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Testing Capital Accumulation-Driven Growth Models in a Multiple-Regime Framework: Evidence from South Africa

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Testing Capital Accumulation-Driven Growth Models in a Multiple-Regime Framework: Evidence from South Africa[1]

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Abstract

This paper proposes two types of AK-style endogenous growth models to test the physical capital accumulation hypothesis in a 'typical' developing country with multiple regimes: a strong version, in which technological progress is fully endogenous to capital accumulation, and a weaker version, where technological progress and capital accumulation are complementary factors in the growth process. The empirical application supports the relevance of the weaker version across South Africa's 'faster-growing' regime (1952-1976) and 'slower-growing' regime (1977-2012). To improve the economy's post-2012 growth performance on a sustainable basis, the simulation exercise suggests a *refined* set of policies that *simultaneously* attracts foreign direct investment and raises the domestic saving/investment rate. Thus, to re-ignite the complementary relationship between technological progress and capital accumulation in the South African economy, both sources of growth should feature prominently in the initial decision-making process of policymakers.

Keywords: AK model; multiple regimes, growth transitions, physical capital accumulation; technological progress; foreign direct investment; South Africa; time-series econometrics

JEL Classification: C22, O11, O41, O47, O55

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1. INTRODUCTION

A major policy issue in developing economies is whether a faster rate of physical capital accumulation is a key determinant of long-run growth transitions, or whether permanent growth shifts are primarily the outcome of an 'unexplained' total factor productivity (TFP)/technology progress component (Rosenstein-Rodan, 1943; Lewis, 1954; Rostow, 1960; King and Levine, 1994; Easterly and Levine, 2001; Helpman, 2004; Bond et al., 2010; Gollin, 2014). To examine this issue in a systematic way, we develop a theoretical and empirical framework to test the relevance of AK-style endogenous growth models in a 'typical' developing country with multiple regimes[2]. The empirical application re-examines the role of physical capital accumulation across South Africa's different growth regimes during 1952-1976 and 1977-2012, and then uses the modelling framework to simulate how the economy can improve its post-2012 growth performance.

AK-type endogenous growth models in the spirit of Lucas (1988), Rebelo (1991), and Romer (1986, 1987) predict that a permanent increase in the physical investment rate leads to a permanent increase in the growth rate of real GDP per capita. In contrast, the original Solow model (1956) assumes that the rate of technological progress is exogenous or fixed, so that permanent changes in the investment rate generate permanent level effects and temporary growth effects in real GDP per capita. Jones (1995) proposes a simple, but intuitively appealing, time-series test of AK-style endogenous growth models. If movements in output growth are permanent/temporary over time, then empirical support for the AK model requires the investment rate to exhibit permanent/temporary movements as well.

[2] Pritchett's (2000) influential study shows that, in contrast to industrialised countries, most developing economies exhibit shifts in growth rates that lead to distinct patterns, and that these patterns remain unexplained in cross-country growth regressions. Motivated by Pritchett and earlier work by Easterly et al. (1993), several recent studies, such as Hausmann et al. (2005), Jerzmanowski, (2006), Jones and Olken (2008), Rodrik (2000), and Kerekes (2012) have attempted to identify the key determinants of growth transitions.

How does Jones's test apply to an economy with two steady-state growth regimes: one a slow-growing regime and the other a faster-growing one? The existence of steady-state regimes by construction implies that output growth in each regime shows no persistent trend movements. To support the AK model, the investment rate in each regime should be non-trended as well. If these preconditions are met *within* each regime, then the AK model predicts that a permanent shift out of a slow-growing regime into a faster-growing one is the result of a permanent, but one-off, increase in the investment rate.

Consider an alternative scenario in which the persistence profiles of investment and growth are different in each regime. Suppose that growth remains stationary in each regime, but the investment rate exhibits persistent shocks. Does this scenario completely rule out the relevance of an AK-type endogenous growth model? In the single-regime framework of Jones (1995) – and related studies by Li (2002), Bond et al. (2010), Herrerias and Orts (2011), and Romero-Ávila (2013) – it does. However, in a multiple-regime setting endogenous growth is still possible, even though the persistence profiles of growth and investment are different.

To formally show how endogenous growth is possible in this scenario, we follow the theoretical framework in Nell (2015) and assume that a 'Solow-type' model (1956), with zero learning-by-doing effects ($\phi \approx 0$), approximates an economy's slow-growing regime. In the faster-growing regime, a semi-endogenous growth model, with positive learning-by-doing effects ($0 < \phi < 1$), becomes the relevant theoretical framework[3]. The regime switch from a Solow model to a learning-by-doing model involves two phases. In the first phase, the growth shift is initiated through an exogenous shock that raises TFP growth and the learning-by-doing parameter. Based

[3] The theoretical models in sections 3 and 6 draw on Kaldor's (1957, 1961) technical progress function analysis, DeLong and Summers' (1992, 1993) equipment investment-growth nexus, new endogenous growth models in the spirit of Romer (1986, 1987) and textbook expositions, such as those in Romer (2006) and Sørensen and Whitta-Jacobsen (2010).

on Berg et al. (2012) and Jones and Olken's (2008) empirical results, the initial shock may originate from greater trade openness or a rise in foreign direct investment (FDI). Second, provided that firms reinvest their profits accumulated during the first phase, the positive learning-by-doing parameter implies that investment determines the long-run growth rate of the economy in the second phase; the rate of technological progress becomes endogenous to physical capital accumulation.

The foregoing discussion distinguishes between two types of AK-style endogenous growth models in a multiple-regime framework: the 'strong' version, in which a permanent increase in the investment rate initiates and sustains the regime switch, and the 'weaker' version, in which the investment rate is not the initiating source of the regime change, but nevertheless determines the rate of technological progress in the second phase and therefore plays an important role in sustaining the growth transition.

The empirical relevance of the multiple-regime AK-style endogenous growth models is illustrated with an application to the South African economy over the period 1952-2012. The key results can be summarised as follows. First, South Africa's growth performance can broadly be characterised by two different regimes: a 'faster-growing' regime (*FGR*) during 1952-1976 and a 'slower-growing' regime (*SGR*) during 1977-2012. Second, consistent with the theoretical framework outlined above, the empirical evidence supports the relevance of the weaker version of the AK-style endogenous growth model. The results show that the saving/investment rate long-run causes the level of per capita income in each regime, while the learning-by-doing parameter decreases sharply from 0.54 in the *FGR* to 0.14 in the *SGR*.

To interpret the results in a policy relevant way, the modelling framework of the weaker version of the AK model and empirical results in each regime are used to simulate how South Africa can improve its post-2012 growth performance. Based on the stylised facts in section 2 and previous growth narratives of the South African economy (Fedderke and Romm, 2006; Gwenhamo and Fedderke, 2013), FDI is identified as an important initiating source of growth, which constitutes the TFP part of the model. Technological progress, on the other hand, becomes endogenous to physical capital accumulation (via learning-by-doing effects) in the second phase of the growth transition. The direct contribution of physical capital accumulation (broadly defined) to the *long-run* growth shift is calculated to be around 54% and the remaining 46% is allocated to TFP growth. To re-ignite the interdependent or complementary relationship between technological progress and physical capital accumulation in the South African economy, policymakers are advised to emphasize *both* sources of growth in their initial decision-making process, rather than one or the other, as in Easterly and Levine's (2001) influential TFP view or the capital accumulation hypothesis of traditional development economists, such as Lewis (1954), Rostow (1960), Nurkse (1953) and Rosenstein-Rodan's (1943) big push model.

Against this background, section 2 identifies several stylised facts of South Africa's growth performance over the period 1952-2012. This section serves as important background information to set up the theoretical model in section 3. Section 4 discusses the empirical methodology and section 5 presents the empirical results. Section 6 conducts a simulation exercise to show how South Africa can improve its post-2012 growth performance, and outlines some policy implications. Section 7 concludes.

2. STYLISED FACTS OF SOUTH AFRICA'S GROWTH PERFORMANCE: 1952-2012

This section draws on descriptive evidence and previous growth narratives to identify several stylised facts of South Africa's growth performance over the period 1952-2012. The analysis serves as essential background information to set up the multiple-regime AK-style endogenous growth model in the next section and to interpret the econometric results later on.

2.1 Identifying Growth Regimes in the South African Economy: a statistical procedure

Following the large literature on growth shifts surveyed in footnote 2, a useful way of indentifying the timing of these shifts is to employ a statistical procedure, such as Bai and Perron's (1998, 2003) multiple breakpoint detection test (see Jones and Olken, 2008; Berg et al., 2012). The main advantage of the Bai and Perron test is that it searches for unknown breaks endogenously, and therefore avoids a subjective and biased analysis where the researcher identifies breakpoints based on her prior assumptions (Hansen, 2001).

The main advantage of the Bai and Peron procedure, however, is also its main disadvantage. It encourages an economic analysis that is in effect purely statistical in nature, without incorporating the benefits of a theory-consistent growth narrative that relies on the researcher's prior knowledge of country-specific features and historical events. The latter approach has often been associated with Hendry's general-to-specific methodology in the econometrics literature (Gilbert, 1986; Hendry 1995). In the context of the South African economy, we show the advantages and complementary nature of both approaches.

Consider an application of Bai and Perron's test to the South African economy. Jones and Olken (2008) show that South Africa's real gross domestic product (GDP) per capita growth rate contains a single down-break in 1981. Kar et al.'s (2013) new structural breakpoint test, which combines the Bai-Perron method and the filter-based approach advanced in Hausmann et al. (2005), identifies two breakpoints in South Africa's real GDP per capita growth rate: a down-break in 1981 and an up-break in 1993.

How robust are these results to an alternative breakpoint detection method and a different data source? The Jones-Olken and Kar et al. studies use purchasing-power-parity (PPP) adjusted data from Penn World Tables (PWT). The annual real GDP per capita series in this paper, on the other hand, is obtained from South Africa's own national accounts (denoted in local prices) and covers a more recent period from 1952 to 2012[4]. By employing Harvey and Koopman's (1992) breakpoint detection test, we identify structural breaks in the growth rate of real GDP per capita in 1981 and 1993, which are significant at the 5% and 10% significance levels, respectively[5].

2.2 Identifying Growth Regimes in the South African Economy: a historical narrative

Are the 1981 and 1993 breakpoints identified in the previous section consistent with some of the main historical events that characterised the South African economy over the period 1952-2012? Growth narratives typically identify the Soweto riots of 1976 as a major turning point in South Africa's growth performance (Mohr and Rogers, 1995; Fedderke and Liu, 2002)[6]. As shown in Fedderke and Liu (2002), the permanent increase in political instability that followed the Soweto uprising triggered a disinvestment campaign by foreign investors and long-term capital flight. The immediate impact of increased political instability on South Africa's economic performance, however, was to some extent mitigated by the high dollar gold price that prevailed during the early 1980s. South Africa, as a major exporter of gold, directly benefited from the high gold price, with per capita income growth surging to an average annual rate of 3.5% over the period 1980-1981.

These historical events suggest that it may be misleading to treat 1981 as a breakpoint in models that relate an economy's growth performance to long-term capital flows[7]. Although the

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[4]All the data in this paper are obtained from the South African Reserve Bank's historical data set (see appendix A for more details). Following Temple (1999), Knowles (2001) and Johnson et al. (2013), it is a useful exercise to examine the robustness of breakpoints across different data sources. These studies show that in many cases there are substantial differences between per capita income growth rate and investment rate data obtained from a country's own national accounts (denoted in local prices) and PPP adjusted PWT accounts. In the case of large discrepancies, it is preferable to use growth and investment data from a country's own national accounts (Temple, 1999; Knowles, 2001; Johnson et al., 2013).

[5] The Stamp 7 programme of Koopman et al. (2006) was used to compute the Harvey and Koopman (1992) breakpoint test. All these results are available on request.

[6] For more on the Soweto uprising, visit Wikipedia at http://en.wikipedia.org/wiki/Soweto_uprising.

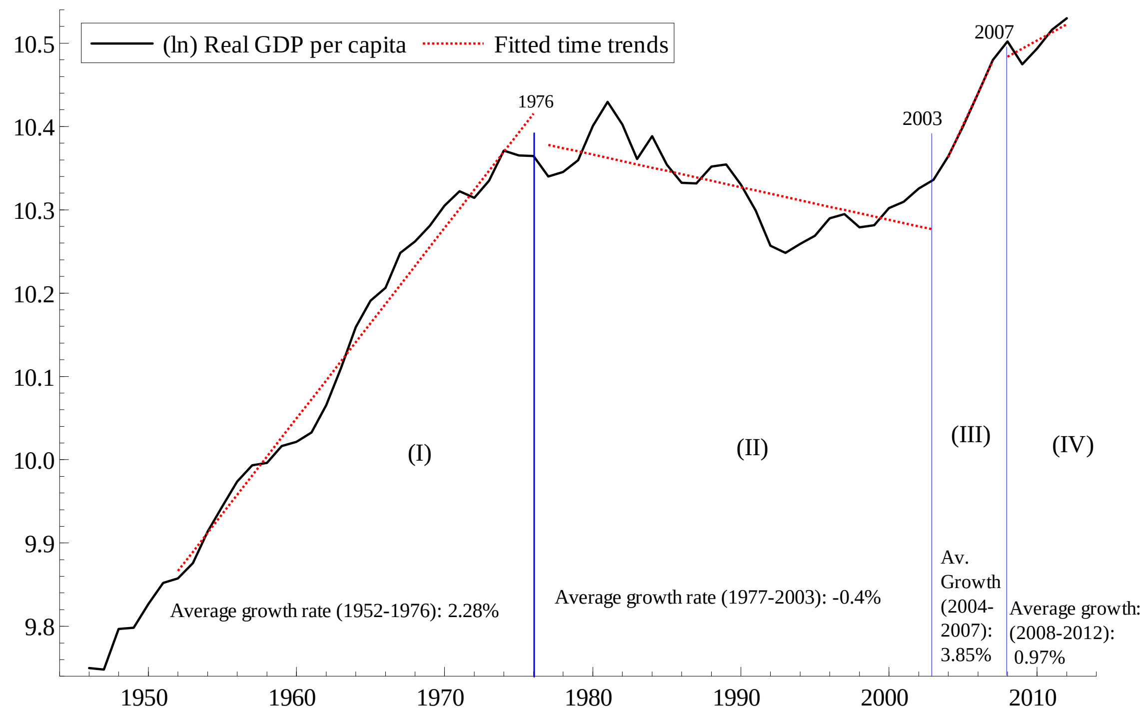
[7] See De Mello (1997) for an overview of these models and a survey of empirical results.

statistical procedures in the previous section provide a good approximation of the breakpoint, we need to combine this information with actual historical events to pinpoint the exact date of the break. The overview suggests that long-term capital outflows since 1976 may well signify a major turning point in South Africa's long-term growth performance, and that this break is to some extent masked over by the high dollar gold price in the early 1980s.

The second breakpoint (1993) identified in the previous section is consistent with Du Plessis and Smit's (2007) growth accounting exercise. They examine the determinants of South Africa's growth revival in the 10 years after the democratic transition in 1994 relative to the period 1985-1994. Nevertheless, by the authors' own account, the 'growth revival' was still modest by international standards and South Africa's own historical performance (Du Plessis and Smit, 2007: p. 669). To put South Africa's 'growth revival' into perspective, over the period 1994-2003 per capita income growth averaged 0.73%. Although this was an impressive transition from the negative averaged rate of -1.22% during 1985-1993, it still remained well below the average rate of 2.28% during the period 1952-1976. 'Super fast' growth of 3.85% was evident over the period 2004-2007, but this was short-lived when growth dropped to an average rate of 0.97% during the period 2008-2012, following the global financial crisis in 2008 and its lingering after effects. Socio-economic instability, related to deteriorating labour market conditions in 2012, also contributed to the slowdown in growth (see Smit et al., 2014).

Figure 1 plots the natural logarithm (ln) of South Africa's real GDP per capita over the period 1952-2012, together with a sub-division of the different regimes identified in the preceding discussion and their corresponding average growth rates. The following regimes are identified: (I) the period up until the Soweto uprising: 1952-1976; (II) the post-1976 period: 1977-2003; (III) the period of 'super fast' growth: 2004-2007; and (IV) the global financial crisis years: 2008-2012.

Figure 1: South Africa's Different Growth Regimes, 1952-2012



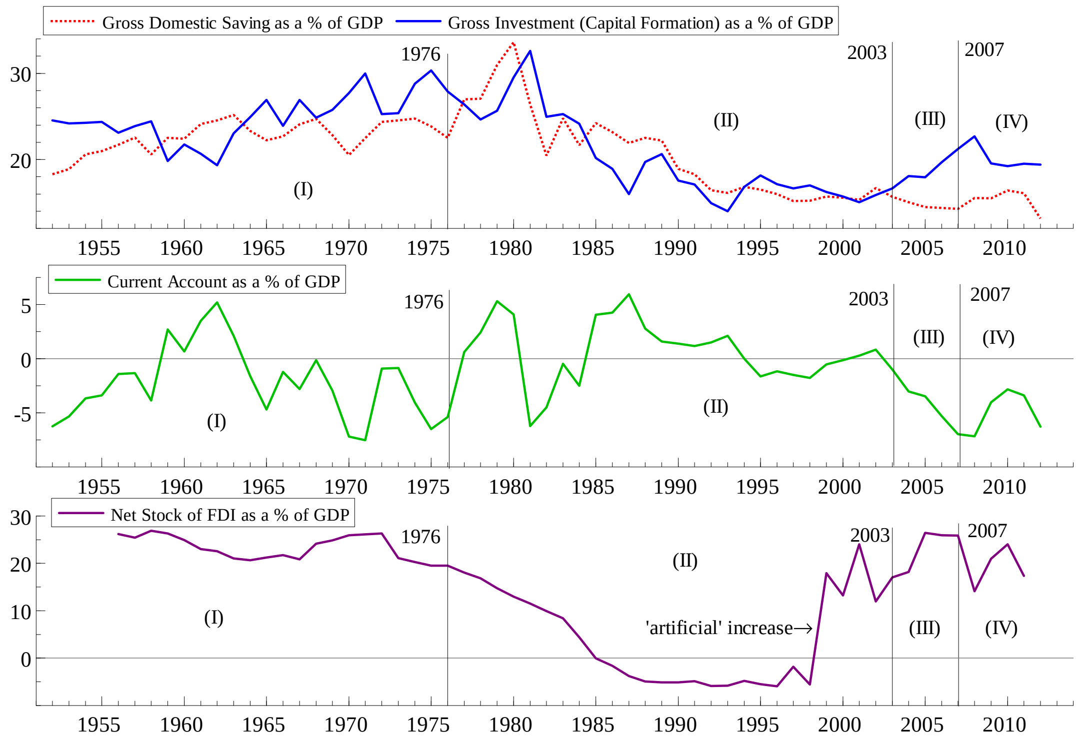
Notes:

1) The average growth rate in each regime is obtained by estimating the following log-linear trend model: $y_t = a + b_1t + u_t$; where y_t is the natural logarithm (ln) of real GDP per capita income, t is a time trend, and u_t is an unobserved disturbance term. The b_1 estimate multiplied by 100 gives the average growth rate.
2) Data Source: South African Reserve Bank. See Appendix A

The close link established in the literature between a developing country's growth performance and foreign direct investment (FDI) flows, both in an international and South African context (De Mello, 1997, 1999; Fedderke and Romm, 2006; Berg et al., 2012; Gwenhamo and Fedderke, 2013), suggests that is may be an informative exercise to examine whether the different growth regimes in Figure 1 are correlated with movements in FDI flows. The next sub-section examines this link in more detail.

2.3 South Africa's Growth Regimes and FDI

Figure 2: The Saving, Investment, Current Account and FDI ratios of South Africa, 1952-2012



Notes:

1) Data Source: South African Reserve Bank. Due to data availability, the net stock of FDI ratio in the bottom panel covers the period 1956-2011.

Consider regime (I) in Figure 1 when growth averaged 2.28% over the period 1952-1976. The top panel in Figure 2 shows that for most of the time the gross domestic investment rate (*i*) exceeded the gross domestic saving rate (*s*) during the first regime. This is reflected in the current account ratio of the balance of payments (*s* – *i*) in the middle panel, which records an average deficit of -2.28% during regime (I). The high net stock of FDI (liabilities – assets) to GDP ratio in the bottom panel of Figure 2 implies that net FDI inflows played a significant role in financing the current account deficit[8].

In regime (II), growth averaged -0.4% during the period 1977-2003 (see Figure 1). The poor growth performance over this period corresponds to a much closer relationship between the investment and saving rates in the top panel of Figure 2 which, in turn, is reflected in an average current account surplus ratio of 0.63% in the middle panel. One of the underlying reasons for the significant change in South Africa's balance-of-payments position in regime (II) relative to regime (I) was the slowdown in net FDI inflows. The net stock of FDI ratio in the bottom panel of Figure 2 shows a declining trend in the aftermath of the Soweto riots in 1976, and then becomes negative since the mid-1980s, following the debt moratorium and economic sanctions imposed by Western nations in reaction to President P.W Botha's infamous 'Rubicon Speech' in 1985[9]. Despite the democratic elections in 1994, the ratio remains negative until the late 1990s.

The sharp and persistent increase in the net stock of FDI ratio since 1999 seems to signify a major turnaround in FDI flows. However, as pointed out in Gwenhamo and Fedderke (2013: p. 764), the large increase in the stock of FDI liabilities (investment by foreigners in South Africa) from 1999 to 2001 was largely due to four of South Africa's largest multinational companies (MNCs) moving their major listing from the Johannesburg Stock exchange to the London Stock exchange, which required these companies to move their headquarters to London[10]. As a result, the South African based plants of these firms became part of South Africa's FDI liabilities in an

[8] FDI liabilities are defined as investment by foreigners in undertakings in South Africa in which they have at least 10% of the voting rights. FDI assets are investment by South African residents in undertakings abroad in which they have at least 10% of the voting rights (Data source and definitions: South African Reserve Bank).

[9] In his 1985 speech, the then president P.W. Botha alienated his Western allies by refusing to consider immediate and major changes to the country's apartheid system.

[10] The four MNCs that moved their headquarters to London in 1999 were Billiton, Anglo American, South African Breweries and Old Mutual. Didata followed them in 2000, and in the same year Richemont moved its major listing to Switzerland (see Gwenhamo and Fedderke, 2013: p. 764).

accounting sense, which gives the artificial impression that there has been a large and permanent increase in the net stock of FDI ratio since 1999.

Finally, returning to Figure 1, regime (III) captures 'super fast' growth of 3.85% over the period 2004-2007, and regime (IV) slower growth of 0.97% during the global financial crisis years (2008-2012). These regimes correspond to a large current account deficit ratio in the middle panel of Figure 2. Although the net FDI ratio in the bottom panel of Figure 2 fluctuates substantially over these regimes, it shows no persistent trend movements from the levels that prevailed in the late 1990s and early 2000s.

2.4 Summary

Based on the breakpoint detection tests and the historical growth narrative in sections 2.1-2.3, the 'long-run' stylised facts of South Africa's growth performance over the period 1952-2012 can succinctly be summarised in Table 1.

Table 1: 'Long-Run' Stylised Facts of South Africa's Growth Performance, 1952-2012

Growth regime	Average Growth Rate of Real GDP per capita (%)	Average Growth Rate of Capital per capita (%)	Current Account as a % of GDP	Average Net Stock of FDI as a % of GDP
1952-1976	2.28	2.48	-2.28	23.30
1977-2012	0.30	-0.30	-0.70	8.38

<u>Notes:</u>

1) Data Source: South African Reserve Bank.
2) Due to data availability, the net stock of FDI ratio covers the sub-periods 1956-1976 and 1977-2011.
3) The average growth rates of real GDP and total fixed capital stock per capita, both in constant 2005 prices, were obtained from log-linear trend models. See note 1 of Figure 1.

Table 1 shows that South Africa's growth performance can broadly be characterised by two regimes: a 'faster-growing' regime during the period 1952-1976, with an average per capita income growth rate of 2.28%, and a 'slower-growing' regime over the period 1977-2012, with an average growth rate of 0.30%. Although there are different regimes within the 'slower-growing' regime (see Figure 1), it is appropriate for now to treat it as one regime. We examine this issue in more detail in the econometrics section (section 5) and the simulation exercise in section 6.

The downward shift in per capita income growth in Table 1 coincides with a significant slowdown in the average growth rate of the total fixed capital stock per capita from 2.48% in the 'faster-growing' regime to a negative rate of -0.30% in the 'slower-growing' regime. Going back to the top panel in Figure 2, the slowdown in the growth rate of capital per capita is reflected in downward trend breaks in both the saving and investment rate across the two regimes.

Lastly, net FDI inflows played a key role in financing the average current account deficit ratio of -2.28% in the 'faster-growing' regime. This is captured by a high net stock of FDI ratio of 23.30% over the period 1952-1976. The structural change in the balance of payments, triggered by the Soweto riots of 1976, is evident in a much lower deficit ratio of -0.70% over the 'slower-growing' regime. Net FDI outflows were a characteristic feature during most of this regime, with a low net stock of FDI ratio of 8.38% over the period 1977-2012. Moreover, following the discussion in section 2.3, the average net stock of FDI ratio would be much lower without the 'artificial' increase from 1999 to 2001.

3. A MULTIPLE-REGIME AK-STYLE ENDOGENOUS GROWTH MODEL

In this section we develop two types of AK-style growth models: a 'strong' version, in which the rate of technological progress is fully endogenous to physical capital accumulation, and a 'weaker' version, in which the rate of technological progress is partly endogenous. The empirical relevance of these two competing models is then assessed by relating some of their predictions to the 'long-run' stylised facts of the South African economy in Table 1. The general theoretical framework adopted in this section is based on endogenous growth models developed in Romer

(1986, 1987), textbook expositions, such as those in Romer (2006) and Sørensen and Whitta-Jacobsen (2010), and the equipment-growth nexus of DeLong and Summers (1992, 1993).

3.1 The Main Equations of the Growth Models

The production function with constant returns to scale is given by

$$Y_t = (K_t)^{\alpha}(A_t L_t)^{1-\alpha}, \qquad 0 < \alpha < 1 \qquad (1)$$

where *t* denotes time, Y_t is real output, K_t is capital input, A_t is 'technology' or 'knowledge' input, and L_t is labour input.

The stock of knowledge at time *t* is modelled as

$$A_t = B_t K_t^{\phi}, \qquad 0 < \phi \leq 1 \qquad (2)$$

where ϕ is a learning-by-doing or capability parameter that measures the new knowledge and skills workers gain from using and installing new capital. A positive learning-by-doing parameter ($0 < \phi \leq 1$) implies that new technology is embodied in new machinery and equipment. When workers and managers use new capital with embodied technical progress, it triggers a process of learning-by-doing, which makes them more knowledgeable on how to adapt and use modern technologies in the most efficient way. In this framework, knowledge accumulation is endogenous with respect to capital accumulation (DeLong and Summers, 1992, 1993). With disembodied technical progress and a resulting learning-by-doing parameter of zero ($\phi = 0$), technology or knowledge becomes completely unexplained ($A_t = B_t > 0$), and we go back to the underlying assumption of the original Solow (1956) model.

The capital accumulation equation can be written as

$$K_{t+1} = sY_t + (1-\delta)K_t, \qquad \text{given } K_0 \qquad (3)$$

where s is the saving/investment rate, δ is the rate at which existing capital depreciates, and K_0 is the initial value of the capital stock.

The labour force and technology grow at the exogenous and constant rates g^n and g^B, respectively:

$$L_{t+1} = (1 + g^n)L_t, \qquad \text{given } L_0 \tag{4}$$

$$B_{t+1} = (1 + g^B)B_t, \qquad \text{given } B_0 \tag{5}$$

where g^n is the population growth rate, and L_0 and B_0 are the initial values of the labour force and technology, respectively. Since equation (4) assumes that the growth rate of the labour force is equal to the population growth rate, $(L_{t+1}/L_t) - 1 = g^n$, the discussion hereafter shall interchangeably refer to output growth in per worker or per capita terms.

3.2 The Strong Version of the AK Model

To derive the strong version of the AK model, set $B_{t+1} = B_t = 1 \Rightarrow g^B = 0$ and $\phi = 1$ in equations (2) and (5). It is further convenient to assume a constant labour force in equation (4), $L_t = L$, which implies that the population growth rate is equal to zero: $g^n = 0$. With these assumptions in place, substitute (2) into (1) to obtain the ‘AK model’:

$$y_t = Ak_t, \tag{6}$$

where $A = L^{1-\alpha}$ is a constant and lower case letters denote the variables in per worker terms. Equation (6) shows that the marginal product of capital is constant ($\partial y_t / \partial k_t = A$), which implies that permanent changes in the investment rate generate permanent growth effects. To analyse the long-run growth implications of the AK model, we follow the standard derivation procedure to obtain

$$(g^y = g^A = g^k) \equiv sA - \delta . \quad (7)$$

From equation (7) it is apparent that a permanent increase in the saving/investment rate (*s*) permanently raises the rates of growth of output per worker (g^y), technological progress (g^A), and capital per worker (g^k). In the strong version of the AK model, technological progress is fully endogenous to physical capital accumulation.

How well does the strong version of the AK model fit South Africa's actual growth performance over the period 1952-2012? To relate the predictions of the model to the long-run stylised facts of South Africa's growth performance in Table 1, it is informative to examine the persistence profiles (à la Jones, 1995) of the gross domestic saving rate (s_t), the gross domestic investment rate (i_t), and per capita income growth rate ($\tilde{g}_t^y$) in each regime. Table 2 reports the autocorrelation coefficients of each variable in South Africa's 'faster-growing' regime (1952-1976) and 'slower-growing' regime (1977-2012), with lag lengths up to order 10.

Except for the first two lags in the 'faster-growing' regime, Table 2 shows that all the lags of the per capita income growth rate variable are statistically insignificant. In contrast, all the lags of the investment and saving rate variables are highly significant. The evidence suggests that shocks to saving and investment are persistent in each regime, whereas shocks to per capita income growth are only temporary. This contrasts with the prediction of the AK model in equation (7), where persistent shocks to the saving/investment rate generate permanent growth effects. Alternatively, let us consider a weaker version of the AK model.

Table 2: Autocorrelation Coefficients of Variables

	'Faster-growing' regime: 1952-1976			'Slower-growing' regime: 1977-2012		
Order	s_t	i_t	$\tilde{g}_t^y$	s_t	i_t	$\tilde{g}_t^y$
1	0.627***	0.646***	0.262	0.850***	0.830***	0.379**
	[0.001]	[0.001]	[0.163]	[0.000]	[0.000]	[0.018]
2	0.247***	0.427***	–0.106	0.731***	0.682***	0.018*
	[0.002]	[0.000]	[0.320]	[0.000]	[0.000]	[0.059]
3	0.068***	0.366***	0.103	0.629***	0.579***	–0.002
	[0.005]	[0.000]	[0.456]	[0.000]	[0.000]	[0.130]
4	0.095***	0.356***	–0.046	0.498***	0.433***	0.048
	[0.010]	[0.000]	[0.613]	[0.000]	[0.000]	[0.218]
5	0.190**	0.216***	–0.226	0.444***	0.270***	0.084
	[0.013]	[0.000]	[0.492]	[0.000]	[0.000]	[0.300]
6	0.209**	0.138***	–0.118	0.423***	0.166***	0.183
	[0.013]	[0.000]	[0.555]	[0.000]	[0.000]	[0.268]
7	–0.043**	0.059***	–0.013	0.338***	0.097***	0.151
	[0.024]	[0.000]	[0.670]	[0.000]	[0.000]	[0.275]
8	–0.196**	–0.124***	–0.030	0.306***	0.037***	0.190
	[0.024]	[0.000]	[0.762]	[0.000]	[0.000]	[0.234]
9	–0.262**	–0.166***	–0.056	0.229***	–0.039***	0.079
	[0.015]	[0.001]	[0.826]	[0.000]	[0.000]	[0.291]
10	–0.166**	-0.144***	0.051	0.138***	–0.109***	–0.032
	[0.016]	[0.001]	[0.877]	[0.000]	[0.000]	[0.371]

Notes:

1) The *p*-values in brackets [·] are based on the Ljung-Box statistic (see Pesaran and Pesaran, 1997).
2) *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level.
3) All the variables are defined in Appendix A. Data source: South African Reserve Bank.

3.3 The Weaker Version of the AK Model

We now set $0 < \phi < 1$ in equation (2) and $g^B > 0$ in equation (5) and maintain the assumption that the population growth rate is zero. From equations (1)-(5), the steady-state *level* of output per worker ($y_{FGR,t} \equiv Y_{FGR,t} / L_{FGR,t}$) along a balanced growth path in South Africa's 'faster-growing' regime (*FGR*) can be derived as

$$y_{FGR,t} = \left(\frac{s_{FGR}}{\left\{ \left[\left(1 + g_{FGR}^{B} \right) \right]^{\frac{1}{1-\phi}} - \left(1 - \delta \right) \right\}} \right)^{\frac{\beta}{1-\beta}} L_0^{\frac{\phi}{1-\phi}} B_0^{1+\frac{\phi}{1-\phi}} \left(1 + g_{FGR}^{A} \right)^{t}, \quad 0 < \phi < 1 \qquad (8)$$

where $\beta = \alpha + \phi(1-\alpha)$ is the elasticity of output with respect to capital[11] and $g_{FGR}^{A} = (1 + g_{FGR}^{B})^{1+\frac{\phi}{1-\phi}} - 1$. The long-run growth rate, g_{FGR}^{A}, is sustained through an exogenous TFP or technology component equal to g_{FGR}^{B}. The steady-state growth path of output per worker is similar to the model derived in Sørensen and Whitta-Jacobsen (2010: p. 222), except that in their model population growth is the source of sustained growth.

3.4 Econometric Specifications

To arrive at an econometric specification of equation (8), take logs to obtain:

$$\ln(y_{FGR,t}) = c + \frac{\beta}{1-\beta} \ln(s_{FGR}) + \kappa(t) + \varepsilon_t, \qquad (9)$$

where ε_t is an error term and *t* is a time trend. The intercept term is equal to

$$c \equiv -\frac{\beta}{1-\beta} \ln\left\{ \left[\left(1 + g_{FGR}^{B} \right) \right]^{\frac{1}{1-\phi}} - (1-\delta) \right\} + \frac{\phi}{1-\phi} \ln\left(L_0 \right) + \left[1 + \frac{\phi}{1-\phi} \right] \ln(B_0) \qquad (10)$$

and the long-run growth rate of the model is equal to

$$\kappa \equiv \tilde{g}_{FGR}^{A} = \left[1 + \frac{\phi}{1-\phi} \right] \tilde{g}_{FGR}^{B}, \qquad (11)$$

[11] The elasticity of output with respect to capital is obtained by substituting equation (2) into equation (1): $Y_t = K_t^{\alpha+\phi(1-\alpha)} B_t^{1-\alpha} L_t^{1-\alpha}$.

where the tilde denotes the approximate growth rate of variable *x:* $\tilde{g}^{x}_{FGR} \equiv \ln x_{t+1} - \ln x_{t}$. Noting that equation (2) in growth rates becomes $\tilde{g}^{A}_{FGR} = \tilde{g}^{B}_{FGR} + \phi(\tilde{g}^{k}_{FGR})$, equation (11) can be written as

$$\kappa \equiv \tilde{g}^{A}_{FGR} = \tilde{g}^{B}_{FGR} + \phi(\tilde{g}^{k}_{FGR}). \tag{11′}$$

Equation (11′) shows that the rate of technological progress ($\tilde{g}^{A}_{FGR}$) in the *FGR* is composed of an exogenous TFP or technology component, $\tilde{g}^{B}_{FGR}$, and an endogenous capital accumulation component equal to $\phi(\tilde{g}^{k}_{FGR})$.

For now we assume that the positive learning-by-doing parameter in equation (11′) is related to South Africa's large stock of FDI ratio during its *FGR* (1952-1976) in Table 1. Contra-wise, it is assumed that the low stock of FDI ratio during South Africa's slow-growing regime (*SGR*) over the period 1977-2012 implies a much lower, but not necessarily zero, learning-by-doing parameter. For ease of exposition we set $\phi = 0$ in equation (8), and then take logs to derive the specification in South Africa's *SGR* as

$$\ln(y_{SGR,t}) = d + \frac{\alpha}{1-\alpha}\ln(s_{SGR}) + \tilde{g}^{B}_{SGR}(t) + \xi_{t}, \tag{12}$$

where ξ_{t} is an error term and the long-run growth rate ($\tilde{g}^{B}_{SGR}$) in the *SGR* is exogenously determined by the rate of technological progress. The intercept term is given by

$$d \equiv -\frac{\alpha}{1-\alpha}\ln\left(g^{B}_{SGR} + \delta\right) + \ln(B_{0}). \tag{13}$$

Equation (12) is similar to the Solow model derived in Mankiw et al. (1992), except that in our specification population growth is set to zero and the model is formulated in discrete time.

3.5 Multiple-Regime Framework of the Weaker AK Model

How compatible are the theoretical predictions of the models in equations (9) and (12) with the persistence profiles of the variables in Table 2? Since the learning-by-doing parameter in each model is less than one, a permanent increase in the saving/investment rate will generate a temporary growth effect and a permanent level effect in per capita income. The persistence profiles of the variables in Table 2 are consistent with these predictions – shocks to per capita income growth have been temporary in each regime, while those to the saving and investment rate have been more persistent. The main implication is that changes in the saving/investment rate cannot initiate a permanent growth transition. A permanent regime switch between the Solow model in (12) and the learning-by-doing model in (9) would require an exogenous shock to technological progress ($\tilde{g}^{B}_{SGR} \rightarrow \tilde{g}^{B}_{FGR}$) and/or the learning-by-doing parameter ($\phi \approx 0 \rightarrow 0 < \phi < 1$). It is important to note, however, that not all of the growth is exogenous; some of it is endogenous to physical capital accumulation through the $\phi(\tilde{g}^{k}_{FGR})$ term that appears in the long-run growth rate of the learning-by-doing model in equation (11′).

In section 6 we will use Kaldor's (1961) technical progress function analysis to model the interrelated relationship between technological progress and physical capital accumulation more clearly across South Africa's different growth regimes. Before we proceed, however, it is first necessary to test empirically whether the learning-by-doing model in equation (9) fits South Africa's *FGR* (1952-1976), and whether the Solow model in equation (12) approximates the economy's *SGR* (1977-2012).

4. ECONOMETRIC METHODOLOGY AND SPECIFICATION

4.1 Econometric Methodology

The econometric methodology employed in this paper follows the structural cointegrating vector autoregressive (VAR) approach first developed by Johansen (1988, 1992) and later advanced in Garratt et al. (2000); Pesaran et al. (2000); and Pesaran and Shin (2002). The statistical framework for the structural cointegrating VAR approach is the following general vector error-correction model (VECM):

$$\Delta y_t = a_{0y} + a_{1y}t - \mathbf{\Pi}_y y_{t-1} + \sum_{i=1}^{p-1} \mathbf{\Gamma}_{iy} \Delta y_{t-i} + \Psi_y w_t + v_t , \qquad (14)$$

where y_t is a vector of I(1) endogenous variables; a_{0y} is a vector of intercept terms; t is a vector of deterministic trends; and w_t is a vector of I(0) exogenous variables and event-specific dummy variables. The matrix $\mathbf{\Pi} = \alpha_y \beta'$ contains the cointegrating relationships, where the α_y matrix represents the error-correction coefficients, or the speed of adjustment towards long-run equilibrium, and β represents the matrix of long-run coefficients.

4.2 VECM Specification

From the learning-by-doing specification in equation (9) and the Solow model in equation (12), the vector of endogenous I(1) variables can be written as $y_t' = [\ln(y_{p/c}), \ln(s)]$, where ln($s$) is the logarithm of the gross domestic saving to nominal GDP ratio, and $\ln(y_{p/c})$ is the logarithm of real GDP per capita, which serves as a proxy for output per worker.[12] Appendix A provides a detailed description of the variables and data source. Consistent with endogenous growth models,

[12] From the available sources, such as the South African Reserve Bank and PWT (8.1), data on South Africa's workforce are only available from 1960 and not the full sample period (1952-2012) covered in this paper.

such as those developed by Romer (1986, 1987), Lucas (1988) and Aghion and Howitt (2007), we use the *aggregate* saving rate to measure capital accumulation in its broadest sense (see Barro and Sala-i-Martin, 1995; and Li, 2002). Further note that capital accumulation is proxied by the saving rate rather than the investment rate. Following Feldstein and Horioka's (1980) hypothesis in an open-economy context, an increase in the saving rate (domestic resources) may not necessarily lead to an equivalent increase in the investment rate (see Romer, 2006). The inclusion of the aggregate saving rate rather than the investment rate in equations (9) and (12) will therefore explicitly measure whether resources generated from the domestic economy are effective in raising living standards.

Based on the long-run stylised facts of South Africa's growth performance in Table 1 and the persistence profiles in Table 2, the models are estimated over the following regimes: (i) *FGR*: 1952-1976; and ii) *SGR*: 1977-2012, where *SGR* stands for 'slower-growing' regime and *FGR* for 'faster-growing' regime[13]. As a pre-test, we will first estimate the models over the full sample period (1952-2012) to examine whether the econometric evidence supports the breakpoints identified in section 2.

5. EMPIRICAL RESULTS

5.1 Full Sample Period: 1952-2012

Before we test for cointegration between the two level variables included in the y_t vector, it is first necessary to verify that they are both I(1), that is, integrated of order one. To test the

[13] Since the empirical models show some signs of structural instability in the immediate aftermath of World War II, we exclude the three-year period 1946-1948 from the South African Reserve Bank's data series. The data set therefore covers the period 1949-2012, but due to lagged and differenced variables, the effective sample period is 1952-2012.

order of integration of the variables, we perform a battery of unit root tests (not reported here) over the full sample period and the different sub-samples identified in Table 1[14]. Overall, the unit root test results suggest that the variables in levels, $\ln(y_{p/c})_t$ and $\ln(s)_t$, are I(1), but their first differences, $\Delta\ln(y_{p/c})_t$ and $\Delta\ln(s)_t$, are I(0). These results are also consistent with the persistence profiles of the variables reported in Table 2.

To determine the optimal lag length of the VECM in equation (14), we begin with an unrestricted VAR model (p = 3) over the full sample period 1952-2012. Akaike's (1974) and Schwarz's (1978) model selection criteria (not reported here) choose an order 2 model, so the lag length is set at p = 2 in equation (14) [15]. Furthermore, the intercept terms enter the VECM unrestrictedly while the deterministic time trends are restricted to lie in the cointegrating space.

We now proceed to test for cointegration between the I(1) level variables that enter y_t' = $[\ln(y_{p/c}),\ln(s)]$ over the period 1952-2012. The trace ($\hat{\lambda}_{\text{trace}}$) test statistic of 21.34 and the maximum eigenvalue ($\hat{\lambda}_{\max}$) statistic of 17.09 fall below Pesaran et al.'s (2000) 90% critical values of 23.08 and 17.18, respectively, so the null hypothesis of no cointegration cannot be rejected at the 10% significance level. Despite evidence of no cointegration, it is still informative to examine the estimation results of the per capita income equation in more detail. By normalising on $\ln(y_{p/c})$, we get the following error-correction mechanism (*ecm*) over the period 1952-2102 (standard errors in parentheses):

$$ecm_{FSP,t} = \ln(y_{p/c}) - \underset{(0.256)}{0.938} \cdot \ln(s) - \underset{(0.003)}{0.017} \cdot trend\ , \tag{15}$$

[14] The unit root tests include those developed by Dickey and Fuller (1979), Phillips and Perron (1988), Kwiatkowski et al. (1992), and Ng and Perron (2001). All the unit root test results were calculated with the software programme, EViews 8.

[15] The cointegration results are computed with Microfit 4.0 (Pesaran and Pesaran, 1997).

where *FSP* stands for full sample period. The long-run per capita income equation is obtained by solving (15) for $\ln(y_{p/c})$. From this relationship it can be seen that the saving rate variable is correctly signed (+) and statistically significant at the 1% level.

A crucial empirical issue is to determine whether the saving rate long-run causes per capita income in equations (9) and (12). Following the weak exogeneity test procedure developed in Johansen and Juselius (1992), we test whether the *ecm* in equation (15) enters significantly in the per capita income growth rate $[\Delta\ln(y_{p/c})_t]$ and saving rate $[\Delta\ln(s)_t]$ equations of the VECM. Table 3 reports the long-run causality tests conducted in an unrestricted error-correction model framework. The error-correction mechanism ($ecm_{FSP,t-1}$) enters significantly in the saving rate equation but insignificantly in the per capita income equation. The results show that the saving rate adjusts towards its long-run equilibrium value in reaction to changes in per capita income, but not the other way around. Or put differently, per capita income is exogenous with respect to the saving rate. This contradicts one of the basic predictions of the learning-by-doing model in equation (9) and the Solow model in equation (12), which postulates a long-run causal effect from the saving rate to per capita income.

Table 3: Long-Run Causality Tests, 1952-2012

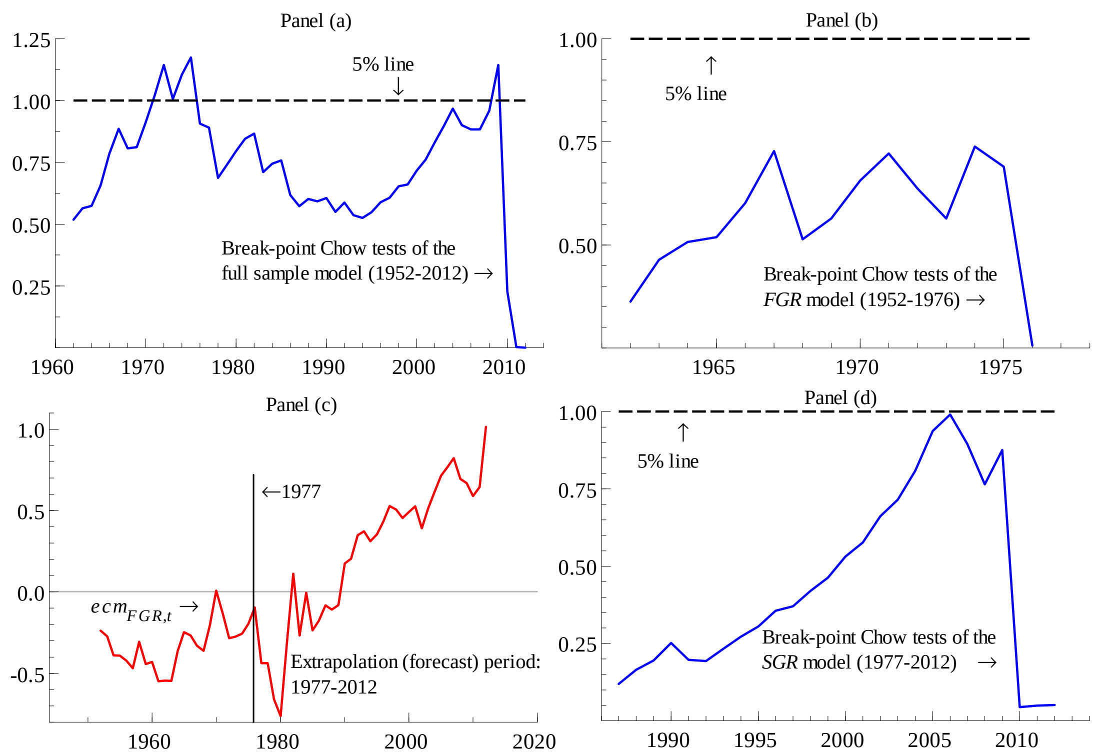
	FSP: 1952-2012	
Equation	$\Delta \ln(y_{p/c})_t$	$\Delta \ln(s)_t$
Intercept	–0.063 (0.190)	–4.776*** (1.153)
$\Delta \ln(y_{p/c})_{t-1}$	0.436*** (0.104)	–0.723 (0.457)
$\Delta \ln(s)_{t-1}$	0.103** (0.040)	0.069 (0.156)
$ecm_{FSP,t-1}$	0.006 (0.016)	0.425*** (0.102)
Diagnostic Tests		
R^2	0.34	0.25
$\hat{\sigma}$	0.018	0.07
F_{ar}	0.205 [0.652]	1.667 [0.202]
F_{reset}	1.196 [0.279]	0.007 [0.929]
$\chi^2_n(2)$	4.57 [0.102]	1.679 [0.432]
F_{het}	0.020 [0.886]	3.774 [0.057]

Notes:

1) Robust standard errors are in parentheses (·) and *p*-values are given in brackets [·]. *** denotes significance at the 1% level and ** at the 5% level. The robust standard errors are derived from the Newey-West procedure using Bartlett weights with a truncation lag of three (see Pesaran and Pesaran, 1997).
2) R^2 is the coefficient of determination and $\hat{\sigma}$ is the residual standard deviation. The diagnostic tests are given as F_j, which indicates an F-test against the alternative hypothesis *j* for: first-order serial correlation (F_{ar}); functional form misspecification (F_{reset}); heteroscedasticity (F_{het}). χ^2_n is a chi-square test for normality. For more details, see Pesaran and Pesaran (1997).

The causality results are thus far consistent with those presented by Odhiambo (2009) for the South African economy over the period 1950-2005. Nevertheless, since the breakpoint analysis in section 2 suggests that the VECM could be structurally unstable, the causality results should be interpreted with some circumspection. To examine the structural stability of the VECM in a succinct way, Figure 3(a) reports the recursively estimated break-point Chow tests of the per capita income growth rate error-correction model in Table 3[16]. The graphical analysis shows that the break-point Chow tests exceed the 5% critical value during the first half of the 1970s and in 2008, so the null of structural stability can be rejected at the 95% confidence level during these periods. The instability of the VECM during the 1970s and global financial crisis in 2008 is consistent with the breakpoint analysis in section 2. Thus, based on this evidence, we proceed with a split sample analysis over the two sub-periods identified in Table 1.

Figure 3: Structural Stability Tests



[16] The break-point Chow tests are computed with PcGive version 14 (see Doornik and Hendry, 2013).

5.2 Sub-Samples: 1952-1976 and 1977-2012

For the split sample analysis we include the following even-specific dummy variables in the w_t vector of the VECM in equation (14). The slowdown in growth following the Sharpeville massacre in March 1960 is modelled by the dummy variable, $D_{(60-61)}$, and takes the value of unity during 1960-1961 and zero otherwise[17]. To model the temporary growth surge associated with the high dollar gold price during the early 1980s together with the downward shift in the saving/investment rate, $D_{(80-84)}$ takes the value of unity during 1980-1984 and zero otherwise. The negative per capita income growth rate of -4.24% in 1992 is modelled by D_{92}, which captures the impact of the global recession during the early 1990s and more restrictive monetary policy measures at home. Lastly, the outlying effects of super fast growth over the period 2004-2007 and the global financial crisis years during 2008-2012 are proxied by $D_{(04-12)}$, and takes the value of unity during 2004-2012 and zero otherwise.

With the dummy variables defined as $w'_{FGR,t} = (D_{(60-61)})$ and $w'_{SGR,t} = (D_{(80-84)}, D_{(92)}, D_{(04-12)})$ in equation (14), cointegration tests are performed over the split samples 1952-1976 and 1977-2012. In contrast to the full sample period results, the trace test and maximum eigenvalue statistics in Table 4 show that there is a unique cointegrating vector (r = 1) at the 95% confidence level in each growth regime. The error-correction mechanism (*ecm*) or cointegrating vector in each regime can be written as (standard errors in parentheses):

[17] For more on the Sharpeville massacre, visit Wikipedia at http://en.wikipedia.org/wiki/Sharpeville_massacre.

$$ecm_{FGR,t} = \ln(y_{p/c}) - \underset{(0.496)}{1.757} \cdot \ln(s) - \underset{(0.771)}{13.080} \tag{16}$$

$$ecm_{SGR,t} = \ln(y_{p/c}) - \underset{(0.077)}{0.462} \cdot \ln(s) - \underset{(0.002)}{0.010} \cdot trend\ , \tag{17}$$

where, as before, *FGR* denotes South Africa's 'faster-growing' regime (1952-1976) and *SGR* its 'slower-growing' regime (1977-2012). The solved long-run per capita equations of (16) and (17) show that the saving rate variable is correctly signed (+) and statistically significant at the 1% level in each regime.

Table 4: Cointegration Tests in Each Sub-Sample

Hypothesis		$\hat{\lambda}_{\text{max}}$			$\hat{\lambda}_{\text{trace}}$		
H_0	H_A	Statistic	95% CV	90% CV	Statistic	95% CV	90% CV
		'Faster-growing' regime (*FGR*): 1952-1976					
r = 0	r = 1	36.51**	15.87	13.81	48.67**	20.18	17.88
		'Slower-growing' regime (*SGR*): 1977-2012					
r = 0	r = 1	40.01**	19.22	17.18	46.25**	25.77	23.08

Notes:
1) The critical values (CVs) of the λ_{max} and λ_{trace} test statistics are obtained from Pesaran et al. (2000). ** denotes significance at the 5% level.
2) The VECM in equation (14) is specified as follows. Akaike's (1973, 1974) and Schwarz's (1978) model selection criteria choose an order one VAR ($p = 1$) for each growth regime. The intercept terms are restricted to lie in the cointegrating space without trends in South Africa's *FGR*. Similar to the cointegration analysis over the full sample period, the option of restricted trends and unrestricted intercept terms is chosen for South Africa's *SGR*.

The long-run causality results for the split samples in Table 5 also tell a different story compared with the full sample period results in Table 3. In the *FGR*, the error-correction mechanism ($ecm_{FGR,t-1}$) enters significantly in the $\Delta\ln(y_{p/c})_t$ equation and insignificantly in the $\Delta\ln(s)_t$ equation, which shows that the saving rate is exogenous with respect to per capita income. In the *SGR*, there is evidence of bi-directional long-run causality – the error-correction mechanism ($ecm_{SGR,t-1}$) is significant in both the $\Delta\ln(y_{p/c})_t$ and $\Delta\ln(s)_t$ equations.

Table 5: Long-Run Causality Tests, 1952-1976 and 1977-2012

	FGR:1952-1976		*SGR*: 1977-2012	
Equation	$\Delta\ln(y_{p/c})_t$	$\Delta\ln(s)_t$	$\Delta\ln(y_{p/c})_t$	$\Delta\ln(s)_t$
Intercept	–	–	3.324*** (0.593)	–10.75*** (2.978)
$ecm_{FGR,t-1}$	–0.067*** (0.008)	0.001 (0.029)	–	–
$ecm_{SGR,t-1}$	–	–	–0.304*** (0.054)	0.985*** (0.272)
$D_{(60-61)}$	–0.021*** (0.003)	0.035 (0.020)	–	–
$D_{(80-84)}$	–	–	0.013** (0.005)	–0.098** (0.045)
$D_{(92)}$	–	–	–0.041*** (0.003)	–0.111*** (0.014)
$D_{(04-12)}$	–	–	0.039*** (0.007)	–0.079*** (0.028)
	Diagnostic tests			
R^2	–	–	0.62	0.30
$\hat{\sigma}$	0.013	0.06	0.015	0.089
F_{ar}	0.004 [0.945]	0.043 [0.836]	1.715 [0.200]	0.086 [0.771]
F_{reset}	0.007 [0.934]	0.102 [0.752]	0.077 [0.783]	2.807 [0.104]
$\chi^2_n(2)$	0.522 [0.770]	1.732 [0.421]	1.057 [0.589]	4.665 [0.097]
F_{het}	0.001 [0.973]	0.795 [0.382]	1.175 [0.286]	1.983 [0.168]

Notes:

1) Robust standard errors are in parentheses (·) and *p*-values are given in brackets [·]. *** denotes significance at the 1% level and ** at the 5% level. The robust standard errors are derived from the Newey-West procedure using Bartlett weights with a truncation lag of three (see Pesaran and Pesaran, 1997).
2) R^2 is the coefficient of determination and $\hat{\sigma}$ is the residual standard deviation. The diagnostic tests are given as F_j, which indicates an F-test against the alternative hypothesis *j* for: first-order serial correlation (F_{ar}); functional form misspecification (F_{reset}); heteroscedasticity (F_{het}). χ^2_n is a chi-square test for normality. For more details, see Pesaran and Pesaran (1997).

The empirical evidence of a long-run causal effect from the saving rate to per capita income in each regime is statistically robust based on the insignificance of all the diagnostic tests in Table 5 and the structural stability tests in Figure 3. Figure 3(b) shows that the per capita income growth rate error-correction model in Table 5 is structurally stable during the *FGR*, with all the Chow tests falling below the 5% critical value. To verify that the regime change occurred in the mid-1970s, Figure 3(c) extrapolates the *FGR* error-correction mechanism in equation (16) over the *SGR*. The visual plot shows that $ecm_{FGR,t}$ represents a stationary, cointegrated relationship over the period 1952-1976, but thereafter drifts upwards and becomes non-stationary over the extrapolation (forecast) period 1977-2012. Once the regime change is taken into account, we obtain a structurally stable per capita income growth rate error-correction model during the *SGR* in Table 5 – the recursively estimated Chow tests of this model all fall below the 5% critical value in Figure 3(d) [18].

5.3 Deriving the Learning-by-Doing Parameter

To derive the learning-by-doing parameter in each regime, we proceed as follows. The saving rate elasticities of the long-run cointegrating vectors in equations (16) and (17) are recorded in column 1 of Table 6. Note that the saving rate elasticity estimates in column (1) are equal to $\hat{\beta}_i/(1-\hat{\beta}_i)$ in the learning-by-doing model of equation (9), where $\hat{\beta}_i$ is the elasticity of output with respect to capital, i = 1 denotes South Africa's *FGR*, and i = 2 its *SGR*. Column (2) reports the solved capital elasticity estimate ($\hat{\beta}_i$) for each regime.

[18] For ease of exposition, Figure 3 only reports the recursively estimated structural stability tests of the per capita income growth rate error-correction models in Table 5. Additional stability tests (not reported here) show that the saving rate equations in Table 5 are also structurally stable.

Table 6: Structural Change in the Learning-by-Doing Parameter

	(1)	(2)	(3)	(4)
Growth Regime	Saving Rate Elasticity: $\hat{\beta}_i/(1-\hat{\beta}_i)$	Capital Elasticity: $\hat{\beta}_i=\alpha+\hat{\phi}_i(1-\alpha)$	Assumed α	Implied $\hat{\phi}_i$
FGR:1952-1976	1.757*** (0.496)	$\hat{\beta}_1$ = 0.64*** (0.060)	0.21	$\hat{\phi}_1$ = 0.54*** (0.060)
SGR:1977-2012	0.462*** (0.077)	$\hat{\beta}_2$ = 0.32*** (0.038)	0.21	$\hat{\phi}_2$ = 0.14*** (0.038)
Estimates over a Different Sub-Sample in *SGR*				
SGR(I):1977-2003	0.400*** (0.065)	$\hat{\beta}_2$ = 0.29*** (0.037)	0.21	$\hat{\phi}_2$ = 0.10*** (0.037)

Note: Standard errors are in parentheses (·). *** denotes significance at the 1% level.

Noting that $\hat{\beta}_i=\alpha+\hat{\phi}_i(1-\alpha)$ in equation (8), it is possible to derive an implied learning-by-doing parameter estimate ($\hat{\phi}_i$) for a given value of capital's share in total income (α). From the labour share data provided by PWT (8.1), we calculate the capital share (one minus the labour share) to be around 0.42, which is consistent with the value used in Du Plessis and Smit's (2007) growth accounting exercise and Caselli and Feyrer's (2007) unadjusted measure[19]. Caselli and Feyrer, however, argue that the conventional way of deriving capital's share may overstate its contribution to income. Their main argument is as follows. When capital's share is derived from labour's share in the national accounts, the measure includes payments accruing to both reproducible and non-reproducible capital, such as land and natural resources. Since standard growth models, including the ones used in this paper, include reproducible capital, capital's share derived from national accounts would tend to overestimate its contribution[20]. Instead, Caselli and

[19] The capital share of 0.42 is the average over the full sample period. Over South Africa's *FGR* and *SGR* the corresponding average values are 0.40 and 0.43, respectively.

[20] The impact of non-reproducible capital is proxied by the initial TFP term, B_0, in equations (10) and (13).

Feyer calculate an adjusted capital share (adjusted for the income contributions of land and natural resources) for South Africa of only 0.21. By using the adjusted estimate of α = 0.21 in column 3 of Table 6, we derive learning-by-doing parameters in column 4 of 0.54 in the *FGR* and 0.14 in the *SGR*.

As an additional robustness check, Table 6 also reports the estimates we get over a different sub-sample in South Africa's *SGR*. The *SGR*(1) period 1977-2003 excludes the large shifts in trend growth experienced over the period 2004-2012. For the *SGR*(1) period we get a learning-by-doing parameter estimate of 0.10, which is close in magnitude to the 0.14 estimate in the *SGR*. Finally, we also checked how robust the estimates are when population growth is included as an additional explanatory variable in the VECM of equation (14). The population growth rate variable turned out to be an insignificant determinant in all the specifications, which supports the zero restriction in equation (9)[21].

6. SOUTH AFRICA'S POST-2012 GROWTH PERFORMANCE

We can now use the learning-by-doing estimates in Table 6 and the long-run stylised facts in Table 1 to model the interdependence between physical capital accumulation and technological progress across South Africa's growth regimes. This information, in turn, can then be used to simulate how the economy can improve its post-2012 growth performance. To illustrate the interdependent relationship in a clear and succinct way, it is informative to express the output/capital per capita growth rate relationship as a 'technical progress function', which is analogous to the functional form originally developed by Kaldor (1957, 1961).

[21] The zero restriction, of course, does not literally mean that population growth is zero. Rather, the insignificance of population growth suggests that its scale effects in the learning-by-doing model may operate in conjunction with other growth determinants that appear in the long-run growth rate component of g^{B}_{FGR} in equation (11′).

To derive the technical progress function, substitute equation (2) into equation (1):

$$Y_t = K_t^{\alpha+\phi(1-\alpha)} B_t^{1-\alpha} L_t^{1-\alpha} . \tag{18}$$

Taking logs and approximate growth rates of equation (18), and maintaining the assumption that the population growth rate is zero, we get:

$$\tilde{g}_t^y = [\alpha + \phi(1-\alpha)]\tilde{g}_t^k + (1-\alpha)\tilde{g}^B , \tag{19}$$

where $\tilde{g}_t^y$ is the growth rate of output per capita; $\tilde{g}_t^k$ is the growth rate of capital per capita; and $\tilde{g}^B$ is the exogenous growth rate of technology. In conventional growth accounting exercises, the share of capital (α) measures the *transitory* growth effect of capital accumulation. The long-run growth effect of technological progress and capital accumulation in (19) can be derived by setting $\alpha = 0$:

$$\tilde{g}_t^y = \phi(\tilde{g}_t^k) + \tilde{g}^B . \tag{20}$$

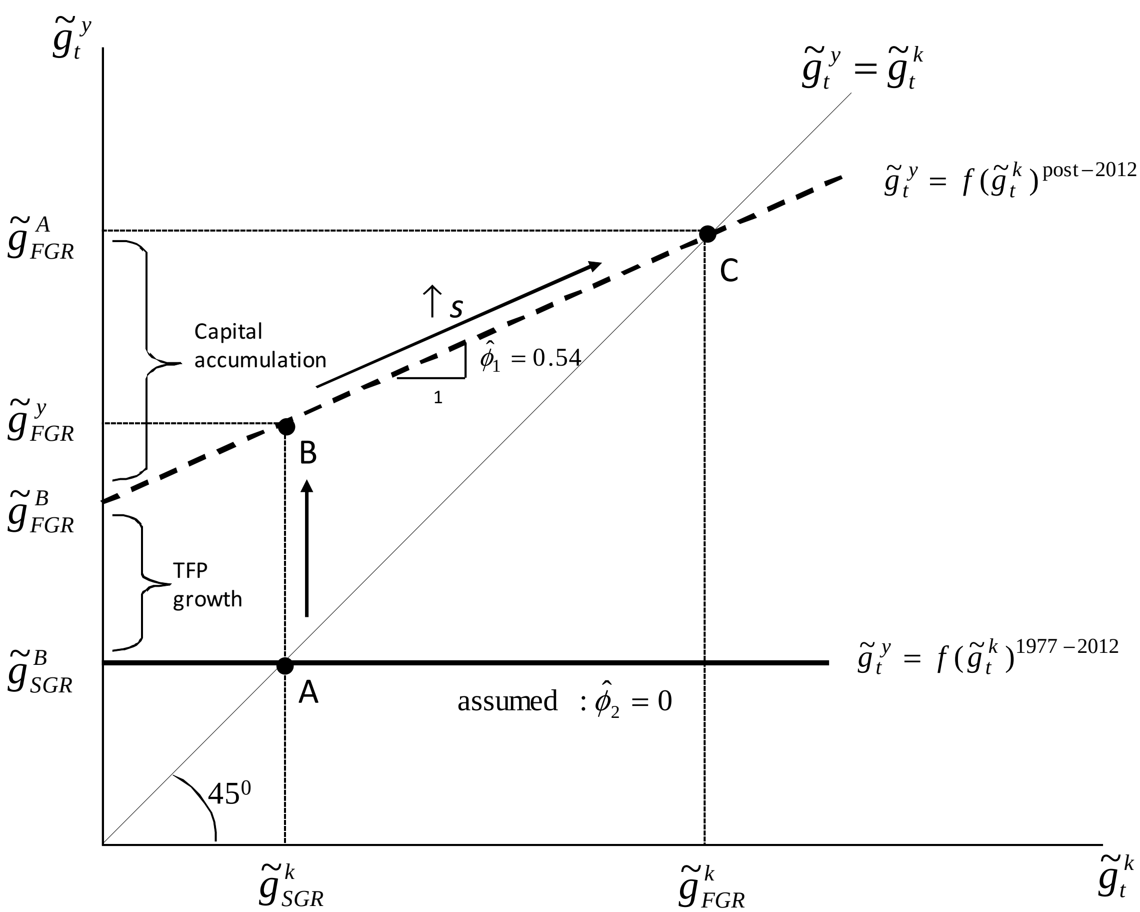
Equation (20) gives a relationship that is similar to Kaldor's (1961) technical progress function. Note that the variables/parameters of the technical progress function constitute the long-run growth rate component of the learning-by-doing model in equation (11′).

6.1 The Interdependence between Capital Accumulation and Technological Progress

Consider a graphical representation of the technical progress function in equation (20). In Figure 4, output per capita growth ($\tilde{g}_t^y$) is measured on the vertical axis and capital per capita growth ($\tilde{g}_t^k$) on the horizontal axis. In South Africa's *SGR*, the position or intercept of the technical progress function is given by $\tilde{g}_{SGR}^B$. From the stylised facts in Table 1 the intercept is drawn for a positive per capita income growth rate of 0.30%. At the same time, although the learning-by-doing estimate in Table 6 shows that $\hat{\phi}_2$ = 0.14 in South Africa's *SGR*, we assume for simplicitly, but without loss of generality, that $\hat{\phi}_2 = 0$. Since the learning-by-doing parameter measures the slope of the function, this assumption implies that the technical progress function in South Africa's *SGR*, $\tilde{g}_t^y = f(\tilde{g}_t^k)^{1977-2012}$, becomes a horizontal line at the exogenously given rate of technological progress, $\tilde{g}_{SGR}^B$. At point A in Figure 4, which is on the 45-degree line, the economy is operating on a balanced growth path:

$$\tilde{g}_{SGR}^y = \tilde{g}_{SGR}^k = \tilde{g}_{SGR}^B \tag{21}$$

Figure 4. Simulating an Improvement in South Africa's Post-2012 Growth Performance



Equation (21) implies a constant output-capital ratio. From the stylised facts in Table 1 it can be seen that the growth rates of output and capital per capita of 0.30% and –0.30%, respectively, roughly approximate each other. For ease of exposition it is useful to relate South Africa's *SGR* to the Solow model in equation (12), and to assume that the economy operates on a 'balanced' growth path, as shown in equation (21)[22].

By starting from an initial equilibrium position at point A in South Africa's *SGR*, how can policymakers 'engineer' a permanent growth transition in the post-2012 period? Consider the impact of an exogenous shock to the saving/investment rate. Because the learning-by-doing parameter of 0.14 in Table 6 is less than one, the marginal product of capital is subject to diminishing returns. Thus, in contrast to the constant returns to capital assumption of the strong version of the AK model in equation (7), a permanent shock to the saving/investment rate will generate a temporary growth effect and a permanent level effect. Evidence of diminishing returns to capital implies that the long-run growth rate is exogenously given at point A in Figure 4.

Alternatively, policymakers will have to initiate a permanent growth transition through a positive shock to productivity growth. To identify a potential source of productivity growth, it is informative to draw on the empirical results in South Africa's *FGR*. In this way, we can use these results to 'simulate' how the economy can improve its post-2012 growth performance. Going back to the stylised facts in Table 1 and previous growth narratives of the South African economy (Fedderke and Romm, 2006; Gwenhamo and Fedderke, 2013), FDI, as a potential source of productivity growth, appears to be a strong candidate. The net stock of FDI ratio in Table 1 is almost three times larger in the *FGR* relative to the *SGR*, and would be even larger without the

[22] Strictly speaking, the economy is operating on a balanced growth path when capital and output grow at the same rate *and* the saving/investment rate is stationary. Following Jones' (2002) terminology, because South Africa's saving/investment rate is non-stationary in each regime, it is perhaps more precise to refer to the equilibrium condition as a constant growth path rather than a balanced growth path.

'artificial' increase from 1999 to 2001. Consistent with these findings, several studies show that portfolio and other investment flows have been the main drivers of net capital inflows since the mid-1990s (Gelb and Black, 2004; Rangasamy, 2014). Moreover, a large proportion of FDI inflows since the 1990s has been in the form of partial cross-border mergers and acquisitions, rather than Greenfield investments (Arvanitis, 2005; Gelb and Black, 2004; Kransdorff, 2010)[23]. It is the latter type of investment that facilitates the transfer of new technologies and knowledge accumulation from abroad. Indeed, as our results in Table 6 show, the learning-doing-parameter of 0.54 in South Africa's *FGR* is more than three times larger than the 0.14 estimate in the *SGR*.

Against this background, and starting from an initial equilibrium position at point A in Figure 4, we can simulate an improvement in South Africa's post-2012 growth performance in the following way. Suppose policymakers succeed in attracting a significant amount of FDI, which is mainly composed of Greenfield investments. The technical progress function shifts up, with the exogenous rate of technological progress increasing from $\tilde{g}^{B}_{SGR}$ in the *SGR* to $\tilde{g}^{B}_{FGR}$ in the simulated *FGR*. At the same time, as a result of knowledge spillovers and the transfer of new technologies from abroad, the slope of the technical progress function becomes steeper, with the learning-by-doing parameter increasing from the assumed $\hat{\phi}_2 = 0$ in the *SGR* to $\hat{\phi}_1 = 0.54$ in the simulated *FGR*. At point B, output per capita growth exceeds capital per capita growth ($\tilde{g}^{y}_{FGR} >$ $\tilde{g}^{k}_{SGR}$), which implies a rise in the marginal product of capital and, by implication, an increase in the profit rate. The growth potential of the economy will be maximised if domestic firms reinvest their profits. Assuming a favourable domestic investment climate, firms will save and invest a larger fraction of their profit income and the economy will move along the technical progress

[23] Greenfield investments occur when multinational companies build new facilities in the recipient country from the ground up.

function from point B to point C. Note that a movement along the technical progress function requires a permanent increase in the total saving/investment *rate*, *s*.[24] This is consistent with the stylised facts of the South African economy in section 2. From the top panel in Figure 2 it can be seen that both the saving and investment rate exhibit large structural breaks across South Africa's *FGR* and *SGR*. In our simulated post-2012 period, a long-run growth acceleration would require an upward break in both the saving and investment rate[25].

Point C in Figure 4 gives the 'balanced' growth path in South Africa's simulated *FGR*:

$$\tilde{g}^{y}_{FGR} = \tilde{g}^{k}_{FGR} = \tilde{g}^{A}_{FGR} \tag{22}$$

The *actual* growth rate data during South Africa's *FGR* in Table 1 show that the average growth rates of output and capital per capita of 2.28% and 2.48% , respectively, closely match each other, which provides some evidence of an economy operating around its 'balanced' growth path.

The difference in the rate of technological progress in the *FGR* relative to the *SGR*, $\tilde{g}^{A}_{FGR} - \tilde{g}^{B}_{SGR}$, is composed of two growth-inducing sources, as shown in Figure 4: i) an exogenous TFP part equal to $\tilde{g}^{B}_{FGR} - \tilde{g}^{B}_{SGR}$, and ii) an endogenous capital accumulation component equal to $\tilde{g}^{A}_{FGR} - \tilde{g}^{B}_{FGR}$. We can roughly quantify the contribution of each growth source as follows. The long-run growth rate of the learning-by-doing model (equation 9) at point C in Figure 4 is given by equations (11) and (11′). By setting these equations equal to the actual per capita income growth rate of 2.28% in South Africa's *FGR*, we can calculate the percentage contributions of capital and

[24] To see this, rewrite equation (3) as a growth rate of capital equation: $[(K_{t+1}/K_t) - 1] = s(Y_t/K_t) - \delta$. Noting that the output-capital ratio (Y_t/K_t) remains constant across South Africa's *SGR* at point A and *FGR* at point C in Figure 4, the only way in which the economy can move along the technical progress function from B to C is through a permanent increase in the saving/investment rate, *s*.

[25] Note that, unlike Solow's (1956) canonical neoclassical growth model, the Kaldorian-type (1957, 1961) technical progress function analysis in Figure 4 explicitly includes the role of profits in the regime switch. The inclusion of profits in the modelling framework ensures that the saving/investment rate changes across regimes, which is consistent with the stylised facts of the South African economy. The Solow model, in contrast, assumes that the saving/investment rate is fixed, so that part of the growth effect of an exogenous shock to technological progress ('manna from heaven') is transmitted through a higher output-capital ratio.

TFP to long-run growth in the simulated *FGR*: 46% is attributed to TFP growth and 54% to capital per capita growth. If we further assume that the 0.30% per capita income growth rate in South Africa's *SGR* approximates zero, then the percentage contributions of TFP and capital to the growth *shift* across regimes remain the same at 46% and 54%, respectively[26]. From these calculations there appears to be a strong interdependent relationship between technological progress and capital accumulation across South Africa's growth regimes.

6.2 Policy Implications

Based on the foregoing analysis, in what way(s) can policymakers in South Africa initiate a long-run growth transition: should they prioritise measures that boost productivity growth, focus on policies that raise the domestic saving/investment rate, or a combination of both? From the interdependent relationship depicted in Figure 4, it would at first appear as if the answer is straightforward – faster productivity growth should be the main policy objective. The graphical analysis of South Africa's regime shift in Figure 4 represents the weaker version of the AK model, in which a rise in the saving/investment rate cannot initiate the growth transition – the bulk of the initial growth shift from A to B is productivity driven. On the surface, this would seem to support the influential TFP or 'technological progress' view of Easterly and Levine (2001), King and Levine (1994), and Helpman (2004).

A policy strategy that only emphasises productivity growth, however, may not be sufficient to initiate a *sustained* growth transition. Consider the movement along the technical progress function from B to C in Figure 4 when the rate of technological progress becomes

[26] These figures do not change much if we use the actual *SGR* growth rate of 0.30% and the learning-by-doing parameter of 0.14 in Table 6. Substituting the *SGR* values into equations (11) and (11′), we get: $\tilde{g}^{y}_{SGR} = \tilde{g}^{B}_{SGR} + \phi_2(\tilde{g}^{k}_{SGR}) = 0.30\% = 0.26\% + 0.04\%$. The corresponding values for the *FGR* are $\tilde{g}^{y}_{FGR} = \tilde{g}^{B}_{FGR} + \phi_1(\tilde{g}^{k}_{FGR}) = 2.28\% = 1.05\% + 1.23\%$. The percentage contribution of TFP growth to the regime shift, $\tilde{g}^{y}_{FGR} - \tilde{g}^{y}_{SGR}$, is 40% and that of capital per capita growth 60%.

endogenous to physical capital accumulation through a rise in the saving/investment rate, *s*. Now consider some of the determinants of South Africa's domestic saving/investment rate that have been identified in the literature: tax incentives, capital subsidies, infrastructure investment, the user cost of capital, market size effects, financial constraints, regulation of the labour market, macroeconomic stability, and political risk (see, for example, Aron and Meullbauer, 2000; Clarke, et al., 2008; Du Toit and Moolman, 2004; Fedderke and Bogetić, 2009, and Fedderke and Simkins, 2012). It is apparent that many of these determinants overlap with some of the main attractors of FDI, such as those highlighted in Fedderke and Romm (2006), Gwenhamo and Fedderke (2013), Kransdorff (2010), and Wentzel and Steyn (2014).

Thus, to initiate a long-run growth transition from an initial position at point A in Figure 4, policymakers will have to identify measures that simultaneously attract FDI and raise the domestic saving/investment rate. This would cause an upward shift and slope increase in the technical progress function, as well as a movement along the function towards point C. The key difference compared with the strong version of the AK model is that the sustainability of the growth transition will depend on the type of saving/investment policies being implemented. Within the theoretical framework of the strong version, any policy that raises *s* will generate a permanent growth transition. Under the weaker version, on the other hand, the ability of policymakers to initiate a long-run growth shift will crucially depend on the exact nature of the saving/investment policies. For example, a large scale government-led infrastructure programme, such as the recent one launched under the Accelerated and Shared Growth Initiative for South Africa (ASGI-SA) programme, may on its own not be enough to initiate a long-run growth transition, unless it is complemented with other investment incentives that relax some of the binding constraints on FDI[27]. The weaker version of the AK model, therefore, presents a middle way between the TFP or 'technological progress' view of Easterly and Levine (2001) and Helpman (2004), and the capital accumulation hypothesis of traditional development economists, such as Lewis (1954), Nurske (1953), Rostow (1960) and Murphy et al.'s (1989) formalisation of Rosenstein-Rodan's (1943) big push model.

7. CONCLUSIONS

In this paper we have developed two types of AK-style endogenous growth models to examine the role of physical capital accumulation in a 'typical' developing country with multiple growth regimes. The empirical application supports the relevance of the weaker version of the AK model across South Africa's 'faster-growing' regime (1952-1976) and 'slower-growing' regime (1977-2012). To improve the economy's post-2012 growth performance on a sustainable basis, the simulation exercise and policy implications outlined in sections 6.1-6.2 suggest that policymakers should introduce a *refined* set of measures that *simultaneously* attracts foreign direct investment (Greenfield investment) and raises the domestic saving/investment rate, s. This contrasts with the prediction of the strong version of the AK model, where long-run growth is invariant to the type of saving/investment policy being implemented – as long as the policy innovation raises s, an increase in long-run growth is guaranteed. The weaker version, on the other hand, depicts an interdependent or complementary relationship between technological progress and capital accumulation in the growth and development process. Thus, to re-ignite the complementary relationship in the South African economy, both technological progress and physical capital accumulation should feature prominently in the initial decision-making process of policymakers.

[27] For a critical evaluation of the ASGI-SA programme, see Frankel et al. (2008).

We have not gone into more detail on what the refined set of policy measures might look like to trigger the complementary relationship between technological progress and capital accumulation in the South African economy. This paper has been concerned with a broader, but nevertheless, important issue in the growth and development literature: that is, whether physical capital accumulation is the endogenous outcome of technological progress or vice versa. As it turns out, both sources of growth are essential to ignite a long-run growth transition in South Africa. In this context, an important area for future research is to identify the *binding* constraints (à la Rodrik, 2006) on Greenfield investment and the domestic saving/investment rate among all the potential candidates that have been identified in the literature survey of section 6.2.

Finally, the theoretical and empirical methodology advanced in this paper is not only confined to the South African economy, but has wider applicability to other developing countries with multiple regimes. One crucial lesson from the South African case study is that it would be highly misleading to draw policy inferences from the single-regime results when in reality the economy's growth experience is characterised by several regimes. Thus, for future research purposes, it would be interesting to test the relevance of the multiple-regime AK models in other developing countries that exhibit long-run growth shifts.

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APPENDIX A, Table A1 – VARIABLE DEFINITIONS AND DATA SOURCE

Variable	Description	Source
$\ln(y_{p/c})_t$	Natural logarithm of real GDP per capita at market prices (constant 2005 prices)	South African Reserve Bank
$\Delta\ln(y_{p/c})_t \equiv \tilde{g}_t^y$	Per capita income growth rate	$\Delta\ln(y_{p/c})_t = \ln(y_{p/c})_t - \ln(y_{p/c})_{t-1}$
$\ln(s)_t$	Natural logarithm of gross domestic saving as a share of nominal GDP at market prices	South African Reserve Bank
$\Delta\ln(s)_t$	Growth rate of domestic saving rate	$\Delta\ln(s)_t = \ln(s)_t - \ln(s)_{t-1}$
i_t	Total gross domestic investment as a share of nominal GDP at market prices	South African Reserve Bank

Note: The data cover the period 1949-2012. Due to lagged and differenced variables the effective sample period is 1952-2012.