unfortunate natural experiment. Schooling matters, but the quality of the schooling offered matters even more.

6 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. Moreover, both knowledge spill-over effects as well as 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. Crucially, however, spill-over effects that are present appear to emerge from human rather than physical capital investment, and investment in quality human capital rather than human capital broadly defined. Finally, the empirical evidence confirms that human capital investment may well have a *direct* impact on aggregate output as hypothesized by Mankiw et al (1992), as long as the quality dimension of human capital investment is accounted for.

Endogenous growth processes thus do find support for a middle income context. We caution that the results presented in the paper point to the presence of endogenous growth processes. They do not 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 spill-over 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. Historically South African education has primarily been concerned with a widening of educational production, with little concern for the deepening of quality (see for instance the discussion in Fedderke, De Kadt and Luiz 2000, 2001b, and Fedderke and Luiz 1999). 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. What matters crucially in the long run is the *quality* of education. In this our results confirm the finding of Hanushek and Kim (1995) and Hanushek and Kimko (2000).

It is also important to emphasize that this is not a requirement for providing more resources to education. South Africa, in expanding its educational system, now spends far more than comparable developing or middle income countries as a percentage of GDP on education - see Table 10. Yet educational achievements in South Africa on many international comparator test scores lie below those of the competitor nations. The problem is thus one of inefficient expenditure, rather than of insufficient expenditure.

Finally, at one level the evidence that we have presented is thus reassuring. Investment in human capital offers a means of improving the growth performance of the South African economy in the long run. On the other hand, this is likely to be a long run impact, playing itself out over a number of generations. And in the meantime we sit with the legacy of the apartheid developmental strategy which wilfully and systematically under invested in one of the central engines of long run growth. Given the *au contraire* behaviour of countries such as Singapore and Korea, it is little wonder that we have such a strong growth differential between South Africa and the Far East.

Public Expenditue on Education:	**% of GDP, 1997**
Argentina	3.5
Botswana	8.6
Brazil	5.1
Chile	3.6
Hong Kong	2.9
India	3.2
Korea	3.7
Malaysia	4.9
Mexico	4.9
Singapore	3.0
South Africa	7.9
Thailand	4.8
Turkey	2.2
Uruguay	3.3

Table 10: International Comparison of Expenditure on Education

Appendix: 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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