# THE EVOLUTION AND CONTRIBUTION OF TECHNOLOGICAL PROGRESS TO THE SOUTH AFRICAN ECONOMY: GROWTH ACCOUNTING AND KALMAN FILTER APPLICATION

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**Abstract**
This study examines the importance of technological progress to aggregate economic growth in South Africa. Quantifying the contribution of technological progress to economic growth has become imperative, considering the outcome of a simple growth accounting exercise. The findings of this exercise indicate that the contribution of technological growth to aggregate economic growth increased substantially, over the past three decades. Economic growth is modelled through a Cobb-Douglas production function, employing Kalman filter to determine the evolution of the Solow residual over time. The Solow residual represents both technological progress and structural change. According to the Kalman filter results, technological progress is characterised by an upward trend since the 1980s with a steeper slope during the 2000s. Our results show that technological progress has become a factor as important to production as capital stock and labour; fact that policy makers should take into consideration to boost economic growth.
JEL Codes
Keywords: technological progress; South Africa; Kalman filter; growth accounting; total factor productivity

## 1. Introduction

Although the South African economy has consistently ranked amongst the strongest on the African continent over the past three decades, it has been influenced by both political and financial events locally and internationally such as the oil crisis of the 1970s, a period of international economic sanctions imposed on South Africa from 1985 onwards in an attempt to end Apartheid, and the country's consequent democratisation in 1994, as well as the recent financial "meltdown" in 2008-2009 whose recessional effects are still active. All these events combined with the important socioeconomic changes influenced the production methods as well as the contribution of each of the factors of production (capital, labour, technological progress) to the final production mix.

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. The production function may also be used as a tool to assess the proportion of any increase (decrease) in output over time which may respectively be attributed to, firstly,

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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.

The ultimate purpose of this study is to describe the evolution of the contribution of technological progress, captured by Total Factor Productivity (TFP) or Solow residual, to economic growth by employing an aggregate neoclassical production function for the South African economy over a thirty-year period. In order to do so, a simple Cobb-Douglas production function is used to estimate the Solow residual. The Kalman filter (Kalman, 1960) is employed to determine the evolution of the Solow residual, representing both technological progress and structural change. Pahlavani (2005) and Hossain (2006) also appreciate the assumption that technological progress changes over time and significant events can have an impact on its evolution.

The paper is structured as follows: section 2 provides an overview of the literature on the theories of growth and technological progress from a supply-side perspective, followed by a discussion on South Africa's growth performance the last three decades, contained in section 3. Section 4 presents the research methodology and a discussion of data used, followed by the empirical results in section 5. Section 6 concludes.

## 2. Literature review: Growth and technology

### *2.1 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 problems in unemployment (Layard et al. 2005) 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 (Du Toit 1999) 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.

### *2.2 From exogenous to endogenous growth theory*

The most well-known and discussed model presenting the neoclassical exogenous growth theory is the Solow and Swan model (Solow, 1956, Swan 1956) .The basic assumptions of the model include an economy with no government interventions, no trade, no technological progress and no population growth. Moreover, one basic assumption is that there is no unemployment which means that the output that is produced is the maximum that can be produced.

Firstly, a production function is presented where output is only based on capital. According to this model, economic growth is a short-term phenomenon. If people are encouraged to save, the growth rate will increase for a short period but in the long run it will fall back to zero.

Trying to take the model a step further, Solow (Solow 1955) held the main assumptions but in this attempt, he assumed that there is a constant population growth. Even if people are encouraged to save more, the economy will reach a point where all the savings should be used to compensate for depreciation and population growth (in the steady state capital stock and output will increase only by the rate of population growth). Therefore, in the long run economic growth (measured as output per person) will stop.

The last step in the model was to include some effectiveness in the production function and efficient labour was chosen for this purpose. The conclusion is that output and capital per capita will increase by the exogenous rate of technological progress (Solow residual) or the rate of effectiveness of every unit of labour. The Solow residual is a number describing empirical productivity growth in an economy. Byun et al. (2012) also defined the Solow residual (or total factor productivity TFP) as an unexplained residual or advancement in knowledge, because TFP cannot be explained by labor, capital, and other product factors The Solow Residual is pro- cyclical and is sometimes called the rate of growth of total factor productivity.

With these sub-models, Solow and Swan showed that firstly, the lower the initial level of per capita GDP, the faster the growth rate will be; and secondly, in the absence of technological progress per capita, growth must in the long run come to an end.

In the early 1970s, macroeconomists considered Ramsey-Koopmans-Cass‘s model (Ramsey 1928; Koopmans 1965; Cass 1965) as the benchmark growth model. While the Solow-Swan model was based on the steady state and the path of the economy, Ramsey and later Koopmans and Cass tried to endogenise the savings rate. Their model predicts that economic policies can affect growth only in the short run, and that in the long run the growth rate of per capita income will always revert to the exogenously given rate of technological progress. Once again the reason for this is the diminishing marginal productivity of capital.

It is possible to add exogenous technological progress to the Ramsey-Koopmans-Cass model, just as Solow-Swan did, and thereby make growth sustainable in the long run. The model is exactly the same as in the case of no technological progress, except that the constant labour has been replaced by the efficient units of labour, exactly as in the Solow-Swan model. This change allows the stock of capital to grow indefinitely without driving the marginal product below the rate of time preference, because the effect of diminishing returns is now offset by the continual rise in productivity.

In the early 1980s significant theoretical and practical work emerged on endogenous growth. The economists that worked in this field, tried to differ from the neoclassical economists. An effort was made to prove the idea that economic growth is an endogenous product and not the result of exogenous forces. The economists tried to build macroeconomic models based on microeconomic foundations. A critical role is usually given to the new technologies (innovation) (Sinha, 2008) and human capital (Loening, 2004).

Various attempts to endogenise technological progress were made before the recent endogenous growth models. Their main weakness was the increasing returns to scale in a general equilibrium framework. Arrow’s (1962) solution to this problem was to suggest that the growth of technological progress is the result of the experience of the labour at producing new goods, or just the acquisition of knowledge, or in more recent terms ‘learning by doing’.

First, learning-by-doing works through each firm's investment. In particular, an increase in a firm's capital stock leads to an analogous increase in its knowledge. Second, knowledge is a public good that every firm is able to access at zero cost. In other words, once discovered, a piece of knowledge spills over instantly across the whole economy. The second assumption allows us to retain perfect competition equilibrium.

However, the Arrow model was based on a fixed capital/labour ratio. This means that in the long run the growth of output was limited by growth of labour. Moreover, the level of new capital is only an indicator of this experience of the labour. When the amount of capital reaches a specific level, this means that labour has also reached a certain level with regards to production.

All exogenous growth models as well as the Arrow model included the rate of technological change but could not deal with issues such as welfare implications or convergence of per capita output.

In his attempt to improve prior models, Romer (1986) proposed a model that combines the basic hypotheses of the Ramsey-Cass-Koopmans and Arrow models, by assuming that "knowledge is a capital good "…which… "is an input in production that has an increasing marginal productivity".

In Romer's model, externalities, increasing returns in the production of output, and decreasing returns in the production of new knowledge have been brought together to specify a competitive equilibrium model of growth. Its limitation might be that it is the complete opposite of the typical model with endogenous increase of physical capital and no improvement of the level of knowledge. But after the first part of the model is proven, it is simple to add state variables and finally, fulfil the theoretical gap.

In 1990, Romer (1990) made a second attempt on endogenising technological progress, by introducing the search for new ideas by researchers interested in profiting from their inventions and assuming that knowledge is a public good, with both public and private good characteristics. 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.

All in all, the technological progress is represented by the total factor productivity that primarily measures the productivity growth of the main factors of production. Salinas Jimenez (2012), however argues that this productivity growth can also be obtained by efficiency gains and not only by technological progress. In her study, she examined the role of human and public capital in the growth of several Spanish regions. The findings conclude that indeed productivity growth is an important factor for economic growth .The results of a decomposition exercise showed that, although, the assumption that efficiency gains are significant holds, the technological progress is responsible for around 60% of the productivity gains.

### *2.3 Background: South Africa*

Closer scrutiny of South Africa's growth performance reveals a downward sloping trend in growth in real domestic product since the 1970s (Figure 1). However the trend started changing since the mid 1990s to upward sloping and it continued in this direction until the global financial crisis of 2008-2009. Since 2008, the South African economic growth rate presented a rapid decrease with even negative values in 2009.

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 (GDP) growth (Figure 1).

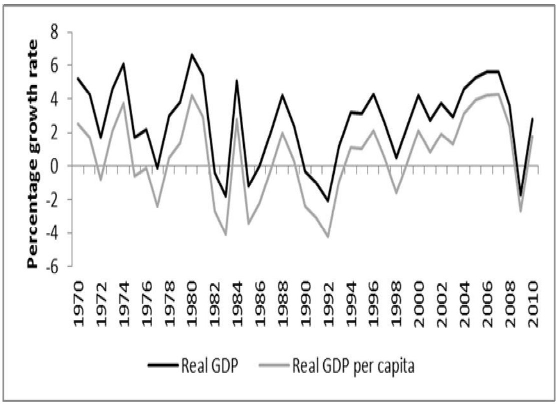


**Figure 1:** South Africa's growth performance: Percentage of Growth of real GDP and real Capita GDP: 1970-2010
Source: South African Reserve Bank (SARB)

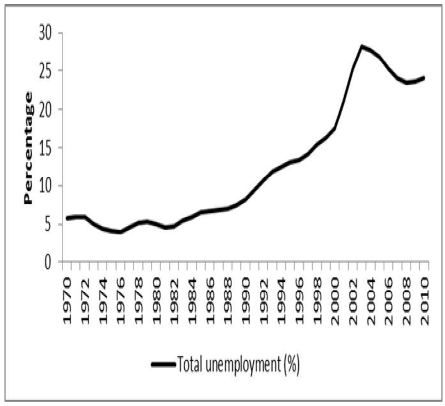


**Figure 2:** South African's unemployment rate (official definition): 1970-201
Source: Quantec Research

The trend of the 1970s and 1980s 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 an increase in the levels of unemployment in the economy (Figure 2). In this figure, it can be seen that the unemployment rate has been increasing since the 1970s but at higher rates from the end of 1980s onwards.

Furthermore, from Figure 2 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 (Figure 3). It is also of significance to observe the increases in employment levels between 2000 and 2006, which shows the results of Black Economic Empowerment (BEE) in the country.

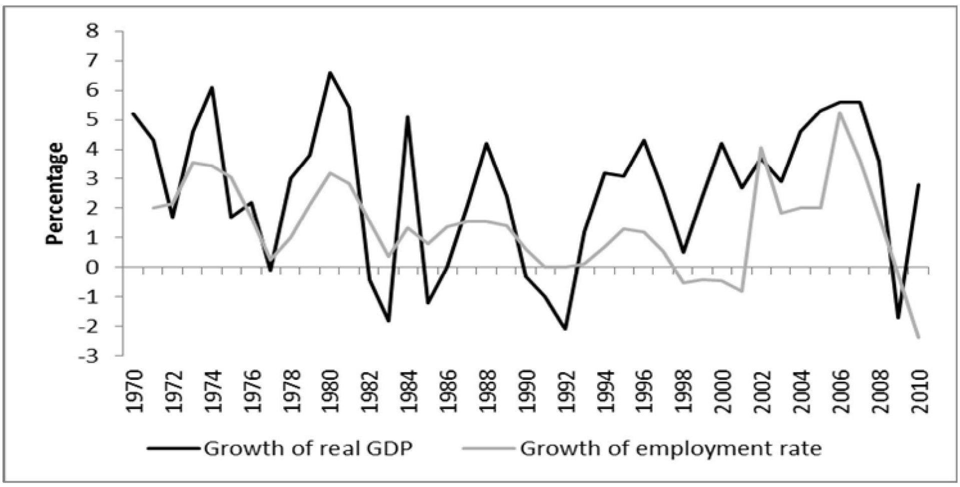


**Figure 3***:* Growth in South Africa's real GDP and employment rate: 1971-2010
Source: South African Reserve Bank (SARB) and Quantec Research

All 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 (Fedderke 2002)– 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.

Therefore, the challenge for the 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 optimizing the long-run growth potential of the economy.

## 3. Research methodology and data

### *3.1. Growth accounting*

"Growth accounting breaks down economic growth into components associated with changes in factor inputs and the Solow residual, which reflects technological progress and other elements"(Barro, 1999). The exercise is based on a production function that tells us what output $Y_t$ will be at some particular time t as a function of the economy's stock of capital $K_t$ , its labour force $L_t$ , and the economy's total factor productivity $A_t$: $Y_t=f(A_t, K_t, L_t)$.

If output changes, it can only be because the economy's capital stock, its labour force, or its level of total factor productivity changes.

From Barro (1999), the growth rate of output can be separated into components associated with factor accumulation and technological progress.

If we differentiate equation (1) with respect to time and after division by Y and rearrangement of terms, we obtain:

$$\frac{\dot{Y}}{Y} = g + \left(\frac{F_K K}{Y}\right) * \left(\frac{\dot{K}}{K}\right) + \left(\frac{F_L L}{Y}\right) * \left(\frac{\dot{L}}{L}\right) \quad \text{eq(2)}$$

where $F_K$; $F_L$ are the factor (social) marginal products and g the growth due to technological change, given by

$$g = \left(\frac{F_A A}{Y}\right) * \left(\frac{\dot{A}}{A}\right) \quad \text{eq(3)}$$

If the technology factor appears in a Hicks-neutral way, so that F(A, K, L) = A f(K, L) then $g = \dot{A}/A$

The rate of technological progress g can be calculated from equation (2) as a residual

$$g = \frac{\dot{Y}}{Y} - \left(\frac{F_K K}{Y}\right) * \left(\frac{\dot{K}}{K}\right) - \left(\frac{F_L L}{Y}\right) * \left(\frac{\dot{L}}{L}\right) \quad \text{eq(4)}$$

However, equation (4) according to Barro (1999) is difficult to be estimated in practice because it requires knowledge of the social marginal products, $F_K$ and $F_L$. Hence, to avoid this predicament, it is usually assumed that the social marginal products can be measured by observed factor prices.

If the factors are paid their social marginal products, so that $F_K = R$ (the rental price of capital) and $F_L = w$ (the wage rate), then an estimate of the rate of technological progress following from equation (4) would be:

$$\hat{g} = \frac{\dot{Y}}{Y} - s_K * \left(\frac{\dot{K}}{K}\right) - s_L * \left(\frac{\dot{L}}{L}\right) \quad \text{eq(5)}$$

where $s_K = \frac{RK}{Y}$ and $s_L = \frac{wL}{Y}$ are the respective shares of each factor payment in total product. The value $\hat{g}$ is often described as an estimate of total factor productivity (TFP) growth or the Solow residual.

An empirical growth accounting exercise for South Africa is included in Section 4.1, covering the period 1971 to 2010.

*3.2. Kalman filter application*

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 had to be placed on the role of TFP 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.

Consider a two-factor Cobb-Douglas production structure:

$Y_t=AK_t^{\alpha} L_t^{\beta}$ eq (6)

Where, as before, Y represents output, K capital and L labour.

The efficiency parameter, A (TFP) represents technology in the model. Note that contrary to the convention of assuming constant returns to scale, α and β are not assumed to add up to unity.

In this representation, where Q= A f(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 (Allen, Hall 1996;Turner, Richardson & 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, Jones 1996) .

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

$Q_t= A_t K_t^{\alpha} L_t^{\beta}$ eq (7)

Similar assumption on the time varying attribute of technological progress was made by Hossain (2006) too. Before equation 7 can be estimated, some form has to be given to the function $A_t$ and in this study, the Kalman filter is used for this purpose.

State-space models were originally developed by control engineers (Wiener 1949;Kalman 1960) with applications, to mention a few examples, in the technology of radars, aircraft stabilization, chemical processes, etc. Only during the 1980s did state-space models started receiving attention in economics literature (Lawson 1980; Harvey 1987; Cuthbertson 1988; Currie & Hall 1994).

Extensive surveys of applications of state-space models in econometrics can be found in Hamilton (n 1985) and Cuthbertson Hall & Taylor (1992). Cuthbertson et al. 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.

*The state-space representation of a dynamic system*

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

$$y_t = A\,x_t + H\,\xi_t + w_t \qquad \text{eq(8)}$$

$$\xi_{t+1} = F\,\xi_t + v_{t+1} \qquad \text{eq(9)}$$

where A, H and F are matrices of parameters of dimension (n×k), (n×r) and (r×r), respectively, and $x_t$ is a (k×1) vector of exogenous or predetermined variables. $\xi_t$ is a (r×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×1) and (r×1) disturbance vectors $w_t$ and $v_t$ are assumed to be independent white noise with

$$E(v_t v_\tau') = \begin{cases} Q & for\ t = \tau \\ 0 & otherwise \end{cases} \qquad \text{eq(10)}$$

$$E(w_t w_\tau') = \begin{cases} R & for\ t = \tau \\ 0 & otherwise \end{cases} \qquad \text{eq(11)}$$

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

$$E(v_t w_\tau') = 0 \text{ for all t and } \tau \qquad \text{eq(12)}$$

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

The system of equations (10) through (11) is typically used to describe a finite series of observations {$y_1$, $y_2$,…,$y_T$} for which assumptions about the initial value of the state vector $\xi_t$ are needed.

The various parameter matrices (F, Q, A, H or R) could be functions of time, in which case equations (10) and (11), i.e. the state-space representation may be altered to:

$$y_t = \alpha(x_t) + [H(x_t)]'\xi_t + w_t \qquad \text{eq(13)}$$

$$\xi_{t+1} = F(x_t)\xi_t + v_{t+1} \qquad \text{eq(14)}$$

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

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

$$\vartheta_{t-1} \equiv (y_{t-1}', y_{t-2}', \ldots\ldots, y_1', x_{t-1}', x_{t-2}', \ldots\ldots, x_1')' \qquad \text{eq(15)}$$

where the vector ($v_{t+1}'$, $w_t'$) has the Gaussian distribution

$$\begin{bmatrix} v_{t+1} \\ w_t \end{bmatrix} | \, x_t, \vartheta_{t-1} \sim N\left\langle \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} Q(x_t) & 0 \\ 0 & R(x_t) \end{bmatrix} \right\rangle. \qquad \text{eq(16)}$$

Equations (13) and (14) allow for stochastically varying parameters, but are more restrictive in the sense that a Gaussian distribution is assumed.

*Endogenising of technological progress*

Endogenising technological progress (or multifactor productivity) 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.

$$Y_t = \xi_t K_t^{\alpha} N_t^{\beta} e^{w} \qquad \text{eq(17)}$$

$$0<\alpha<1; \quad 0<\beta<1 \qquad \text{eq(18)}$$

$$\xi_t = \xi_{t-1} + v_t \quad , \quad v_t \sim N(0,Q). \qquad \text{eq (19)}$$

where $Y_t$ is the real GDP in period t; $K_t$ the real capital stock in period t; $N_t$ the total employment in period t; $w_t$, $v_t$ are the stochastic disturbance terms and $\xi_t$ is the time varying constant, representing technological progress.

Equation (17) represents the measurement (or observation) equation of the state-space model in Kalman filter terms, while equation (19) represents the state (or transition) equation.

### *3.3 Data*

The sources and construction of the data series used to empirically estimate the theoretical model of production and technological progress are presented in Table 1 (See Appendix for data plots).

**Table 1: Sources of data**

| Variable | Description | Source |
|---|---|---|
| *cap* | Capital stock at constant 2000 prices | South African Reserve Bank |
| *gdp* | Gross value added at factor prices | South African Reserve Bank |
| *empl* | Total employment | Quantec Research |

Next, the univariate characteristics of the variables are discussed. In analyzing the univariate characteristics of the data, the Augmented Dickey-Fuller and Phillips-Perron tests were employed to determine the order of integration of data series, all variables in natural logarithmic form. According to results of the tests[4] , all variables are considered to be integrated of order 1.

## 4. Empirical results

### *4.1 Growth accounting exercise*

The growth accounting calculations (Table 2) indicate that the relative contribution of technological growth has increased over time and has become an important source of output growth during the 2000s.

In contrast, even if capital growth has still remained the primary source of growth in the 2000s, its relative contribution has decreased substantially since the 1980s. The contribution of labour has gained space in the 1990s (especially after 1994) but decreased again in the 2000s due to the significant advances in technological progress.

[4] The detailed results of the ADF and PP tests for stationarity are presented in the Appendix.

Regardless of whether constant, increasing or decreasing returns to scale (CRTS, IRTS, or DRTS) properties are assumed, this exercise indicates that the relative contribution of growth in technology has increased over time and has become as important source of output growth as capital and labour growth during the 2000s.

**Table 2: Growth accounting exercise results: 1971-2010**

| | | | | | |
|---|---|---|---|---|---|
| **constant returns to scale (α+β=1)** | | | | | |
| | Labour share | Capital share | β*labour | α*capital | TFP |
| 1971-1980 | 0.573 | 0.427 | 1.233 | 2.450 | -0.650 |
| 1981-1990 | 0.565 | 0.435 | 0.902 | 1.153 | 0.185 |
| 1991-2000 | 0.563 | 0.437 | 0.202 | 0.476 | 0.712 |
| 2001-2010 | 0.507 | 0.493 | 0.869 | 1.381 | 1.260 |
| **decreasing returns to scale (α+β=0.90)** | | | | | |
| | Labour share | Capital share | β*labour | α*capital | TFP |
| 1971-1980 | 0.573 | 0.327 | 1.233 | 1.88 | -0.076 |
| 1981-1990 | 0.565 | 0.335 | 0.902 | 0.89 | 0.450 |
| 1991-2000 | 0.563 | 0.337 | 0.202 | 0.37 | 0.821 |
| 2001-2010 | 0.507 | 0.393 | 0.869 | 1.10 | 1.540 |
| **Increasing returns to scale (α+β=1.1)** | | | | | |
| | Labour share | Capital share | β*labour | α*capital | TFP |
| 1971-1980 | 0.573 | 0.527 | 1.233 | 3.02 | -1.224 |
| 1981-1990 | 0.565 | 0.535 | 0.902 | 1.42 | -0.080 |
| 1991-2000 | 0.563 | 0.537 | 0.202 | 0.58 | 0.603 |
| 2001-2010 | 0.507 | 0.593 | 0.869 | 1.66 | 0.980 |

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

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.

Therefore, in modelling the production function, as integral part of a model of the supply-side model of the economy, specific emphasis had 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 total factor productivity according to the Solow-residual approach.

*4.2 Kalman filter results*

From equation 19, the unknown parameters of the system will be estimated along with the (1×1) state vector, $\xi_t$. The state vector will be assumed to evolve through time according to a random walk process, that is

$$\xi_t = \xi_{t-1} + v_t \qquad \text{eq(20)}$$

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 as in equation (21)

lgdp = c(1) * lcap +c(2) * lempl+ sv1 eq(21)

where L denotes that all the variables are in logarithmic form, gdp is the gross domestic product, cap is the fixed capital stock (both in constant 2000 prices), empl is the total employment and sv1 notates the TFP or A of the Cobb-Douglas production function.

Table 3 reports the Kalman Filter estimation results. The final values of the state vector, $\xi$, with associated standard errors, are also reported in the top part of the table. sv1, represents the time-varying coefficient of the production function, representing technological progress.

**Table 3: Kalman Filter estimation results**

| Sample 1980-2010. Included observations 32 | | | | |
|---|---|---|---|---|
| ***lgdp=c(1)*lcap+c(2)*lempl+sv1*** | | | | |
| | **Coefficient** | **Std. Error** | **z-Statistic** | **Prob.** |
| c(1) | 0.452 | 0.160 | 2.832 | 0.005 |
| c(2) | 0.862 | 0.344 | 2.505 | 0.012 |
| | **Final State** | **Root MSE** | **z-Statistic** | **Prob.** |
| sv1 | 0.710 | 0.022 | 32.951 | 0.000 |
| | | | | |
| **Log likelihood** | 64.74355 | **Akaike info criterion** | | -3.85442 |
| **Parameters** | 5 | **Schwarz criterion** | | -3.62313 |
| **Diffuse priors** | 1 | **Hannan-Quinn criter.** | | -3.77903 |

Before we look at the estimated TFP, it is important to note here that the sum of the two coefficients of capital and labour shares is higher than 1 (0.452 + 0.862= 1.314) showing thus that the production is characterised by increasing returns to scale (IRTS).

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.

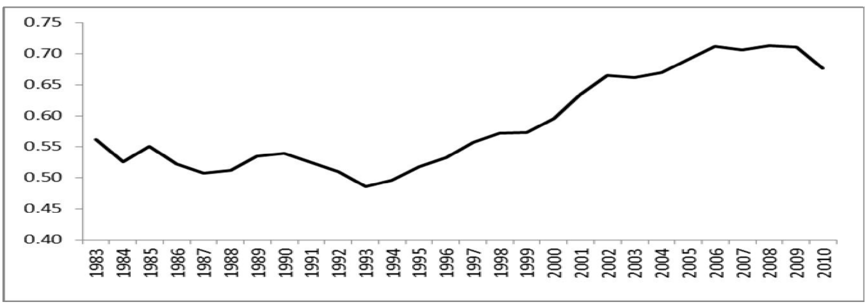


**Figure 4**: Time varying coefficient representing total factor productivity (technological progress)

The sideways trend from the 1980s 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 most significant contribution of technology to economic growth during the 2000s is visible in the upward trend until the end of the 2000s. The small decline at the end of the sample might be contributed to the global recession of 2008-2009. It is too early to conclude that this decrease shows that technological progress has started been a weaker contributor to growth. As the years progress, we will be able to see whether this decline was a structural break to the increasing trend or the direction of the trend has changed.

## 5. Discussion and Conclusion

In the past, models of South African production primarily assumed that technological progress was constant over time or not of importance. Their main emphasis was the labour and/or capital intensity of the economy. However, growth accounting calculations indicate that the relative contribution of technological growth has increased over time since the 1980s and has become as important a source of output growth as capital and labour growth during the 2000s. In contrast, both the relative contributions of capital and labour have decreased in comparison to the 1970s. These findings confirm Du Plessis and Smit (2007) that state "TFP growth accounts for the bulk of the growth in South Africa" especially after 1994. Also, Phillips (1987) already in the 1980s had identified the importance of technological innovations and progress to the South African society.

Therefore, given the evidence of structural transformation of the production in South Africa, it has become important to investigate the nature and extent of the changes. The challenge for analysts and subsequently policy makers is to identify the key drivers of economic growth and to direct economic policy towards optimizing the long-run growth potential of the economy.

In order to analyze, economic growth and its potential, it is necessary to model and capture the underlying properties of the production structure of the economy. Firstly, the growth accounting analysis showed that the contribution of technological progress to South African economic growth has increased through the years and it has become a production factor equally important as capital and labour.

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

According to results of the Kalman filter, technological progress is characterised by an upward trend since the 1980s with a steeper slope during the 2000s.

The increased and substantial contribution of technological growth since the 1980s, confirmed both by the growth accounting exercise and Kalman filter, 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 (Fedderke, de Kadt & Luiz 2003), 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 spill-over effects and greater private sector participation in the economy increases the scope for technological innovation. It is therefore evident that technological progress has become a strong 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. Towards the building of a knowledge economy in South Africa, the capacity to innovate and keep up to date with the international technology is imperative for the future growth of the country (Blankley and Booyens, 2010).

In conclusion, further research is required to unfold the determinants of technological progress (or total factor productivity) in South Africa and the magnitude of their impact to economic growth (Fleisher et al., 2010). This will allow us to identify the source of technological progress in the country and will assist the policy makers into implementing policies to boost it (Du Plessis and Smit, 2007). For example, Iyer (2011) found that Foreign Direct Investment (FDI) inflows, trade openness and human capital can promote the level of technological progress in the country towards catching-up with more technologically advanced countries.

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## Appendix

- Results of unit root testing

Table 4: Unit root testing

| ADF test | | | | | | | PP test | | | Conclusion |
|---|---|---|---|---|---|---|---|---|---|---|
| **series** | **model** | **lags** | **$\tau_\tau, \tau_\mu, \tau$** | | **$\varphi_3, \varphi_1$** | | **lags** | **PP** | | |
| **lgdp** | trend | 1 | -1.72 | | 3.673 | | 1 | -1.007 | | |
| | constant | 2 | 1.598 | | 2.187 | | 2 | 1.456 | | |
| | none | 1 | 2.665 | | - | | 2 | 4.497 | | non-stationary |
| **d(lgdp)** | trend | 1 | -4.03 | ** | 6.58 | *** | 7 | -5.171 | *** | |
| | constant | 0 | -4.05 | *** | 16.41 | *** | 1 | -4.098 | *** | |
| | none | 0 | -2.8 | *** | - | | 2 | -2.776 | *** | stationary (lgdp=I(1)) |
| **lcap** | trend | 2 | -1.46 | | 46.61 | * | 4 | -1.402 | | |
| | constant | 2 | 0.763 | | 56.64 | | 4 | 0.139 | | |
| | none | 2 | 2.084 | | - | | 4 | 4.549 | | non-stationary |
| **d(lcap)** | trend | 1 | -2.82 | | 7.285 | *** | 7 | -3.216 | | |
| | constant | 1 | -2.6 | | 10.11 | *** | 3 | -2.27 | | |
| | none | 1 | -1.48 | | - | | 3 | -1.582 | | stationary[5] (lcap=I(1)) |
| **lempl** | trend | 1 | -2.87 | | 6.438 | *** | 2 | -1.766 | | |
| | constant | 1 | -0.88 | | 4.835 | | 1 | -0.485 | | |
| | none | 1 | 1.124 | | - | | 1 | 3.276 | | non-stationary |
| **d(lempl)** | trend | 0 | -2.45 | | 3.085 | | 3 | -2.564 | | |
| | constant | 0 | -2.53 | | 6.408 | *** | 3 | -2.642 | ** | |
| | none | 0 | -2.37 | ** | - | | 1 | -2.395 | ** | stationary (lempl=I(1)) |

[5] based on graph and correlogram

- Data Plots:

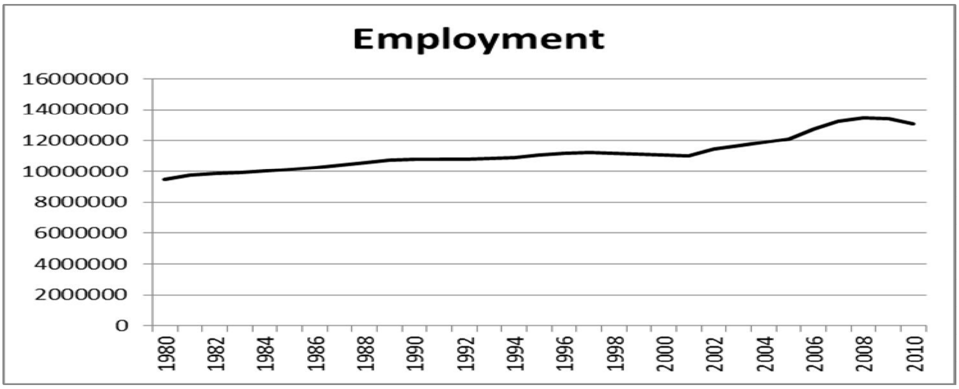


**Figure 5: Total employment**
Source: Quantec

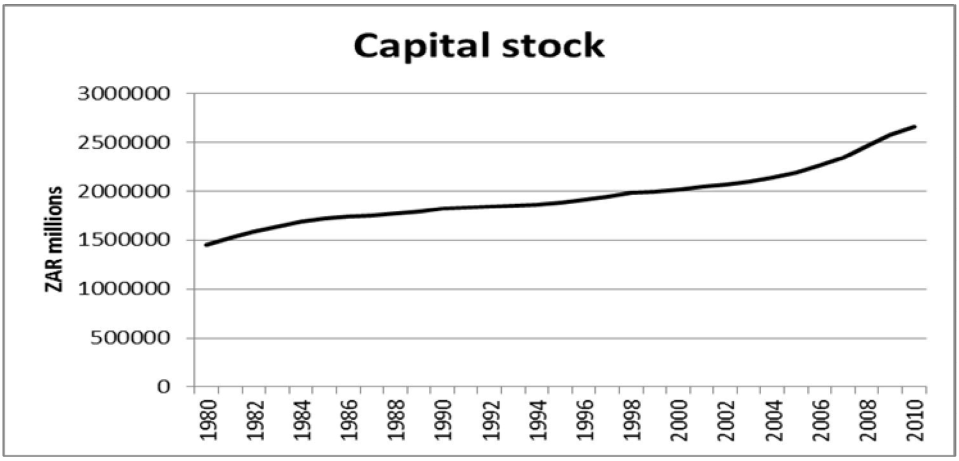


**Figure 6: Capital stock at constant 2000 prices**
Source: South African Reserve Bank

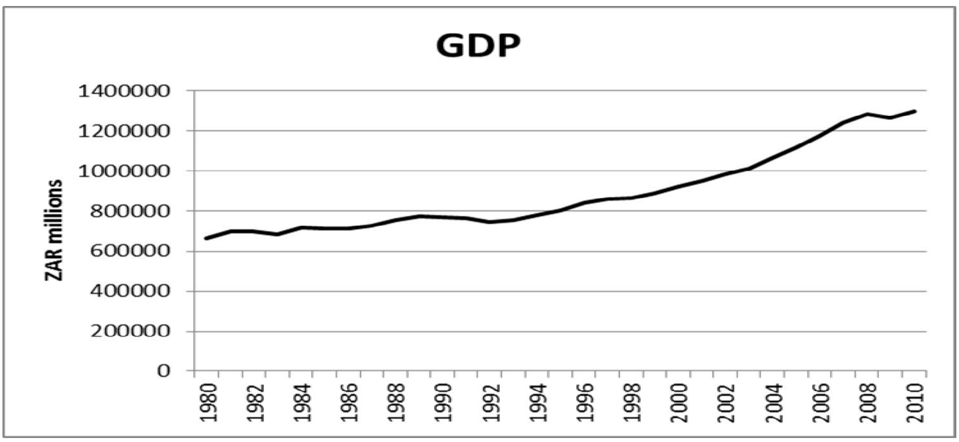


**Figure 7:** GDP at constant 2000 prices. Source: South African Reserve Bank

Table 5. Data.

| | Capital stock | Employment | GDP |
|---|---|---|---|
| 1980 | 1449035,88 | 9466306 | 662771,2 |
| 1981 | 1522641,5 | 9736597 | 698300,8 |
| 1982 | 1585829,38 | 9886028 | 695623,6 |
| 1983 | 1639289,25 | 9921560 | 682778,6 |
| 1984 | 1686763,63 | 10054285 | 717594,3 |
| 1985 | 1722936,5 | 10133543 | 708900,4 |
| 1986 | 1737638,75 | 10272265 | 709027,1 |
| 1987 | 1746241 | 10432695 | 723921,8 |
| 1988 | 1766471 | 10595843 | 754327,3 |
| 1989 | 1793728,88 | 10746358 | 772391,8 |
| 1990 | 1818349,5 | 10814583 | 769937,4 |
| 1991 | 1834958,25 | 10817507 | 762097,5 |
| 1992 | 1844186,13 | 10820127 | 745811,2 |
| 1993 | 1851552,38 | 10832270 | 755011,1 |
| 1994 | 1865081,63 | 10907207 | 779429 |
| 1995 | 1886110,75 | 11048530 | 803713,4 |
| 1996 | 1914494,5 | 11178965 | 838326,9 |
| 1997 | 1945977 | 11242321 | 860515,9 |
| 1998 | 1980033,63 | 11182690 | 864968 |
| 1999 | 1998783,75 | 11136290 | 885365 |
| 2000 | 2019216,5 | 11088069 | 922148 |
| 2001 | 2040636,25 | 10996934 | 947373 |
| 2002 | 2062966,13 | 11443043 | 982121 |
| 2003 | 2094733 | 11655106 | 1012763 |
| 2004 | 2136366 | 11891051 | 1062027 |
| 2005 | 2188461 | 12130869 | 1115135 |
| 2006 | 2260867 | 12766828 | 1175216 |
| 2007 | 2346948,31 | 13230326 | 1240651 |
| 2008 | 2462162,13 | 13460571 | 1285017 |
| 2009 | 2572982,32 | 13430943 | 1263401 |
| 2010 | 2659411,66 | 13111030 | 1299397 |