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Estimating Technical Progress for South Africa

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ESTIMATING TECHNOLOGICAL PROGRESS FOR SOUTH AFRICA

Abstract

Production models have to allow technology to improve over time in order to explain growth in the presence of diminishing returns to scale production structures. In the past, models of South African production primarily assumed constant technological progress over time.

In this paper an attempt is made to analyse the determinants of technological progress (total factor productivity), by incorporating the new developments in growth theory. An alternative approach is followed by employing the Kalman filter to determine the evolution of the Solow residual, estimated from a simple Cobb-Douglas production function. These residuals are then explained endogenously, distinguishing between the roles of technological progress and structural changes in the South African production structure over time.

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Keywords: technological progress; production function, cointegration, Kalman filter

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1. INTRODUCTION

Production models have to allow technology to improve over time in order to explain growth in the presence of decreasing returns to scale production structures. In the past, models of South African production primarily assumed constant technological progress over time.

In this paper an attempt is made to analyse the determinants of technological progress, by incorporating the new developments in endogenous growth theory. The assumption is made that technological progress captures total factor productivity (TFP).

In order to do so, a simple Cobb-Douglas production function[1] is used to estimate the Solow residual. The Kalman filter is employed to determine the evolution of the Solow residual, representing both technological progress and structural change.

The Solow residual is subsequently modelled in terms of the explanatory variables suggested by endogenous growth theory.

The paper is structured as follows. Section 2 contextualizes the importance and problems associated with modelling technological progress for the South African economy. Section 3 gives an overview of the various representations of technological progress as a primary contributor to long-run economic growth against the backdrop of the developments in growth theory: from neoclassical, exogenous representations to endogenous alternatives. In section 4 the technology stance in South Africa is discussed. Section 5 reviews existing literature and disseminates some research findings for South Africa, followed by the empirical analysis in section 6, presenting the results of the Kalman filter estimations, as well as the construction and estimation of the technological progress index. The two-equation technology-growth model is then simulated to determine the response characteristics and policy implications of the technology-growth model. The final section contains a summary and some conclusions that may be derived from the research.

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1 Du Toit (1999), who estimated a general translog cost function, has proven that the restricted Cobb-Douglas functional form can econometrically be validated for South Africa. It is therefore possible to estimate a Cobb-Douglas production function for the South African economy.

2. GROWTH AND TECHNOLOGY: A CONTEXTUALIZATION

(a) A supply-side approach

Recognition of supply-side fundamentals in economic theory, policy and modelling has become imperative. The deficiencies of demand-oriented theory, policy and models to solve unemployment and inflation discredited the seemingly irrefutable Keynesian principles that had been at the core of economic policy for many decades. Their inadequacy to account for and deal with the problems of stagnation, lagging productivity, double-digit inflation, high interest rates and depreciating currencies, led to the emergence of supply-side economics.

It is increasingly recognised that the cost-minimising or profit-maximising decision-making processes of the firms responsible for production activities in the economy, need to be examined and modelled. Supply-side economics stresses the necessity of understanding the structure of the production process and the effect of each of the production factors on the level of output.

In order to analyse long-run economic growth and its potential, it is necessary to model and capture the underlying long-run properties of the production structure of the economy.

The ultimate purpose of this study is to estimate an aggregate neoclassical production function for the South African economy as the key component of a supply-side model. At the macro-level the production function may be used to explain economic growth, the prices of various factors of production and the extent to which these factors are utilised. At a micro-level, a production function is useful to analyse the degree of substitution between the various factors of production and also the extent to which firms experience decreasing or increasing returns to scale as output expands. On both macro- and micro-level, the production function may be used as a tool to assess the proportion of any increase (decrease) in output over time which may respectively be attributed to, firstly, increases (decreases) in the inputs of factors of production; secondly, to the existence of increasing (decreasing) returns to scale; and thirdly, to the technological progress (or lack of it) taking place in the economy.

(b) Growth performance and structural changes

Closer scrutiny of South Africa's growth performance paints a rather dismal picture. The growth in real domestic product has been downward sloping since the 1970s (figure 1). This alarming trend has had several harmful effects, such as negative real per capita growth rates, a persistently unequal distribution of income and a continued decrease in the labour absorption capacity of the economy. The latter implies a increase in the levels of unemployment in the economy (figure 2). Economic welfare in South Africa, measured in terms of real per capita income, has declined progressively since 1970. Even more alarming is that per capita income growth has been falling behind real gross domestic product growth (figure 1). Furthermore, from figure 3, it is evident that unemployment has been non-cyclical in nature - the economy has experienced decreasing and negative growth in employment, despite periods of positive economic growth. These features suggest that the South African economy has been undergoing structural changes - the underlying production structure of the economy has changed to such an extent that certain inherent deficiencies in the economy are preventing labour to be employed in periods of increasing GDP. This again, despite some increases in GDP, is eroding the potential of the economy to grow – resulting in the South African economy growing at much lower levels than it ought to. The underlying production structure of the economy may even exhibit decreasing returns to scale properties.

Figure 1. South Africa's growth performance: Real GDP and real per capita GDP

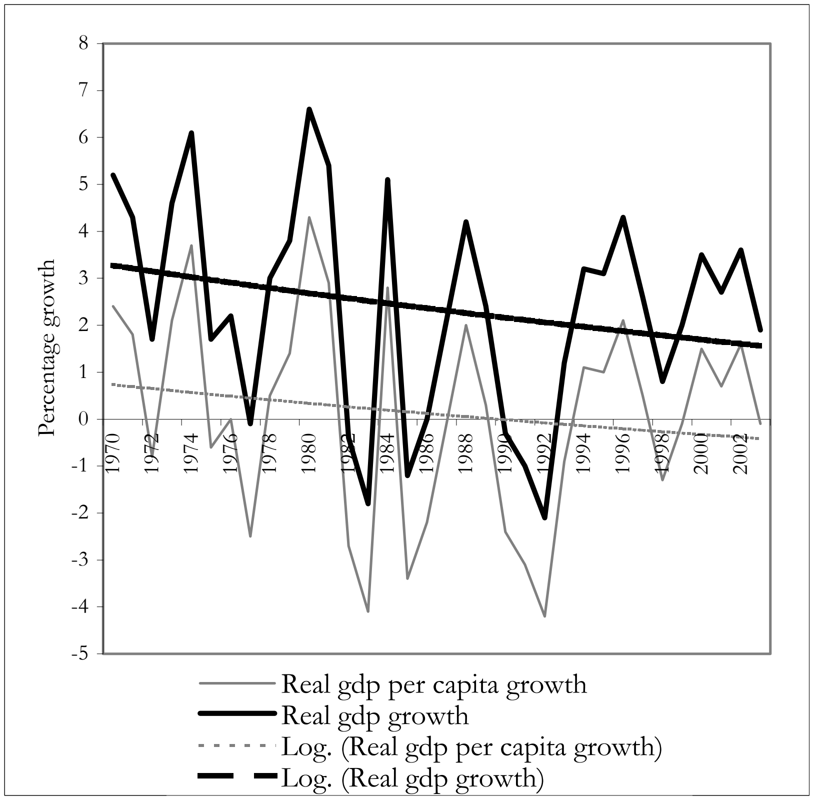


Figure 2. South Africa' unemployment rate (official definition)

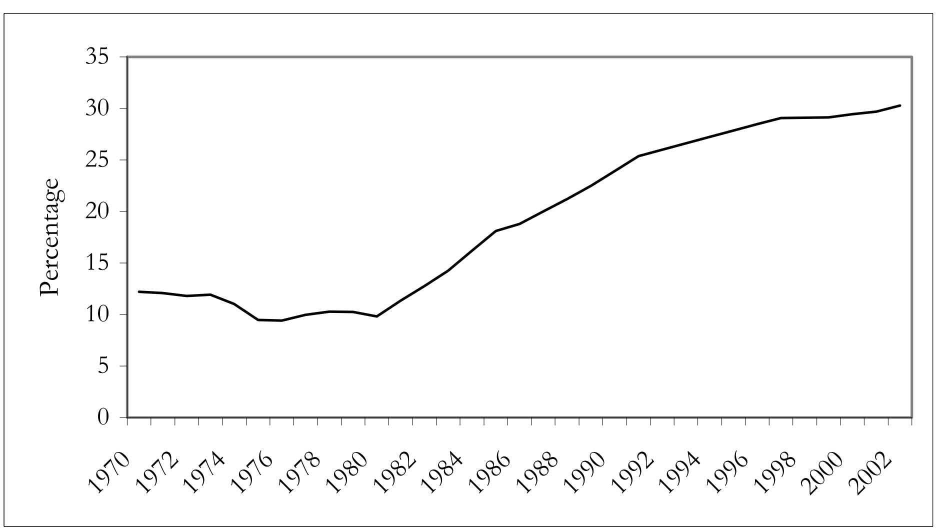
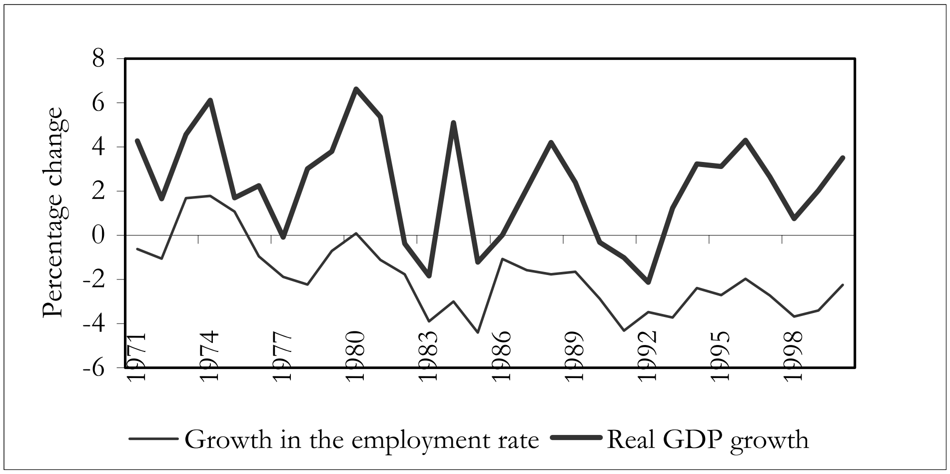


Figure 3. Growth in South Africa's real GDP and employment rate



Therefore, the challenge for policy makers is to understand the nature of changes in the underlying production structure and to identify the key drivers of economic growth in order to direct economic policy towards optimising the long-run growth potential of the economy.

(c) The sources of economic growth

In an attempt to identify the structural changes that occurred in the South African economy, it will be useful to decompose the growth performance into its primary sources. Standard growth-accounting techniques indicate that advancements in technology or total factor productivity have indeed become the primary contributor to economic growth in South Africa.

Evidence from South Africa's growth performance suggests that the economy has been subjected to structural change since the 1970s. Against the background of declining employment rates, despite periods of positive output growth, which in itself suggests severe structural deficiencies in especially the labour market, it has become imperative to investigate the nature and extent of changes in the underlying production structure of the South African economy.

As a point of departure, it would be useful to identify the main sources of economic growth and any changes that might have occurred in their relative contributions/importance over time. Following Solow (1956) and others, we perform a simple accounting exercise to break down output growth into growth in capital, growth in labour and growth in technology, or total factor productivity.

The growth accounting equation states that output growth is equal to the weighted sum of capital and labour growth, plus the growth in total factor productivity or technology:

$$\frac{\dot{Y}}{Y} = \alpha\frac{\dot{K}}{K} + \beta\frac{\dot{L}}{L} + \frac{\dot{A}}{A} \quad \text{with} \quad \frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \alpha\frac{\dot{K}}{K} - \beta\frac{\dot{L}}{L}$$

where

$$\frac{\dot{Y}}{Y} = \text{rate of output growth;}$$

$$\frac{\dot{K}}{K} = \text{rate of capital growth;}$$

$$\frac{\dot{L}}{L} = \text{rate of labour growth;}$$

$$\frac{\dot{A}}{A} = \text{rate of total factor productivity growth;}$$

α = elasticity of output with respect to capital; and β = elasticity of output with respect to labour.

However, in doing so, we acknowledge that there are limitations to this methodology and that the results can only be translated as generally suggestive, thereby directing further investigation.

Similar to Fedderke (2001a) we follow convention and calculate the growth contributions from 1970 to 2000 and distinguish between 3 periods, the 1970s, 1980s and 1990s.

We follow 2 approaches. First, in line with common practice, we assume constant returns to scale and generate the sources of growth associated with the standard Cobb-Douglas production function.

We then relax the assumption of constant returns to scale and compute the returns to scale parameters from the estimated Cobb-Douglas production function, which were generated with the Kalman filter methodology (see section 6 for the estimation results). The estimation results show that the South African economy exhibits decreasing returns to scale properties in production with respect to capital and labour inputs, which seems plausible given the lack of foreign direct investment, the "vulnerability" of the economy associated with the degree of openness and the structural deficiencies in the labour market, which again contributed to the slide in the labour absorption capacity of the economy. Nonetheless, a decreasing returns to scale production structure poses serious challenges for policy makers to increase the productive potential of the economy.

Table 1. Contributions to growth: 1970 – 2000 (per cent)

	Real GDP growth	**Sources of growth**			
		Constant returns to scale			*Decreasing returns to scale*
		Labour growth	Capital growth	Technology growth	Technology growth
1970s	3.03	0.80	3.64	-1.41	-0.30
1980s	2.24	0.42	1.72	0.10	0.62
1990s	1.58	-0.52	0.58	1.52	1.73

Source: Authors' calculations based on SARB data and own estimations

Regardless of whether constant or decreasing returns to scale properties are assumed, the growth accounting calculations (table 1) indicate that the relative contribution of growth in technology has increased over time and has become the primary source of output growth during the 1990s. In contrast, both the relative contributions of capital and labour have decreased. Capital growth has been a very weak source of growth in the 1990s, while labour has had a negative contribution, thereby hampering economic growth. Prior to that, increases in factor accumulation have almost fully generated economic growth.

These results, although only indicative, support the initial hypothesis of structural changes that occurred in the South African economy, but more specifically in its underlying production structure.

The arguments presented for explaining the decreasing returns to scale properties also support the evidence of a decline in the contribution from factor accumulation. On the other hand, the increased and substantial contribution of technology growth since the 1990s reflects the policy and institutional changes during that period. In a post-apartheid era, South Africa engaged in policies for social upliftment in support of education, health, crime and infrastructure. South Africa, during this period, also gained access to world markets and economies. International trade and investment offer important vehicles for technological spillover effects and greater private sector participation in the economy increases the scope for technological innovation. It is therefore evident that technological progress has become the engine of economic growth and a powerful tool to be used by economic policy makers to effectively address the growth and employment problems of the South African economy.

Therefore, in modelling the production function and subsequent supply-side model, specific emphasis has to be placed on the role of technological progress in the presence of structural changes and deficiencies that occurred in the South African economy over time.

In the following sections the Kalman filter methodology is employed to estimate a Cobb-Douglas production function, generating a time-varying series for technology according to the Solow-residual approach.

3. THE PRODUCTION STRUCTURE AND TECHNOLOGICAL PROGRESS

Against the background of structural changes in the production structure of the South African economy towards the increased contribution of technology in generating long-run economic growth, specific emphasis has to be placed on the role of technological progress in modelling the production function. In the past, models of South African production primarily assumed constant technological progress over time, *i.e.* efficiency parameters were estimated as constants. However, production models have to allow technology to improve over time in order to explain growth in output in the presence of diminishing returns to scale production structures.

Therefore, given the primary objective of this paper, namely to analyse and model the determinants of technological progress for the South African economy, it is necessary to investigate the evolution of growth theory in incorporating technology advances in growth models.

Consider a two-factor Cobb-Douglas production structure:

$Q_t = AK_t^{\alpha} L_t^{B}$
with Q output, K capital and L labour.

The efficiency parameter, A represents technology in the model.

Note that contrary to the convention of assuming constant returns to scale, a and β are not assumed to add up to unity.

In this representation, where $Q = Af(K, L)$, A is said to be "Hicks-neutral". The other possibilities are $Q = f(AK, L)$, which is known as "capital-augmenting" or "Solow-neutral" technology, and $Q = f(K, AL)$, which is known as "labour-augmenting" or "Harrod-neutral" technology (Hall 1997; Turner, Richardson and Rauffet 1993). An extension of the latter is where labour is set to be human capital-augmented, reflecting the role of education and skills development (Hall and Jones 1996).

Technology progress can then be introduced by making the efficiency parameter, A, vary over time so that:

$$Q_t = A(t)K_t^{\alpha} L_t^{B}. \tag{1}$$

Before equation 1 can be estimated, some form has to be given to the function $A(t)$.

(a) The neoclassical approach

According to the neoclassical models, technological improvements arrive exogenously at a constant rate, g, and differences in technologies across countries are unexplained. Technology is therefore represented by:

$$A(t) = A_0 e^{gt}$$

where A_0 and g are constants, so that equation 1 becomes

$$Q_t = A_0 e^{gt} K_t^{\alpha} L_t^{B}. \tag{2}$$

A_0 represents the value of $A(t)$ at time = 0. Partially differentiating equation 2 with respect to t yields

$$\frac{\partial Q_t}{\partial t} = gQ_t .$$

Hence,

$$\frac{\partial Q_t}{\partial t} \Big/ Q_t = g .$$

Thus, g measures the proportionate change in output per time period when input levels are held constant. Put differently, g is the proportionate change in output that results from technological progress.

It is convenient to estimate equation 2 in logarithmic form, as it simply requires the inclusion of a time trend in the usual Cobb-Douglas estimation equation:

$$\log Q_t = \log A + gt + \alpha \log K_t + \beta \log L_t . \tag{3}$$

Although production functions with neutral specifications of technological progress are most commonly used in practice, they have definite limitations.

- *Constancy of g*

  The implication of a constant g, *i.e.* that technological progress occurs at a constant rate, may not be realistic.

- *Neutrality of technological progress*

  The neutrality of technological progress implies that it has no effect on the marginal rate of substitution of capital for labour[2] and hence for a given ratio of factor prices does not influence the proportions in which capital and labour inputs are combined.[3] Thus, such technological progress does not affect the capital or labour intensity of the productive process, while it is most probable that technological innovations will

2 For equation 2 it is still true that $\partial Q_t / \partial K_t = \alpha(Q_t / K_t)$ and $\partial Q_t / \partial L_t = \beta(Q_t / L_t)$ so that

$$MRS = \left(\frac{\beta}{\alpha}\right)\left(\frac{K_t}{L_t}\right)$$

The MRS remains constant for any K/L ratio. This occurrence is known as the Hicks-neutral technological progress. It is also Harrod-neutral, since for any Q/K ratio, the marginal product of capital is left unchanged.

3 This form of technological progress means that the isoquants are all shifted towards the origin, but their slopes at the point where they meet any ray from the origin (*i.e.* for any K/L ratio) remain unchanged.

either be labour-saving or capital-saving. A non-neutral technological progress will permit the α/β-ratio to vary over time.

- *Technological progress exogenous and disembodied*

  Technological progress in this case is exogenous because it has been superimposed on the system. (*A* is simply assumed to grow over time for no stated reason.)

  Disembodied technological progress is a form of exogenous technological progress, implying that all existing factors of production are transformed, no matter how long these factors have been in existence. This is clearly unrealistic, certainly as far as capital inputs are concerned. The occurrence of some new invention does not normally mean that all existing capital machinery, no matter of what age, can now be fully adapted to take advantage of the new technique (Thomas 1993).

(b) The endogenous or "new" growth theory approach

Technological progress is the engine of economic growth. The "new" growth theorists, led by Paul Romer[4] are concerned with endogenising technological progress in growth models, primarily by introducing the role of human capital. Given the non-rivalry nature of technological progress, which results in increasing returns to scale properties, since additional benefits can be transferred without any cost, it has become imperative to ascertain the inherent determinants of technological progress.

Instead of assuming that growth occurs because of automatic and exogenous improvements in technology, the endogenous growth theory focuses on understanding the economic forces underlying technological progress. The mere fact that the creation of new ideas and solutions are driven by the profit-maximising behaviour of firms and inventors, makes the improvements in technology and the process of economic growth itself, an endogenous outcome of the economy. Technological progress arises as individuals seek out new ideas in an effort to capture some of the social gains that these new ideas generate in the form of profit.

The Romer model therefore endogenises technological progress by introducing the search for new ideas by researchers interested in profiting from their inventions. It is the presence of patents, copyrights and other economic incentives related to investment that enable inventors to earn profits, so as to cover the initial costs of developing new ideas. In this sense, technology is dependent on the investment in physical capital. Human-capital improvements are then a natural consequence of (1) the knowledge firms create through "learning-by-doing" and (2) "knowledge-

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4 Paul Romer constructed the endogenous growth theory in a series of papers, including a 1990 paper titled "Endogenous Technological Change". Other notable contributions to the literature on R&D-based growth models include Grossman and Helpman (1991) and Aghion and Howitt (1992), which are occasionally referred to as Schumpeterian models (Jones, 2002:97).

spillovers", which result from the fact that ideas and inventions are non-rivalrous or non-excludable – new ideas create benefits that the inventor is unable to capture.

According to the developments in endogenous growth theory, the basic elements of the model consist of 3 sets of factors that need consideration:

1. *Research and development (R&D)*

Technological progress is driven by research and development (R&D) in the advanced world; which, amongst others, can be represented by the resources devoted to R&D, for example the spending on research and development[5]. The number of new ideas produced is dependent on the number of researchers (the human-capital component) and the stock of ideas that have already been invented, which again raises the productivity of researchers and inventors to generate new ideas (Jones 2002:99-100).

2. *Technology transfers*

However, in the case of small countries, potentially far removed from the technological frontier, growth is driven by the transfer of ideas and technology. Economies grow because they learn to use new ideas invented throughout the world (Jones 2002:129).

3. *Social infrastructure and political environment*

The market structure and economic incentives lie at the heart of this process. The transfer of technology is likely to be complicated by issues related to international patent protection; property rights; the cost of adapting or licensing new designs; trade barriers such as tariffs; and institutional/infrastructure barriers. The social infrastructure and political framework of an economy – the rules and regulations and the institutions that enforce them – is a primary determinant of the extent to which individuals are willing to make the long-term investments in capital, skills, and technology that are associated with long-run economic success. Economies in which the government provides an environment that encourages production are extremely dynamic and successful. Those in which the government abuses its authority are correspondingly less successful. Changes in government policies and institutions that make up the economic environment have a huge impact on the development and transfer of ideas and technology (Jones 2002:131,147).

(c) Setting up a technology model for the South African case

In modelling technological progress for South Africa, the theoretical priors as outlined by the new growth theory need to be incorporated. In doing so, we follow on empirical work by Budd

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5 According to Shell (1966) technology progress is dependent on the amount of resources devoted to research and development (Fedderke, 2001b).

and Hobbis (1989) who applied their analysis to the UK production function in order to address the problem of how best to represent technological progress. In line with endogenous growth theory, they argue that there are two main sources of technological advance. First, it may come through domestic research effort which they proxy by the number of new patents taken out in the US by UK residents. Secondly, new technology can be imported from abroad and this flow is proxied by imports of new machinery and by royalty payments to foreign countries.

In applying this for the South African case, the production function is modelled by specifying technology in the Hicks-neutral fashion[6], $Q = Af(K, L)$, where technology (*A*) is explained in terms of human capital and other drivers as proposed by endogenous growth theory. The implication of this specification is that output can grow due to augmentation of human capital stocks as well as augmentation of physical capital, labour and technology.

Incorporating new growth theory, technology is then specified and modelled in terms of the number of scientists and engineers in the economy, the number of patents registered and certain international factors. The latter is captured by the degree of openness of the economy and an "international position" index, constructed as a weighted average of factors such as the exchange rate, foreign investment and the levels of domestic and international competitiveness. The expenditure on R&D is also incorporated in representing the allocation of resources in the economy towards technology advancement.

In line with endogenous growth theory, the number of scientists and engineers accounts for the human capital in the economy; the number of patents registered proxies the existing stock of ideas and inventions; while the measure of openness of the economy and the international position index capture technology transfers and the underlying institutional properties and policy framework of the economy.

The two-equation technology-growth model, consisting of a Cobb-Douglas production function and an endogenously specified technology function, is represented by:

$$Y_t = A_t K_t^{\alpha} N_t^{B} \quad 0<\alpha<1; \ 0<\beta<1$$
$$A_t = f(NSEDEG; \ PATENTS; \ INTPOS \ \big| \ R\_D; \ OPEN)$$

with

Y_t	=	Real GDP in period t
K_t	=	Real capital stock in period t
N_t	=	Total employment in period t
A_t	=	Technological progress (time varying parameter obtained from Kalman filter estimation)

6 This approach has been introduced by Mankiw, Romer and Weil (1992) where they've introduced human capital as an additional factor of production to physical capital and labour (Fedderke, 2001b).

$NSEDEG_t$	=	Number of Natural Sciences and Engineering degrees
R_D_t	=	A measure of expenditure on R&D
$PATENTS_t$	=	Number of patents registered
$OPEN_t$	=	Openness of the economy to international trade
$INTPOS_t$	=	International position index

Note that the specification of the production function does not necessarily imply constant returns to scale. The estimation results are presented in section 6.

4. THE SCIENCE AND TECHNOLOGY STANCE IN SOUTH AFRICA

South Africa's scientific and technological capacities are considerable, certainly by comparison with other African countries. That is the view of Kaplan in a 1995-paper, where he surveys the new government's inheritance with respect to science and technology (S&T).

This section attempts to provide a brief overview of the development, current status and policy context of the state of science and technology in South Africa.

Under the previous government, management of S&T was divided – responsibility for science rested with the Department of Education, while technology was the responsibility of the Department of Trade and Industry. The key source of advice to government on science policy was previously the Scientific Advisory Council, located in the Department of National Education, who were criticised for a lack of transparency, composition of its membership and limited oversight of the system. After the 1994 democratic elections, the management responsibility became that of the Department of Arts, Culture, Science and Technology (DACST). On 1 August 2002, the Department was divided into two departments – the Department of Arts and Culture and the Department of Science and Technology. The National Advisory Council on Innovation (NACI) has been created by legislation [NACI Act of 1997] to advise the Minister of Science and Technology on the role and contribution of science, mathematics, innovation and technology, including indigenous technologies, in promoting and achieving national objectives.

National surveys of R&D expenditure conducted in 1991, 1993, 1997 and 2001 point to the following key factors (Department of Science and Technology: 2004):

- R&D expenditure showed a decrease between 1991 and 1993. Since 1993, R&D expenditure has both grown in nominal and real terms. In 2001/02 total R&D expenditure in South Africa reached a level of R7.5 billion representing an average annual real growth of 2.5 per cent since 1991.
- Despite increases in R&D expenditure in real terms since 1993, this has not kept pace with the growth in the economy since 1991, when R&D expenditure represented 1.04 per cent of GDP (a measure of the intensity of R&D in the economy). However, there has been an encouraging increase in R&D expenditure as a percentage of GDP from 0.69 per cent in 1997 to 0.76 per cent in 2001. This suggests there is some robustness in the current system if innovation, but the challenge to reach the goal of 1 per cent of GDP remains.
- South Africa may have a higher R&D intensity than many developing countries, but

needs to keep pace with competitor countries[7].

- The number of full time equivalent (FTE) researchers (per 1 000 employed) is an important indicator of the availability of research skills in the labour force of a country. At a level of 1.88 FTE researchers per 1 000 employed, South Africa has a relatively low number of researchers. (This has however increased from a figure of 1.71 FTE researchers in 1997.) Figures for other countries are: Australia 7.2, South Korea 6.4, Canada 6.1, Spain 5.0, Argentina 2.0, and China 1.0.
- South Africa devotes most of its R&D to fields in the natural sciences (20.2%), followed by engineering sciences (15.2%). Information, computer and communication technologies account for a further 13.7% of expenditure.

The main focus of the current system of Innovation is the improvement of quality of life and wealth creation. Improvement and innovation (technological progress), with the aforementioned aim, are to be achieved through R&D capacity, SET (science, engineering and technology) human capital, imported know-how, and business involvement.

The R&D performing sectors include the Science Councils (ARC, CSIR, CGS, HSRC, Mintek, MRC, NRF and SABS), Higher Education and Industry. Industry and government are the main funders of R&D in South Africa, while the business sector performs most of the country's R&D. Higher Education is funded mainly by government through General University Funds (GUF), research agency funding and government contracts. About 56 per cent of the funding of the Science Council is channelled through the parliamentary science vote, while the remainder is made up of contributions from industry (29%), and government contracts and foreign funders (15%).

The new direction in S&T is partly due to a new consolidated policy, published in 1996, *The White Paper on Science and Technology: Preparing for the 21st century* (DACST:1996). The new policy:

- broadened the scope of policy from S&T innovation;
- recognised R&D as crucial to growth and to the improvement of quality of life;
- supports the coordination and non-duplication of structures;
- pursues the levelling of historical inequalities and human capacity building;
- provides core funding in terms of a three-year cycle through the MTEF (medium-term expenditure framework) for capacity building and maintenance in R&D and related activities, while R&D services for clients are managed on a commercial basis with full cost recovery; and
- requires regular reviews of government science, engineering and technology institutions (SETs).

5. LITERATURE REVIEW

Since the emergence of endogenous growth theory in the 1980s, there has been no shortage of empirical analyses conducted around this topic. In fact, this body of work is so large that to give

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7 Sweden, the OECD leader in R&D intensity, has a R&D expenditure equivalent to 4.27 per cent of GDP. For other developing countries, these figures are: China 1.09%, Malaysia 0.5% and Argentina 0.42%. The figures for Spain and Australia are 0.96% and 1.53% respectively.

a comprehensive and complete review would not only prove to be extremely cumbersome but perhaps even impossible. Therefore, this literature review will focus on the work that has been conducted in South Africa.

In contrast to the international situation, the literature on endogenous growth theory in South Africa suffers from a severe dearth of empirical work. However, one should not discount the non-empirical research that has been conducted. This research often offers valuable insights into the theoretical implications and international lessons that can be used to place South Africa on a sustainable 'endogenised' growth path (such as Holden 1993 and Gries 2002). In addition, discussion and formulation of science and technology policy (as in Kaplan 1999) is essential for the continued technological progression of South Africa and her people.

The most notable empirical contribution to the application of endogenous growth theory in South Africa, is that of Johannes Fedderke (2001a, 2002). Conducting a simple growth accounting decomposition at an aggregate and sectoral level, it was shown that changes in total factor productivity, i.e. technological progress, have a dominant influence on growth within the South African economy. Furthermore, in Fedderke (2002), he attempts, through a characterisation of South Africa's education system, to determine the sustainability and quality of human capital formation as a primary source of continual technological progress. Another empirical contribution is Fedderke's (2001c) study, using panel econometrics, which evaluates the contribution of technology and human capital to growth in South Africa's manufacturing sectors. An interesting example of applied work is that of Bailey, *et. al.* (2003), who compare approaches to the measurement of technological change bias in South Africa's agricultural sector. As is done is in this paper, they too model technological change as an unobservable stochastic component. However they opt for a regression-based approach (based on Maddala and Kim 1989), instead of using the Kalman filter, as we do.

6. APPLYING THE KALMAN FILTER TO THE PRODUCTION FUNCTION SPECIFICATION

State-space models were originally developed by control engineers (Wiener 1949; Kalman 1960, 1963) with applications, to mention a few examples, in the technology of radars, aircraft stabilisation, chemical processes, etc. Only during the 1980s did state-space models start to receive attention in economics literature (amongst others, Lawson 1980; Harvey *et al.* 1987; Cuthbertson 1988; Barrel *et al.* 1994; Currie and Hall 1994).

Extensive surveys of applications of state-space models in econometrics can be found in Hamilton (1994:372-408) and Cuthbertson *et al.* (1992:191-225). Cuthbertson *et al.* (*op cit.*: 191) distinguish between two types of models especially amenable to representation via the Kalman filter, namely *unobservable components* models and *time-varying parameter* models. In this study, the state-space model with stochastically time-varying parameters has been applied to a linear regression − the production function − in which the coefficient representing total factor productivity (or technological progress) is allowed to change over time.

The next section describes how a dynamic system can be written in state-space form, which is suitable for the application of the Kalman filter.

(a) The State-space Representation of a Dynamic System

The state-space representation of the dynamics of a $(n\times 1)$ vector, y_t, is given by the following system of equations:

$$y_t = A'x_t + H'\xi_t + w_t \qquad (4)$$
$$\xi_{t+1} = F\xi_t + v_{t+1} \qquad (5)$$

where A', H' and F are matrices of parameters of dimension $(n\times k)$, $(n\times r)$ and $(r\times r)$, respectively, and x_t is a $(k\times 1)$ vector of exogenous or predetermined variables. ξ_t is a $(r\times 1)$ vector of possibly unobserved state variables, known as the *state vector*. The first equation is known as the *observation* (or measurement) equation and the second is known as the *state* (or transition) equation. The $(n\times 1)$ and $(r\times 1)$ disturbance vectors w_t and v_t are assumed to be independent white noise with

$$E(v_t v'_\tau) = \begin{cases} Q & \text{for } t = \tau \\ 0 & \text{otherwise} \end{cases} \qquad (6)$$

$$E(w_t w'_\tau) = \begin{cases} R & \text{for } t = \tau \\ 0 & \text{otherwise} \end{cases} \qquad (7)$$

where Q and R are $(r\times r)$ and $(n\times n)$ matrices, respectively. The disturbances v_t and w_t are assumed to be uncorrelated at all lags:

$$E(v_t w'_\tau) = 0 \qquad \text{for all } t \text{ and } \tau. \qquad (8)$$

The statement that x_t is predetermined or exogenous means that x_t provides no information about ξ_{t+s} or w_{t+s} for $s = 0,1,2,\ldots$ beyond what is contained in $y_{t-1}, y_{t-2},\ldots,y_1$. Thus, x_t could include lagged values of y or variables which are uncorrelated with ξ_τ and w_τ for all τ.

The system of equations (4) through (8) is typically used to describe a finite series of observations $\{y_1, y_2,\ldots,y_T\}$ for which assumptions about the initial value of the state vector ξ_t are needed.

The various parameter matrices (F, Q, A, H or R) could be functions of time, in which case equations (4) and (5), *i.e.* the state-space representation may be altered to:

$$y_t = a(x_t) + [H(x_t)]'\xi_t + w_t \qquad (9)$$
$$\xi_{t+1} = F(x_t)\xi_t + v_{t+1}. \qquad (10)$$

Here $F(x_t)$ denotes a $(r\times r)$ matrix whose elements are functions of x_t; $a(x_t)$ similarly describes an $(n\times 1)$ vector-valued function and $H(x_t)$ a $(r\times n)$ matrix-valued function.

It is assumed that conditional on x_t and on the data observed through date $t-1$, denoted

$$\vartheta_{t-1} \equiv (y'_{t-1}, y'_{t-2}, ..., y'_{1}, x'_{t-1}, x'_{t-2}, ..., x'_{1})',$$

the vector $(v'_{t+1}, w'_{t})'$ has the Gaussian distribution

$$\begin{bmatrix} v_{t+1} \\ w_{t} \end{bmatrix} | x_{t}, \vartheta_{t-1} \Bigg] \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} Q(x_{t}) & 0 \\ 0 & R(x_{t}) \end{bmatrix}\right). \tag{11}$$

Equations (9) to (10) allow for stochastically varying parameters, but are is more restrictive in the sense that a Gaussian distribution is assumed.

For a technological exposition of the derivation of the updating equations and the recursive algorithm of the Kalman filter, refer to Hamilton (1994:372-408) and Cuthbertson (1992:191-225).

(b) Endogenising of Technological Progress

Endogenising technological progress has been approached as follows. The model essentially contains three equations, namely, the two equations set out below to obtain a measure for total factor productivity or technological progress, and then the explanation thereof.

$$Y_t = \xi_t K_t^{\alpha} N_t^{\beta} e^{w_t} \qquad 0<\alpha<1;\ 0<\beta<1 \tag{12}$$

$$\xi_t = \xi_{t-1} + v_t \qquad v_t \sim N(0,Q). \tag{13}$$

with

Y_t	=	Real GDP in period t
K_t	=	Real capital stock in period t
N_t	=	Total employment in period t
w_t, v_t	=	Stochastic disturbance terms
ξ_t	=	The time varying constant, representing technological progress

Equation (12) represents the measurement (or observation) equation of the state-space model in Kalman filter terms, while equation (13) represents the state (or transition) equation.

In a subsequent step, the variable representing technological progress is then explained using variables like expenditure on R&D, patents registered and the number of scientists and engineers. Technology transfer is allowed for by two variables, namely a measure of the openness of the economy to international trade and other international factors (denoted by an index *intpos*) such as exchange rate, foreign investment, level of domestic and international competitiveness, share in world trade, etc. The latter also captures the underlying institutional factors in the economy. Standard cointegration techniques are employed in this estimation.

The model of production and technological progress may then be solved dynamically and the response characteristics of the system tested when factors contributing to technological progress (or total factor productivity) are positively influenced.

(c) *Estimation results*

The unknown parameters of the system will be estimated along with the (1×1) state vector, ξ_t. The state vector will be assumed to evolve through time according to a random walk process, that is

$\xi_t = \xi_{t-1} + v_t$.

All variables are integrated of order 1 (see Appendix 1) and all variables are utilised in natural logarithm form.

The first step in the estimation process would be to estimate the time-varying parameter of the production function (the observation equation), representing technological progress. Table 2 reports the hyperparameters and residual diagnostics.

The variances of the error terms of the observation and state equations are reported in the top part of the table. The exponential function of *C(3)* represents the variance of the error term of the observation equation (equal to *R(1,1)* in equation 7) and the exponential function of *C(4)* represents the variance of the error term or adjustment factors of the state equation (equal to *Q(1,1)* in equation 6). The latter, often called hyperparameter(s), determine the speed of adjustment and reflect the signal to noise ratio the variable(s); hence they also reflect the rate of convergence of the model. Note that the hyperparameters are not necessarily expected to be statistically significantly different from zero as measured by the z-statistic. Both the variances may be very small and not statistically different from zero. (If they were actually zero, this would mean that the true coefficients were fixed. Under this condition, the Kalman filter gives recursive OLS estimates and the estimated coefficients would still adjust.)

Furthermore, the hyperparameter(s) only make sense when compared to the variance of the error term of the observation equation. In this comparison, the magnitude of the hyperparameter(s) is indicative of the speed at which the time-varying parameter(s) are allowed to change.

The final values of the state vector, ξ, with associated standard errors, are also reported in the top part of the table. ξ_1, represents the time-varying coefficient of the production function, representing technological progress.

Table 2. Hyperparameters, Final Value of the State Vector and Equation Diagnostics from the Time-varying Kalman Filter Estimates

Dependent variable: $lnGDP_t$

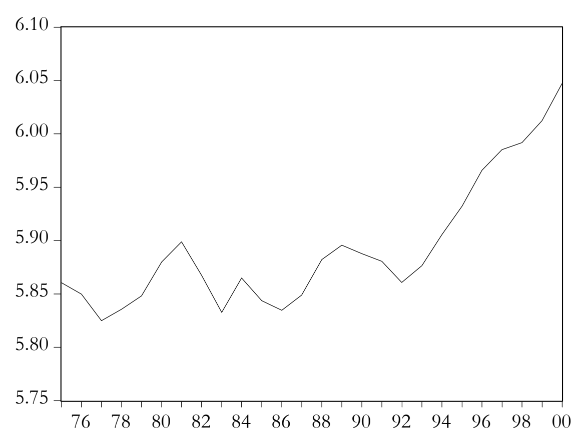
Variables	Coefficient	Std.Error	z-Statistic	Prob
C(1)	0.46896	0.15937	2.94268	0.0033
C(2)	0.34636	0.37722	0.91817	0.3585
C(3)	-30.4658	1.16E+08	4.46E-07	1.0000
C(4)	-7.63621	0.44687	-17.0882	0.0000
Final SV1	6.04726	0.02196	275.259	0.0000

lnGDP = C(1)**lnCap* +C(2)**lnN* +SV1 + [var=expC(3)]
SV1 = SV1(-1) + [var=expC(4)]

Sample period: 1970 to 2000
Log Likelihood = 64.1456
Akaike info criterion = -3.88
Schwarz criterion = -3.69
Hannan-Quin criterion = -3.82

The estimated time-varying coefficient, assumed to evolve as a random walk process, displays a reasonable degree of variation over the period. Figure 4 illustrates the evolution thereof, approximating technological progress. The sideways trend from the 1970s through to the early 1990s supports the earlier evidence of structural changes and deficiencies that occurred in the underlying production structure of the South African economy during this period. Also, the more significant contribution of technology to economic growth during the 1990s that became evident from the growth accounting exercise is visible in the trend.

Figure 4. Time varying coefficient representing Technological Progress



The Kalman filter prediction of technological progress can next be employed as a dependent variable in an attempt to explain and thus endogenise it in the system. Standard residual-based cointegration techniques render the following result:

$$
\begin{aligned}
\Delta TP_t = & -0.0246 + \underset{(2.07)}{0.2589}\,\Delta \ln NSEDEG_t + \underset{(3.90)}{0.1666}\,\Delta \ln R\_D_t \\
& + \underset{(2.33)}{0.04077}\,\Delta \ln INTPOS_t + \underset{(1.85)}{0.0548}\,\Delta \ln PATENTS_{t-2} + \underset{(1.82)}{0.1884}\,\Delta \ln OPEN_t \\
& - \underset{(-2.45)}{0.5134}[TP_{t-1} - 4.3787 - 0.1752 \ln NSEDEG_t - 0.0274 \ln INTPOS_t \\
& \quad - 0.1165 \ln PATENTS_t]
\end{aligned}
\tag{14}
$$

Adjusted R^2: 0.77
Equation standard error: 0.0115
Normality test: BJ(2)=1.586 [0.452]
Serial correlation: LB(6)=7.092 [0.245]; LM(2)=4.522 [0.104]
Heteroscedasticity: ARCH(1)=0.002 [0.963]; White(1)=14.335 [0.280]
Stability: RESET(2)=1.167 [0.434]
ADF[8]: -4.52

where

TP_t	=	Representation of technological progress (time varying parameter obtained from Kalman filter estimation)
$NSEDEG_t$	=	Number of natural sciences and engineering degrees awarded
R_D_t	=	A measure of expenditure on R&D
$PATENTS_t$	=	Number of patents registered
$OPEN_t$	=	Openness of the economy to international trade
$INTPOS_t$	=	International position index

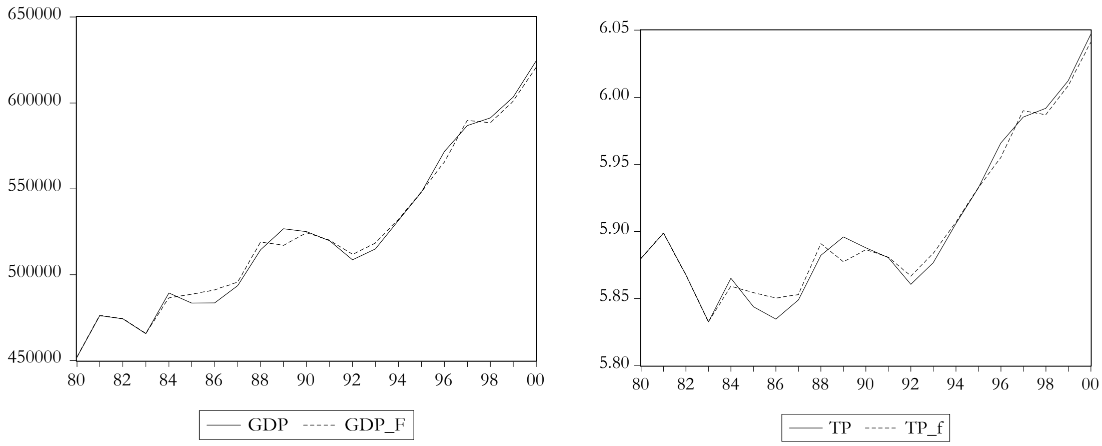
The standard variables suggested in theory to influence technological progress prove to be significant. Variables driving technological progress as proposed by the long-run cointegration equation (documented in square brackets in equation (14)), are the number of scientists and engineers in the economy, the number of patents registered and certain international factors (the index *INTPOS* is a weighted average of factors such as the exchange rate, foreign investment, level of domestic and international competitiveness, etc.) All of these also influence the short-run dynamics of the system.

In addition to the long-run driving forces, the expenditure on R&D and the openness of the economy proved to be significant in the estimation. The measure of openness of the economy and the international position index accounts for technology transfer.

Solving this two-equation system simultaneously, yield the results presented in Figure 5.

8 Unit root test on the residual of the long-run equilibrium equation.

Figure 5. Dynamic fit of the two-equation system



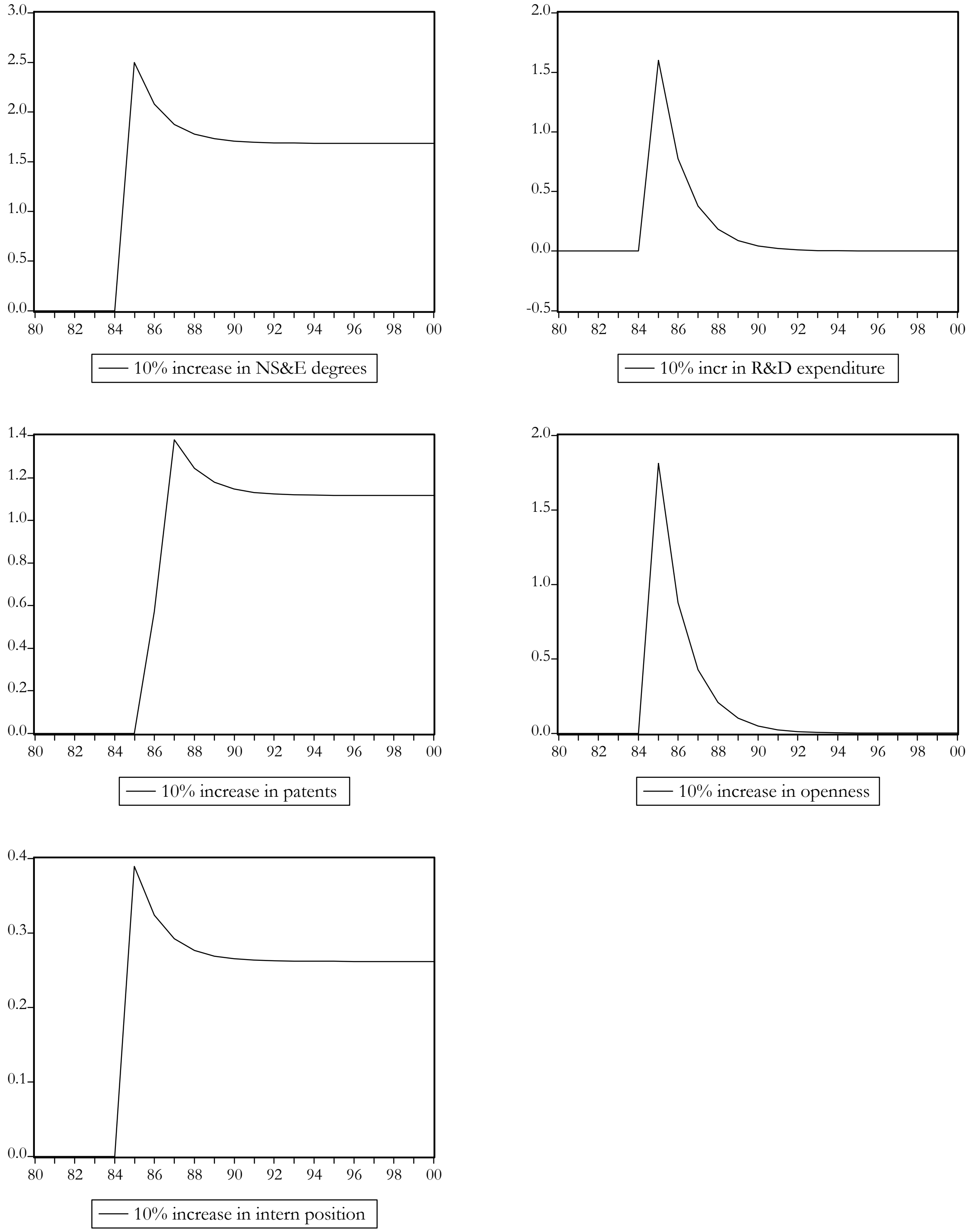
For the purpose of testing and evaluating the response characteristics of the model, a series of dynamic simulations are performed where each of the explanatory variables in the technology specification is subjected to sensitivity testing by increasing (shocking) each of them independently by 10 per cent from 1985 onwards. The effect of each of these shocks on real GDP is then calculated. These results are depicted in Figure 7.

Having applied a 10 per cent shock to each of the long-run explanatory variables, the dependent variable, real GDP, converged to a new long-run equilibrium. Increases in the number of scientists and engineers, the registration of new patents and improvements in the international position of South Africa, all lead to sustained increases in real GDP. The short-run explanatory variables, expenditure on R&D and the degree of openness of the economy, only led to temporary improvements in real GDP, suggesting the necessity for continued government interaction with respect to these.

7. CONCLUSION

South Africa's growth performance since the 1970s has been characterised by decreasing output growth, rising unemployment and associated poverty. In addition, growth accounting calculations indicate that the relative contribution of growth in technology and total factor productivity has increased over time and has become the primary source of output growth during the 1990s. In contrast, both the relative contributions of capital and labour have decreased. These characteristics, along with the sideways trend in the time-varying series for technology from the 1970s through to the early 1990s, indicate that the South African economy has been subjected to structural changes - the underlying production structure of the economy has changed to such an extent that intrinsic deficiencies in the labour and capital markets of the economy are preventing labour to be employed and foreign direct investment to be attracted in periods of increasing GDP. This in turn diminishes the potential of the economy to grow.

Figure 7. Response characteristics: Effect on real GDP of 10 per cent increases in explanatory variables of technology equation



Therefore, given the evidence of structural deficiencies, it has become imperative to investigate the nature and extent of changes in the underlying production structure of the South African economy. The challenge for policy makers is to identify the key drivers of economic growth and to direct economic policy towards optimising the long-run growth potential of the economy.

In order to analyse long-run economic growth and its potential, it is necessary to model and capture the underlying long-run properties of the production structure of the economy.

Production models have to allow technology to improve over time in order to explain growth in output in the presence of decreasing returns to scale production structures. In the past, models of South African production primarily assumed constant technological progress over time.

In this paper an attempt was made to analyse the determinants of technological progress according to the endogenous or new growth theory. Incorporating new growth theory, technology is specified and modelled in terms of the number of scientists and engineers in the economy (the human capital component), the number of patents registered (representing the existing stock of knowledge) and certain international factors (capturing technology transfers and the underlying institutional properties and policy framework of the economy).

Employing the Kalman filter methodology, a Cobb-Doublas production function was estimated and used to generate a time-varying series for technology according to the Solow-residual approach. Technological progress was subsequently estimated in terms of the standard variables suggested by growth theory.

A number of important conclusions and policy implications can be drawn from analysing the estimation results and the response characteristics of the dynamic two-equation technology-growth model.

An alarming feature, which surfaced from the Kalman filter estimations, is that the South African economy exhibits decreasing returns to scale properties in production with respect to capital and labour inputs. This seems plausible given the lack of foreign direct investment, the "vulnerability" of the economy associated with the degree of openness and the structural deficiencies in the labour market, which again contributed to the slide in the labour absorption capacity of the economy. Nonetheless, a decreasing returns to scale production structure poses serious challenges for policy makers to increase the productive potential of the economy. However, when we recognize that ideas, which generate technological progress, are also an input into production, this situation may be less serious. Technological progress typically exhibits increasing return to scale properties and may support the production structure to such an extent that the economy as a whole may experience constant or even increasing returns to scale.

The challenges for policy makers in South Africa are demanding and multi-faceted: (1) to resolve the structural problems hampering saving/investment and the labour market absorption capacity of the economy, thereby addressing the decreasing returns to scale property of production with respect to capital and labour; (2) to stimulate technological progress through incentive schemes, e.g. by sponsoring R&D; by creating legal mechanisms to protect the intellectual property rights of those who have invested at great cost into generating innovations; (3) to improve and increase human capital through training and skills development, thereby narrowing the existing skills gap in the economy, but also to create an environment where skilled individuals would be willing to participate in the domestic economy – it is of the utmost importance to eliminate the "braindrain" trend, which depletes the stock of human capital of the South African economy; (4) to improve access to existing knowledge, thereby improving the productivity of researchers and inventors; (5) to reduce the barriers for the development and transfer of ideas and knowledge; and finally (6) to create a social infrastructure and policy framework conducive to entrepreneurship and production.

History has proven that economies in which the government provides an environment that encourages production and invention are extremely dynamic and successful.

APPENDIX 1:

Sources of Data and Calculations

The sources and construction of the data series used to empirically estimate the theoretical model of production and technological progress are discussed in this section, as well as the univariate characteristics of the data.

Data series employed in empirical estimation are listed in Table A1. Sources of data include the South African Reserve Bank, Statistics South Africa, the Development Bank of Southern Africa, Trade and Industrial Policy Strategies (TIPS), the World Bank, the Department of Science and Technology, the CSIR and the US Patent and Trademark office.

Table A1. *List of variables*

Variable	Description
cap	Capital stock at constant 1995 prices
gdp	Gross domestic product at constant 1995 prices
intpos	International position index
n	Total employment
nsedeg	Number of natural sciences and engineering degrees awarded
open	Openness of the economy to international trade
patents	Number of patents registered in the US Patents and Trademark Office
R&D	Expenditure on R&D
tp	Technological progress

Data on real gross domestic product and capital stock was obtained from the South African Reserve Bank's database. The openness to international trade variable was computed as *(exports/gdp+imports/GDE)/2*. These series were also sourced from the above-mentioned database. Likewise for the components of the international position index, calculated as a weighted average of factors such as the exchange rate, foreign investment, level of domestic and international competitiveness, etc.)

The main source of employment data (including formal and informal sector employment) is Statistics South Africa, but other data sources were also consulted in constructing the series historically, including the Development Bank of Southern Africa, Trade and Industrial Policy Strategies (TIPS) and the World Bank.

The measure of human capital, namely the number of scientists and engineers in the economy, as proxied by the number of natural science and engineering degrees was obtained from Fedderke (2003) for the sample period up to 1993. This was updated from Statistics South Africa sources.

The number of patents registered in the US Patents and Trademark Office (a measure of the stock of ideas) was obtained from a special report of this office (2002). South African origin patents registered in the US annually have exceeded 100 since 1987.

Expenditure on R&D by the CSIR obtained from their financial statements was taken as a representative trend in gross domestic expenditure on R&D, since constructing a time series comparable over 20 to 30 years, including all R&D performing sectors most definitely is a challenging task. The CSIR is furthermore the largest Science Council in terms of expenditure on R&D, when compared to the ARC, CGS, HSRC, Mintek, MRC, NRF and SABS. All of these, however displayed similar expenditure trends over the period 1997 to 2003 (DACST:2002). The R&D performing sectors include the Science Councils, Higher Education and Industry. The first two receive funding from Industry, Government (via GUF (General University Funds) and government contracts (e.g. THRIP)), the NRF and foreign donors, while research activities in the business/industry sector are mostly funded from internal sources.

Order of integration

In analysing the univariate characteristics of the data, the Dickey-Fuller (DF) and Augmented Dickey-Fuller tests were employed to establish the order of integration of data series, all variables in natural logarithmic form. The testing strategy is as suggested by Dolado *et al.* (1990). (Also see Enders (1995:257)).

The number of lags used in the estimated equations was determined in a similar way as suggested by Perron (1989:1384), namely starting with eight lags and testing downwards, until the last lag is significant or there are no lags left.

Tables A2 and A3 report the outcomes of the ADF-tests for all relevant data series employed in the estimations. The series tested are listed in the first column. The second column reports whether a trend and a constant (Trend), only a constant (Constant), or neither one (None) is reported. The next column shows the ADF t-statistic, called τ_τ when a trend and a constant are included, τ_μ when only a constant is included, and τ when neither is included. The last column reports the F-statistic, Φ_3 (Φ_1), testing whether the trend (constant) is significant under the null hypothesis of no unit root.

According to Table A2, unit root tests render some of the variables stationary in levels, for example expenditure on R&D (R_D), capital stock (cap) and the international position index (intpos). However, upon visual inspection of graphical representations of the series and inspection of the relevant correlograms, it is clear that these variables cannot be stationary in levels. The results may be contributed to small sample bias, given the fact that we only have between 21 and 31 observations available for the series tested. All variables are therefore considered to be integrated of order 1 (see Table A3).]

Table A2. Augmented Dickey-Fuller Tests for Non-Stationarity, Levels, 1970-2000
(All data series in natural logarithmic form)

Series	**Model**	**Lags**	**τ_τ,τ_μ,τ[a]**	**Φ_3,Φ_1[b]**
cap	Trend	2	-2.75	150.25**
	Constant	2	-3.60*	208.63***
	None	3	0.30	
gdp	Trend	1	-2.43	2.86
	Constant	0	-1.65	2.71
	None	0	5.11	
intpos	Trend	0	0.25	2.32
	Constant	0	-1.98	3.90
	None	0	-3.00***	
n	Trend	4	-1.26	16.97
	Constant	1	-2.60	24.56**
	None	1	0.12	
nsedeg	Trend	4	-2.28	3.52
	Constant	0	1.04	1.08
	None	0	9.34	
open	Trend	0	-0.74	7.16
	Constant	1	-1.13	4.70
	None	1	-0.89	
patents#	Trend	0	-2.31	3.00
	Constant	0	-1.85	3.42
	None	0	-2.26**	
R&D#	Trend	1	-2.16	6.57**
	Constant	0	-4.18***	17.46***
	None	0	-2.09**	
tp	Trend	0	-0.53	3.26
	Constant	0	1.03	1.05
	None	1	1.34	

*(**)[***] Significant at a 10(5)[1]% level.

a At a 10(5)[1]% significance level the MacKinnon critical values are -3.23(-3.60)[-4.36] when a trend and a constant are included (τ_τ), and -2.62(-2.97)[-3.68] when only a constant is included (τ_μ) and -1.61(-1.95)[-2.64] when neither is included (τ). The standard normal critical value is -1.697(-2.04)[-2.75].

b At a 10(5)[1]% significance level the Dickey-Fuller critical values are 5.91(7.24)[10.61] when a trend and a constant are included (Φ_3) and 4.12(5.18)[7.88] when only a constant is included (Φ_1).

Tested over the period 1980-2000
At a 10(5)[1]% significance level the MacKinnon critical values are -3.28(-3.67)[-4.53] when a trend and a constant are included (τ_τ), and -2.66(-3.03)[-3.83] when only a constant is included (τ_μ) and -1.61(-1.96)[-2.69] when neither is included (τ). The standard normal critical value is -1.697(-2.04)[-2.75].

Table A3. *Augmented Dickey-Fuller tests for non-stationarity, first differenced,1970-2000. (All data series in natural logarithmic form)*

Series	**Model**	**Lags**	τ_τ,τ_μ,τ[a]	Φ_3,Φ_1[b]
Δcap	Trend	1	-2.52	4.61
	Constant	2	-1.62	5.70
	None	2	-2.32**	
Δgdp	Trend	0	-3.98**	8.02***
	Constant	0	-4.02***	16.14***
	None	0	-2.70***	
Δintpos	Trend	0	-4.98***	12.43***
	Constant	0	-4.41***	19.46***
	None	0	-4.05***	
Δn	Trend	3	-5.38***	9.76***
	Constant	4	-1.42	5.92
	None	4	-2.05**	
Δnsedeg	Trend	2	-1.81	12.96*
	Constant	2	-1.64	16.38
	None	2	-0.41	
Δopen	Trend	0	-4.33***	9.47***
	Constant	0	-2.99**	8.92***
	None	0	-3.04***	
Δpatents[#]	Trend	0	-4.76***	11.35***
	Constant	0	-4.75***	22.59***
	None	0	-4.50***	
ΔR&D[#]	Trend	0	-2.69	3.71
	Constant	0	-2.24	5.01**
	None	0	-1.65*	
Δtp	Trend	0	-4.54***	10.40***
	Constant	0	-3.77***	14.22***
	None	0	-3.64***	

*(**)[***] Significant at a 10(5)[1]% level.

a At a 10(5)[1]% significance level the MacKinnon critical values are -3.23(-3.60)[-4.36] when a trend and a constant are included (τ_τ), and -2.62(-2.97)[-3.68] when only a constant is included (τ_μ) and -1.61(-1.95)[-2.64] when neither is included (τ). The standard normal critical value is -1.697(-2.04)[-2.75].

b At a 10(5)[1]% significance level the Dickey-Fuller critical values are 5.91(7.24)[10.61] when a trend and a constant are included (Φ_3) and 4.12(5.18)[7.88] when only a constant is included (Φ_1).

[#] Tested over the period 1980-2000

At a 10(5)[1]% significance level the MacKinnon critical values are -3.28(-3.67)[-4.53] when a trend and a constant are included (τ_τ), and -2.66(-3.03)[-3.83] when only a constant is included (τ_μ) and -1.61(-1.96)[-2.69] when neither is included (τ). The standard normal critical value is -1.697(-2.04)[-2.75].

REFERENCES

AGHION, P. AND HOWITT, P. (1992) A Model of Growth through Creative Destruction. *Econometrica,* No. 46 (June): 385 – 406.

ALLEN, C.B. (1997). A survey of flexible functional forms applied to production analysis, In Allen, C.B. and Hall, S.G. (eds.), *Macroeconomic Modelling in a Changing World: Towards a Common Approach*. Chichester: John Wiley and Sons.

ARROW, K.J., CHENERY, H.B., MINHAS, B.S. & SOLOW, R.M. (1961). Capital-labour substitution and economic efficiency. *Review of Economics and Statistics*, 43: 225-50.

BAILEY, A., BALCOMBE, K., MORRISON, J. & THIRTLE, C. (2003). *A Comparison of Proxy Variables and Stochastic Latent Variable Approaches to the Measurement of Bias in Technological Change in South African Agriculture*. Economics of Innovation and New Technology, 12(4): 315-324.

BARREL, R., CAPARALE, G.M., HALL, S.G. & GARRATT, A. (1994), Learning about monetary union. An analysis of boundedly rational learning in European labour markets, in *Applied Economic Forecasting techniques*. Hall, S.G. (ed.) Harvester Wheatsheaf, New York.

BERNDT, E.R. (1991). *The Practice of Econometrics: Classic and Contemporary*. New York: Addison-Wesley Publishing Company.

_____ & WOOD, D.O. (1975). Technology, prices and the derived demand for energy. *Review of Economics and Statistics*, 57: 259-68.

BUDD, A., DICKS, G., HOLLY, S., KEATING, G. & ROBINSON, B. (1984). The London Business School Econometric Model of the UK. *Economic Modelling*, 1(4).

_____ AND HOBBIS, S. (1989) Cointegration, technology and the long run production function. *Centre for Economic Forecasting Discussion paper*.

CURRIE, D. & Hall, S.G. (1994), Expectations, learning and empirical macro-economic models, in *Applied Economic Forecasting techniques*. Hall, S.G. (ed.) Harvester Wheatsheaf, New York.

CUTHBERTSON, K. (1988), Expectations, learning and the Kalman filter, *Manchester School,* LVI (3), September: 223-46.

_____, Hall, S.G. & TAYLOR, M.P. (1992), *Applied Econometric Techniques*. Harvester Wheatsheaf, Hemel Hempstead.

DEPARTMENT SCIENCE AND TECHNOLOGY. (2004), High Level Key Results. *South African National Survey of Research and Experimental Development (R&D) (2001/02 Fiscal Year)*.

DOLADO, J.J., JENKINSON, T., & SOSVILLA-RIVERO, S. (1990), Cointegration and unit roots: a survey, *Journal of Economic Surveys,* 4: 249-76.

DU TOIT, C.B. (1999). *A Supply-side Model of the South African Economy: Critical Policy Implications*, Unpublished Doctoral Thesis, Pretoria: University of Pretoria.

FEDDERKE, J.W. (2001a). The Contribution of Growth in Total Factor Productivity to Growth in South Africa, 1970-1997. *Econometric Research Southern Africa Policy Paper*. University of the Witwatersrand.

_____. (2001b). Technology, Human Capital, Growth and Institutional Development: lessons from endogenous growth theory? *Econometric Research Southern Africa Policy Paper,* No 14. University of the Witwatersrand.

_____. (2001c). Technology, Human Capital and Growth: Evidence from a Middle-Income Country Case Study Applying Dynamic Heterogeneous Panel Analysis. E*conometric Research Southern Africa Policy Paper* No. 23, University of Witwatersrand.

_____. (2002). Toward an Understanding of the Growth Absence: Reviewing the Evidence that can Account for the Poor Growth Performance of South Africa. *TIPS Working Paper.*

_____, DE KADT, R.H.J., & LUIZ, J., 2003, A Capstone Tertiary Educational system: Inefficiency, Duplication and Inequity in South Africa's Tertiary Education System, 1910-93, *Cambridge Journal of Economics*, 27(3), 377-400.

GRIES, T. (2002). Catching-up, Falling Behind and the Role of FDI: A Model of Endogenous Growth and *Development. South African Journal of Economics*, 70(4): 588-610.

GROSSMAN, G.M. & HELPMAN, E. (1991) *Innovation and Growth in the Global Economy*. Cambridge Massachusetts: MIT Press.

HALL, R.E. & JONES, C.I. (1996). The productivity of nations. *NBER Working Paper Series*, No. 5812. Cambridge: NBER.

HALL, S.G. (1997) "Macroeconomic modelling: A perspective", In Allen, C.B. and HALL, S.G. (eds.), *Macroeconomic Modelling in a Changing World: Towards a Common Approach*. Chichester: John Wiley and Sons.

HAMILTON, J.D. (1985), Uncovering Financial Market Expectations of Inflation, *Journal of Political Economy* 93: 1224-41.

HARVEY, A.C. (1987), Applications of the Kalman filter in econometrics, in Bewley, T.F. (ed.), *Advances in Econometrics, Fifth World Congress,* Vol. 1, Econometric Society Monograph No. 13, Cambridge University Press, Cambridge.

HOLDEN, M. (1993). Lessons for South Africa from the New Growth and Trade Theories. S*outh African Journal of Economics*, 61

JONES, C.I. (2002). *Introduction to Economic Growth*. Second Edition. New York: Norton & Company.

KALMAN, R.E. (1960), A new approach to linear filtering and prediction problems. *Journal of Basic Engineering, Transition of the ASME Series D,* 82: 35-45.

_____. (1963), New methods in the Wiener Filtering Theory, in Bogdanoff, J. and Kozin, F. (eds.), *Proceedings of the First Symposium of Engineering Applications of Random Function Theory and Probability:* 270-388. New York: Wiley.

KAPLAN, D.E. (1995). The State of Science and Technology in South Africa: New Priorities, New Policies. *Development Policy Research Unit Working Paper 95/06*, University of Cape Town.

_____. (1999). On the Literature of the Economics of Technological Change. *South African Journal of Economics*, 67(4): 473-490.

LAWSON, T. (1980), Adaptive expectations and uncertainty, *Review of Economic Studies,* XLVII (2): 305-20.

LAYARD, R., NICKELL, S. & JACKMANN, R. (1991). *Unemployment, Macroeconomic Performance and the Labour Market*. Oxford: Oxford University Press.

LUCAS, R.E. (1990). Supply-side economics: An analytical review. *Oxford Economic Papers,* 42: 293-316.

MADDALA, G.S. & IN-MOO KIM (1989). *Unit Roots, Cointegration and Structural Change*. Cambridge: Cambridge University Press.

MANKIW, N.G., ROMER, D. AND WEIL, D. (1992). A Contribution to the Empirics of Economic Growth. *Quarterly Journal of Economics,* No. 107 (May): 407 – 38.

NATIONAL ADVISORY COUNCIL ON INNOVATION. (2002). South African Science and Technology. Key Facts and Figures 2002.

PERRON, P. (1989). The great crash, the oil price shock, and the unit root hypothesis, *Econometrica,* 57 (6): 1361-401

ROMER, D. (1990) Endogenous Technological Change. *Journal of Political Economy,* No. 98 (October): S71-S102.

ROMER, D. (1996). *Advanced Macroeconomics*. New York: McGraw Hill.

SOLOW, R.M. (1956). The Production Function and the Theory of Capital. *Review of Economic Studies*, 23: 101-8.

SOUTH AFRICAN RESERVE BANK *Quarterly Bulletin*, (various issues).

THOMAS, R.L (1993) *Introductory Econometrics: Theory and Applications*. New York: Longman Publishing.

TURNER, D., RICHARDSON, P. AND RAUFFET, S. (1996) The Role of Real and Nominal Rigidities in Macroeconomic Adjustment, *OECD Economic Studies*, No. 21. Paris: Organisation for Economic Co-operation and Development (OECD).