

# **Infrastructural Investment in Long-run Economic Growth: South Africa 1875-2001**

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## **Abstract:**

Productive public expenditure in the area of infrastructure (such as roads, transportation and housing) can play an important role in promoting economic growth and encouraging private investment. Developments in endogenous growth theory introduce the possibility of a productive role for public expenditure. This paper seeks to explain the relationship between investment in economic infrastructure and long-run economic growth by examining the experience of South Africa in a time-series context. The main findings that emerge from our examination of economic growth and economic infrastructure in South Africa may be summarized as follows: investment in infrastructure does appear to lead economic growth in South Africa and does so both directly and indirectly (the latter by raising the marginal productivity of capital); there is weak evidence of feedback from output to infrastructure; while the finding of an infrastructure growth impact is robust.

**JEL:** H54, L91, L92, L93, L94, L96, L98, N47, N77, E62,

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## 1. INTRODUCTION

Standard economic theory often highlights the crowding-out effects of government expenditure. While relevant, this approach makes no differentiation between types of government expenditure. There is a growing literature that indicates that the relationship between public expenditure and growth is more complex, and that it is necessary to differentiate between the various components of government expenditure. Productive public expenditure in the areas of infrastructure (such as roads, transportation and housing) and human capital can play an important role in promoting economic growth and encouraging private investment. Developments in endogenous growth theory have explored the possibility of productive public expenditure with an associated possibility of increasing returns to scale (see for instance Barro, 1990, 1991). This paper seeks to explain the relationship between investment in economic infrastructure and long-run economic growth by examining the experience of South Africa in a time-series context.

The South African case is of interest both as an important emerging market and because of its particular history of state planning. The 'grand plan' of apartheid (1948-1994 and its antecedent) required substantial supremacy by the central agency of the state. The state fashioned almost every facet of South African life by managing a complex system of separate development whilst simultaneously promoting industrialization. Its plans were ambitious and controversial, its effects long-lasting.

The main findings that emerge from our examination of economic growth and economic infrastructure in South Africa may be summarized as follows.

- (i) Investment in infrastructure does appear to lead economic growth in South Africa.
- (ii) The impact of infrastructure on output is both direct and indirect, the latter occurring through its effects on raising the marginal productivity of capital.
- (iii) There is weak evidence of feedback from output to infrastructure, though this evidence is not robust.
- (iv) The finding of an infrastructure growth impact is robust both to the use of a parsimonious growth model, and to the use of a fuller specification incorporating institutional determinants of economic growth.

The paper begins by providing a generic explanation of the role of infrastructural investment in growth processes and a review of the existing evidence. This is followed by an examination of economic infrastructural investment in South Africa since 1875 and the presentation of our econometric results.

There is an additional issue of potential trade-offs that may exist between different types of government spending, specifically spending on social versus economic infrastructure. This is particularly relevant in a country which has systematically deprived the majority of its population of social and political rights and opportunities. The question arises whether a country such as South Africa can afford to build its economic infrastructure at the 'expense' of redressing inequities and investing in social infrastructure. For example, Terreblanche (2002) argues that although there has been a political transformation, the parallel socio-economic transformation has not yet happened and that in fact deep-seated inequalities may actually have been further perpetuated in post apartheid South Africa. However, this needs to be looked at in

the context of a sharp decline in South African economic growth from the 1970s onwards (see Jones, 2002), with the associated precipitous collapse in physical infrastructural investment. Given our findings of a strong impact of spending on economic infrastructure on growth, we are at least able to point to the importance of maintaining physical capital investments as a means of generating growth, with relatively short lag structures. Given the potentially extended time lags between social infrastructural expenditure (such as on schooling) and growth, there is at least the possibility that the growth pay-off to spending on economic infrastructure can serve as a source of increased financing of social infrastructure. These considerations serve to emphasize that the modeling challenges of isolating the impact of social infrastructure on productivity are substantially different from those for economic infrastructure – particularly given South Africa’s history of allowing differential access to social infrastructure for different parts of its population – and merit a separate paper. For all these reasons the focus of the present paper will be on economic infrastructure, rather than on social infrastructure.

## **2. THE ROLE OF INFRASTRUCTURE IN ECONOMIC GROWTH**

The relevant question to an examination of the impact of infrastructure on output growth concerns why infrastructural investment should be distinguished from generic investment in physical capital stock.

In section 2.1, we note a generic account of why infrastructural capital may merit distinction from physical capital stock. Section 2.2 explores the relevance of the theoretical model in the light of prior international empirical findings.

**(a) A generic explanation of the role of infrastructure in economic growth**

The core rationale for infrastructural investment that emerges from the theoretical literature is that it raises the marginal product of other capital used in production.<sup>4</sup>

Consider a framework in the spirit of Barro (1990). Posit an endogenous growth model in which government owns no capital and does not produce services, but purchases private-sector output in order to provide productive services which serve as inputs in private-sector production or as consumption services to households. The services are purchased under a balanced budget constraint, financed by a flat-rate income tax without cost recovery.

By way of condensed illustration, under closed-economy conditions, Cobb-Douglas technology and homogeneity of degree one, our labor-intensive production function might be:

$$y = Ag^\alpha k^{1-\alpha}, \quad 0 < \alpha < 1, \quad [1]$$

where  $y$  denotes output per worker,  $A > 0$  the level of technology,  $g$  productive government expenditure (or services) per worker with no congestion effects,<sup>5</sup> and  $k$  an inclusive measure of private capital per worker.<sup>6</sup> It follows that the marginal products of  $g$  and  $k$  are, respectively,  $\partial y/\partial g = A\alpha(k/g)^{1-\alpha} > 0$ , and  $\partial y/\partial k = A(1-\alpha)(g/k)^\alpha > 0$ . The positive effect of infrastructure on the marginal product of physical capital is clearly illustrated – analogous to the Arrow (1962) and Romer (1986) learning-by-doing growth models.

Suppose further that a representative, infinite-lived household seeks to maximize overall utility:

$$U = \int_0^{\infty} u(c)e^{-\rho t} dt \quad [2]$$

with:

$$u(c) = (c^{1-\sigma} - 1)/(1-\sigma) \quad [3]$$

where  $c$  is consumption per worker,  $-\sigma$  is the elasticity of marginal utility with respect to consumption ( $\sigma > 0$ ), and  $\rho > 0$  is the constant rate of time preference.

Since the balanced budget constraint imposes a tax rate of  $g/y$ , the steady state growth rate, denoted  $\gamma$ , can be shown to be:

$$\gamma = \frac{\dot{c}}{c} = \frac{\dot{y}}{y} = \frac{\dot{g}}{g} = \frac{\dot{k}}{k} = \frac{1}{\sigma} \cdot \left[ \left(1 - \frac{g}{y}\right) \cdot A \cdot \left(\frac{g}{k}\right)^{\alpha} \cdot (1 - \alpha) - \rho \right] \quad [4]$$

It follows that:

$$\frac{d\gamma}{d(g/y)} = \left(\frac{1}{\sigma}\right) \cdot A \cdot \left(\frac{g}{k}\right)^{\alpha} \cdot \left(\frac{\partial y}{\partial g} - 1\right) \quad [5]$$

Now consider a policy intervention under which  $d(g/y) > 0$  (given any level of  $k$ ). From [4] it follows that  $\gamma$  decreases due to the tax effect in  $g/y$ , and increases due to the increase in  $g/k$  that is the consequence of the positive effect on the marginal product of  $k$ . The net effect depends on which of the two impacts is dominant. Since  $g/k = (Ag/y)^{1/(1-\alpha)}$ , and hence  $d(g/k)/d(g/y) > 0$ , it follows from [5] that the net effect of  $d(g/y) > 0$  is conditional on the positive but decreasing

$\partial y/\partial g$ , with  $d\gamma/d(g/y) > 0$  for  $\partial y/\partial g > 1$ ,  $d\gamma/d(g/y) < 0$  for  $\partial y/\partial g < 1$ , and  $\gamma_{max}$  at  $\partial y/\partial g = 1$ . Thus the capital productivity effect dominates at low  $g/y$ , and the tax effect at high  $g/y$ .

A clear, theoretical link between output and government infrastructural investment follows. Infrastructural expenditure ( $g$ ) can prevent diminishing returns to scale in private-sector capital ( $k$ ), raise the marginal product of private-sector capital ( $\partial y/\partial k$ ), and raise the rate of growth of output ( $\gamma$ ).<sup>7</sup> An equally important message is that government intervention of this nature can raise economic growth only within limits. Once the marginal product of government productive expenditure falls below unity, further increases in  $g/y$  are harmful to economic growth, since the tax effect comes to dominate the capital productivity effect.<sup>8</sup>

Equally, the exposition identifies a possible source for a distinction between infrastructure and other physical capital – the indirect productivity effect of infrastructure on physical capital stock.

A further implication that follows from the model is that any  $d(g/y)$  will carry consequences not only for the growth rate of output directly, given  $d\gamma/d(g/y) \neq 0$ , but also for the level of investment in private-sector capital stock, since  $\partial y/\partial k = A(1-\alpha)(g/k)^\alpha > 0$  suggests  $\partial k/\partial g \neq 0$ . Under a model that introduces a rationale for distinguishing public from private capital, through productivity enhancement of private-sector capital, the expectation is not only of a direct growth rate impact of changes in public-service provision, but also of an indirect effect on output and growth through changes in the stock of private-sector capital.

The substantive implication of the theoretical model postulates the system of simultaneous equations given by:

$$y = y(k, g) \quad [6]$$

$$k = k(y, g) \quad [7]$$

such that infrastructure impacts on both final output directly as a factor of production, and also serves to have a secondary impact on other physical capital stock.<sup>9</sup> The feedback loop from output to capital is generic to theories of investment.<sup>10</sup>

The distinction between infrastructural and private capital presented here is the standard one which rests on the possibility of productivity spill-overs from public to private capital. The significance of this approach extends beyond theory to implications for the appropriate empirical estimation approach to be adopted. To capture both direct and indirect impacts of infrastructural investment, a systems approach to estimation looms.

### **(b) A brief review of existing evidence**

A range of studies has addressed the question of the empirical and economic significance of infrastructural investment. Some of these are outlined below.

The striking feature of the studies is the strength of association many report between infrastructure and output. For instance, an early contribution to the empirical debate is provided by Aschauer (1989a), who found an elasticity of output with respect to non-military public capital stock of 0.39 in the United States.<sup>11</sup> The implication is thus of a strong, positive relationship between infrastructure and output. “Core” infrastructure (transport, power and water) is found to be the main contributor, with hospitals, educational buildings and conservation and development structures contributing in smaller measure, or even negatively.

Similarly Munnell (1990a) estimates the public capital elasticity of output in the United States to be 0.34, an estimate she came to regard as too large to be credible (Munnell, 1992: 191). In a similar exercise for American states Munnell (1990b) finds an elasticity of 0.15, lower than the result at national level but still substantial.<sup>12</sup> Mitra et al. (2002) find further confirmation of a substantial public capital effect at the state level – this time for India. High elasticities were also reported by Easterly and Rebelo (1993), who investigated the impact of different types of public investment on economic growth using cross-sectional country data. They find that transport and communication have a strong impact on economic growth, particularly when estimated using instrumental variables.

One reason for high estimates of infrastructural coefficients in earlier studies is the use of OLS with nonstationary infrastructure and output time series. More recent econometric studies have used alternative estimation techniques, and modified the early empirical findings – see for instance Hulten and Schwab (1991), Holtz-Eakin (1994), and Garcia-Milà et al. (1996).

Using data from 48 American states, Holtz-Eakin (1994) demonstrates that a high elasticity of output with respect to public capital (0.203) can be estimated using OLS. Yet under state-specific effects, generalized least squares (with state-specific effects in the error term), instrumental variables, and instrumental variables with first differences, the elasticity is either significantly negative or not significantly different from zero. Similarly, Garcia-Milà et al. (1996) also investigate output and public capital at state level (48 American states), and while OLS with fixed state effects provides significant elasticities, first difference (of output and infrastructure) estimation with fixed state effects provides negative and insignificant elasticities.<sup>13</sup> Both studies conclude that previous findings of positive statistically significant elasticities are spurious.

Pereira (2000), noting the methodological criticism of OLS estimators in the context of non-cointegrated nonstationary variables producing spurious results with simultaneity bias, employs a multivariate time-series framework. The study is of the US relationship between economic growth and different types of public capital (roads, electricity, gas, transit systems, sewerage, water supply, educational and hospital buildings, other buildings, conservation structures, development structures, civilian equipment). A VAR approach is chosen in order to consider dynamic feedback effects which, Pereira argues, are likely to exist between public investment and the private sector. The finding is that in the long term aggregate public investment crowds in private investment (elasticity of 0.229) and private employment (elasticity of 0.007), and has a positive impact on private output (elasticity of 0.043). Thus while the final elasticity is lower than in many previous studies, it remains significant, and the indirect effects of infrastructural investment confirm that public capital may be a powerful means of promoting economic growth.

For South Africa three studies have examined the impact of infrastructure on output, though only one employs estimation techniques that pay some attention to the time series character of the data. The Development Bank of Southern Africa (DBSA) (1998) reports all three sets of econometric results for South African data, all of which employ Cobb-Douglas production function specifications. The DBSA's own study relates to the period 1967–1996, and controls for time and capacity utilization. The results indicate a strong, positive relationship between public-sector capital and output, although the OLS estimates are spurious (elasticity of approximately 0.3). Using Engle-Granger cointegration estimation, the DBSA study also finds strong crowding-in effects of infrastructure on private-sector non-residential investment.

A final class of studies has examined the potential microeconomic impact, postulated by the Barro (1990)-type models, of improving the productivity of private capital, or the cost structure of the private sector, rather than the final growth impact of infrastructure. Kessides (1993), Jimenez (1995), Munnell (1990a), Murphy et al. (1989) and Amsden (1989) all emphasize the importance of these factors. Lee, Anas and Oh (1999) provide empirical verification.

### **3. ECONOMIC GROWTH AND ECONOMIC INFRASTRUCTURE IN SOUTH AFRICA**

Apart from the national accounts data, the data set on which our analysis is based was compiled largely from the statistical publications of Statistics South Africa and its predecessors. Unfortunately the publication of most of the time series relating to infrastructure (e.g. rail, roads, ports, air travel, telephones) was discontinued by Statistics South Africa in the late 1980s and 1990s, and for the purposes of this study they had to be updated from individual organizations.<sup>14</sup>

The South African Reserve Bank (SARB) publishes the economic infrastructural component of South Africa's gross fixed capital formation and fixed capital stock of the public sector (both general government and public corporations). Figure 1 shows indices of both of these measured per capita, and both demonstrate a long-term deterioration: from the mid-1970s in the case of investment, and from the mid-1980s in the case of fixed capital stock. Investment per capita fell from R1 268 in 1976 to R356 in 2002 (1995 prices), a collapse of 72%. Investment fell from 8.1% of GDP to 2.4% of GDP, which lies below the international benchmark of approximately three to six per cent identified by Kessides (1993: ix). In 2002, 72% of public-sector infrastructural investment consisted of transport, communication, power and water. The recovery of infrastructural investment in the 1990s and the subsequent slump were mainly the

result of expansion programs by the telephone (Telkom) and electricity (Eskom) utilities to extend telephone lines and electricity to areas which were under-served, and the purchase of new aircraft by the national carrier (South African Airways) (SARB annual economic reports, 1996–2000).

Figure 1 about here.

The decline in infrastructural investment between the mid-1970s and 2002 was part of an overall decline in gross fixed capital formation (GFCF) over the same period. As a percentage of GDP, South Africa's gross savings also fell during the 1980s and 1990s.<sup>15</sup> Falling infrastructural investment may also have been a response to overcapacity in certain areas (Merrifield, 2000: 92).<sup>16</sup>

Perkins et al. (2005) provides a comprehensive description of particular economic infrastructural developments in South Africa since 1875. Figure 2, which shows the long-term development of selected infrastructural measures in the form of indices, provides a summary account, and suggests a series of sequential periods of infrastructural roll-out in South Africa. The first wave of infrastructural development was railways over the 1875–1930 period, after which there was little change in the route-kilometer railway line distance – though rolling stock continued to increase. See also Table 1. The second take-off in infrastructural investment was in inter-city roads, which reached a plateau around 1940, after which the focus was on the paving of national and provincial roads. In the 1920s and 1930s growth in road traffic far exceeded growth in rail transport, and with the paving of roads after 1940 road traffic continued to grow faster than rail for the rest of the century. See again the evidence of Table 1. While ports constitute South Africa's oldest form of infrastructure, substantial expansion in port capacity was constrained to

the 1970s through the construction of two new ports, doubling the volume of cargo handled. The final phase of infrastructural development was in telephones and electricity. While the average growth rate for fixed phone lines dropped in the 1960s, it rose again in response to the introduction of information and cell phone technology.

A number of implications follow from the descriptive evidence. Firstly, South Africa's stock of economic infrastructure has developed in stages. Figure 2 suggests that infrastructural development tends to take place in phases of development – with a series of sequential periods of infrastructural roll-out.

Figure 2 about here.

Table 1 about here.

Secondly, causality between infrastructural investment and economic growth appears to run in both directions. The long-run relationship between economic infrastructure and real GDP was tested employing the bounds analysis of Pesaran, Shin and Smith (2001),<sup>17</sup> which explores the direction of association between variables. Results are reported in Table 2. Specifically, we find a forcing relationship running from infrastructural fixed capital stock to GDP suggesting that infrastructure leads growth, though we also find evidence of potential simultaneity between infrastructure and output (GDP and locomotives; GDP and goods stock; goods vehicles and GDP; GDP and electricity), of output leading infrastructure (GDP and railway lines; GDP and coaching stock; GDP and rail passenger journeys; GDP and port cargo; GDP and SAA passengers; GDP and fixed phone lines), and of no association at all (GDP and rail carrying capacity; GDP and rail freight; GDP and international air passengers).

Economic growth thus appears to provide both the need for, and the resources to fund, various types of infrastructure. It is plausible that phases of infrastructural development took place both in response to changes in the structure of the economy, while also impacting on economic performance in their own right.<sup>18</sup>

Table 2 about here.

Finally, a conjecture that is suggested by the two substantive implications of the descriptive evidence is that the need for investment in economic infrastructure may never go away. Until such time as existing infrastructure becomes obsolete it needs to be maintained, and as certain infrastructural programs reach maturity new ones may need to be implemented in response to the economy's changing technological needs. From ports, to railways, to roads, to telecommunications, and beyond, infrastructure may remain a prevailing enabler of private capital stock productivity growth.

#### **4. ESTIMATION OF THE STRUCTURAL MODEL**

We wish to emphasize once again that the focus of the present analysis is on economic infrastructure, and not on social infrastructure. This is not to deny the importance of social infrastructure – but instead to assert that the methodological challenges in isolating its impact are somewhat distinct. This is apparent from the substantial international literature which examines the impact of health,<sup>19</sup> and of schooling, though results are often mixed.<sup>20</sup> In any South African applications the separate modeling challenges compound, since Apartheid

policies generated differential access not so much in physical infrastructure, but to social infrastructure.<sup>21</sup>

The descriptive evidence on infrastructural development in South Africa suggests one important extension to the structural theoretical framework that emerged from the discussion in section 2 of the paper. The evidence, which considered directions of association between variables, suggested that infrastructure and output might mutually determine one another. Thus the bounds tests reported suggest that public-sector infrastructure, railway goods stock, locomotives, unpaved and paved roads, goods and passenger vehicles, and electricity generation were found to be forcing variables of output – but equally output was found to force railway lines and rolling stock, rail passenger journeys, goods vehicles, port cargo, airway passengers, the number of telephone lines, and electricity generation. The core structural formulation of equations [6] and [7] thus requires modulation, and we postulate:

$$y = y(k, g) \quad [6']$$

$$k = k(y, g) \quad [7']$$

$$g_i = g(y, g_j) \quad i \neq j \quad [8]$$

where the notation follows the convention of the paper. The feedback loop from output to infrastructure captures the possibility that economic development may lead public investment in infrastructure, as discussed above (see Easterly and Rebelo, 1993).<sup>22</sup> We also explore the possibility of sequencing in the different types of infrastructure through the possibility of interaction between types of infrastructure,  $g_i$  and  $g_j$ . Equation [8] can in principle be thought of in vector terms, allowing for multiple interactions between different types of infrastructure.

In the process of identifying the models to be estimated below, we provide additional substantive detail on the empirical specifications of [6'] through [8] that we considered.

### (a) Estimation methodology

Estimation of the structural system is by standard time series techniques, with variables that are first-difference stationary. Johansen<sup>23</sup> techniques of estimation are now standard, so that discussion of estimation methodology here can be brief. We employ a vector error-correction mechanism (VECM) framework, for which, in the case of a set of  $k$  variables, we may have cointegrating relationships denoted  $r$ , such that  $0 \leq r \leq k - 1$ . This gives us a  $k$ -dimensional VAR:

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

where  $m$  denotes lag length,  $\mu$  a set of deterministic components and  $\delta$  a Gaussian error term.

Reparameterization provides the VECM specification:

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

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

$$H_1(r) : \Pi = \alpha\beta'$$

where  $\Pi$  is  $p \times p$ , and  $\alpha, \beta$  are  $p \times r$  matrices of full rank.  $H_1(r)$  is thus the hypothesis of reduced rank of  $\Pi$ . Where  $r > 1$ , issues of identification arise.<sup>24</sup> Estimation is by VECM cointegration.

### (b) The univariate time series characteristics of the data

Stationarity characteristics of our data are established by standard augmented Dickey-Fuller test statistics. Table 3 reports. All variables are examined in log transform. We find that all variables are first-difference stationary, except aggregate physical capital stock and aggregate public-sector infrastructural capital stock, which are integrated of order 2.<sup>25</sup>

Estimation proceeds under the relevant transformation in order to render the variables of the long-run equilibrium relationship first-difference stationary.

Table 3 about here.

### (c) Testing for simultaneity between output and infrastructure

We begin with a parsimonious specification of [6'] through [8], employing only a subset of the measures of infrastructure this study has accumulated. Justification of the parsimonious specification is threefold. Given the possibility of multiple relationships between different forms of infrastructure, a proliferation of cointegrating relationships in the presence of many infrastructural measures may render identification of the system difficult. Instead, we focus closely on the substantive question of possible simultaneity between output and infrastructure. Finally, in addition to the descriptive findings of Section 3 in which investment in roads in particular proved to force output, we are led by the prior literature that is concerned with the impact of both public-sector investment and electricity generation.<sup>26</sup>

We therefore begin with the just-identified system given by:

$$\begin{bmatrix} LNYPC \\ DLNKPC \\ DLNIFPC \end{bmatrix} = \begin{bmatrix} 1 & \beta_{12} & 0 & 0 & \beta_{15} \\ \beta_{21} & 1 & \beta_{23} & 0 & 0 \\ \beta_{31} & 0 & 1 & \beta_{34} & 0 \end{bmatrix} \begin{bmatrix} LNYPC \\ DLNKPC \\ DLNIFPC \\ LNTORD \\ LNELEC \end{bmatrix} \quad [9]$$

In Table 4 we report the maximal eigenvalue and trace statistics for the number of cointegrating vectors. While the maximal eigenvalue test statistic confirms the presence of two cointegrating

vectors, the trace statistic accepts the presence of three cointegrating vectors at the 10% level of significance. Given the better power characteristics of the trace statistic, we proceed with the estimation of the three-vector system provided by [9].<sup>27</sup>

Results of estimation under the identifying restrictions are reported in Table 5.

We find that output responds positively to investment in fixed capital stock, and to electricity generation.<sup>28</sup> Public-sector infrastructural investment does not enter into the determination of output directly, but does serve to raise investment in physical capital stock, while the feedback loop from output to investment finds support. Note that while aggregate public-sector infrastructural investment does not enter the output equation, infrastructure does impact on output through the measure of electricity generation – suggesting both a direct and indirect impact of infrastructure on long-run growth – electricity has a direct impact on output, aggregate infrastructure an indirect impact by stimulating capital investment. Finally, investment in public-sector infrastructure itself appears driven by output, and is a reflection of investment in infrastructure such as roads.

The statistical association between variables proves to be economically meaningful. The implied elasticity of output with respect to investment in physical capital stock ranges from -0.06 to 0.20 from the in-sample minimum to maximum range of physical capital investment values, assuming a 0.06 elasticity at the mean value of investment. The elasticity of output with respect to electricity generation is 0.20 – not dissimilar to the values for public infrastructural capital in the USA found by Munnell (1990a, 1990b).

Investment in physical capital stock proves sensitive to both output and infrastructural investment. The elasticity of total investment in physical capital stock with respect to investment in public-sector infrastructure is strong.<sup>29</sup> The implied elasticity at the mean values of physical capital and infrastructural investment is 1.37. With respect to output, the elasticity of investment in physical capital is 2.44 at the mean value of investment.

Finally in Table 5, public-sector infrastructural investment responds to both output and road infrastructure. The responses here are particularly strong. The elasticity of public-sector infrastructural investment with respect to per capita output is 3.93 at the mean level of public-sector infrastructural investment. While this seems too strong to be plausible at first sight, it would serve to explain the precipitous fall in the ratio of infrastructural investment to GDP from 8% to 2.5% over the 1976 – 2002 period, over which real per capita GDP declined by 4%. The elasticity of public-sector infrastructural investment with respect to a 1% increase in the stock of roads appears even more dramatic at 87.72. Again, this may seem implausible. But it should be borne in mind that this is an elasticity of the investment flow with respect to infrastructure stock. Given that a 1% increase in the stock of roads amounts to approximately 2 000km (computed as a 1% increase at the mean of the in-sample road stock), and assuming an average cost of 1 km of road of approximately R5.4 million in 1995 prices,<sup>30</sup> the implied investment cost of R10 753 million is approximately 52% of the implied R20 490 million cost that would be given by a 1% increase on the current stock of infrastructure. Since road infrastructure is serving as an indicator of all feasible forms of public infrastructure (such as railways, telecommunications), this may go some way toward explaining the large elasticity of the flow with respect to the stock. While the estimated elasticity may thus be justified, note that the sensitivity analysis below comes to considerably modify this finding.

We undertake two sets of robustness checks of our findings. Both relate particularly to the third of our hypothesized cointegrating relationships as specified by equation [8]. Since the introduction of equation [8] into the estimation is empirically rather than theoretically motivated, both on the basis of the South African bounds test and on the basis of prior international empirical findings, its justification is less robust than that for equations [6] and [7].

In the first set of robustness checks, we re-estimate the system given by [9], replacing LNTORD with a range of alternative infrastructural measures, covering ports, railways, roads and telecommunications. Results are reported in Table 6A for estimated parameter values, and in Table 6B for the implied elasticity values at relevant mean variable magnitudes.<sup>31</sup> With the sole exception of the systems incorporating LNRGDS and LNRCAP, both the first and second cointegrating vector parameter values prove generally robust to the use of alternative  $g_j$  measures, while the third cointegrating vector (determining the LNIFPC aggregate infrastructural measure) is not robust to the use of the alternative measures. In particular, in the first cointegrating vector, the implied elasticity of per capita output to investment in real physical capital is constrained to the 0.03 – 0.09 range, while the elasticity of output with respect to electricity generation rarely deviates strongly from 0.2. In the second cointegrating vector, the elasticity associated with what amounts to an accelerator term in output is generally distributed over the 2 to 4 range (with one outlier at 6.7), while the physical capital investment – infrastructural investment elasticity ranges up to 1.54.

Table 4 about here.

Table 5 about here.

Table 6A about here.

Table 6B about here.

The crucial indication of parameter instability emerges with respect to the third cointegrating vector. The elasticity of infrastructural investment with respect to output ranges over the 2.73 to 24.77 range (with the latter value difficult to credit), while with respect to the  $g_j$ -measure of infrastructure the elasticity reverses its strong positive sign, in favor of a negative elasticity that is difficult to justify on a priori theoretical grounds, but also proves strong.

Additional evidence of instability emerges with respect to the equation systems incorporating the LNRGDS and LNRCAP measures of infrastructure. Here both the elasticity of output with respect to electricity and of physical capital investment with respect to infrastructural investment reverse sign to become negative – reversals that are difficult to justify theoretically.

One response to these findings might be that not all infrastructural investment is equally important – that roads might occupy a particularly significant place in South African economic development. Certainly the bounds analysis of section 3 indicated the most consistent impact on GDP to emerge from the road infrastructural measures.

Notwithstanding this possibility, the fragility of the result is striking – even to alternative measures of the roads and related transport infrastructure. Given that the postulate of the feedback from output to infrastructural development was principally empirically motivated from the bounds analysis of section 3, and given the relatively weak evidence in favor of three cointegrating vectors in our data, we therefore estimate the more parsimonious system implied

by equations [6] and [7], which our theoretical overview suggested. The relative stability of the first two cointegrating vectors in [9] provides a starting point which allows for the impact of both aggregate infrastructural investment and of the electricity generation variable.

Identification is by means of:

$$\begin{bmatrix} LNYPC \\ DLNKPC \end{bmatrix} = \begin{bmatrix} 1 & \beta_{12} & 0 & \beta_{14} \\ \beta_{21} & 1 & \beta_{23} & 0 \end{bmatrix} \begin{bmatrix} LNYPC \\ DLNKPC \\ DLNIFPC \\ LNELEC \end{bmatrix} \quad [10]$$

Relevant tests for the reduced rank are reported in column (1) of Table 7, with the estimated  $\beta$ -coefficients reported in column (1) of Table 9. Estimation of the system as two rather than three equations maintains parameter stability (see the implied elasticities computed at relevant mean magnitudes of variables reported in column (1) of Table 8), and confirms both the direct (through LNELEC) and indirect (through the DLNIFPC impact on DLNKPC) impact of infrastructural investment on long-run economic growth.<sup>32</sup>

Table 7 about here.

Table 8 about here.

Of course, a trivial observation concerning the system given by [10] is that its representation of any growth process is parsimonious in the extreme. The obvious related concern is, therefore, the extent to which the findings presented thus far may be spurious, in the sense that they prove sensitive to the inclusion of additional regressors into the growth system. We therefore follow the lead of earlier findings on growth in South Africa, by including measures of property rights (LNPROP) and political stability (LNINST) into the estimation,<sup>33</sup> such that:

$$\begin{bmatrix} LNYPC \\ DLNKPC \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \\ \alpha_{31} & \alpha_{32} \\ \alpha_{41} & \alpha_{42} \\ \alpha_{51} & \alpha_{52} \\ \alpha_{61} & \alpha_{62} \end{bmatrix} \begin{bmatrix} 1 & \beta_{12} & \beta_{13} & \beta_{14} & \beta_{15} & \beta_{16} \\ \beta_{21} & 1 & \beta_{23} & \beta_{24} & \beta_{25} & \beta_{26} \end{bmatrix} \begin{bmatrix} LNYPC \\ DLNKPC \\ DLNIFPC \\ LNELEC \\ LNPROP \\ LNINST \end{bmatrix} \quad [11]$$

We estimate two alternative specifications. The first is under the exclusion of the property rights variable,  $\alpha_{51}=\alpha_{52}=0=\beta_{15}=\beta_{25}$ . Second, we estimate under the identification structure  $\beta_{15}=\beta_{16}=\beta_{24}=0$ , but also impose the weak exogeneity restrictions given by  $\alpha_{31}=\alpha_{32}=\alpha_{41}=\alpha_{51}=0$ .<sup>34</sup>

Estimation results are reported in columns (2) and (3) of Table 9, with the imputed elasticities at relevant mean values of variables in symmetrical columns of Table 8. The impact of the property rights variable on investment in physical capital stock is positive, while the instability variable reports a negative elasticity. The core finding to emerge from the estimations is that both the direct (LNELEC on LNYPC) and indirect (LNIFPC on DLNKPC) infrastructural investment impacts are maintained – though in the presence of the institutional variables the direct infrastructural elasticity is statistically significantly increased – from approximately 0.16 to either approximately 0.50 or 0.40 depending on the specification. By contrast the indirect infrastructural impact on physical capital investment, while remaining strong (with an elasticity above a unitary value), is of the same order of magnitude reported throughout this study (we here find a range up to 1.67). The other variable to show sensitivity to the inclusion of the institutional measures is the output accelerator term in the investment function – whose impact is markedly increased once property rights and instability have been controlled for.

Table 9 about here.

Both the property rights measure and the political instability measure prove to have the anticipated impact on investment in physical capital stock. The instability measure confirms the findings of prior studies – of a negative impact on physical capital stock investment.<sup>35</sup> While elasticity concepts related to the instability index are perhaps not particularly meaningful, the implied elasticity of 0.16, given the substantial variation in the South African measure of instability (with a strong peak in the 1980s, declining strongly during the 1990s), does point to the importance of changes in this measure of uncertainty to physical capital investment. In the case of the property rights measure, the direct elasticity of 1.68 on investment is even more dramatic. The institutional context of investment is thus important in the South African case.

Since the institutional context of investment has been more fully explored elsewhere, here the main inference we draw from the sensitivity analysis of results presented is that the finding that infrastructural investment has a significant impact on long-run output in South Africa appears to be robust to alternative parsimonious or more elaborate specification.<sup>36</sup> Indeed, the finding is that both the direct and indirect impacts of infrastructural investment on economic growth in South Africa prove to be both strong in economic terms and robust in statistical significance terms to the estimation of alternative specifications.<sup>37</sup> By contrast, the existence of a feedback from economic growth to infrastructural investment, while receiving some support, proves considerably less robust, though here too the implied economic impact is potentially large.

## 5. CONCLUSION

The relationship between economic growth and infrastructural investment has not been without controversy. Whilst a number of studies find high returns to infrastructural investment, concerns

have been raised about these results especially regarding the direction of association between infrastructure and output.

In this paper we have examined this relationship in a time series context for South Africa. While we find some statistical support for causality running in both directions, we conclude that this result is not robust to the use of alternative measures of infrastructure. One avenue for further research might be to investigate in greater detail the precise sequencing of development between different types of infrastructural investment.

A result of the paper that does prove robust is that infrastructure appears to have both a direct and an indirect impact on output. Electricity generation consistently is shown to impact positively and directly on output in South Africa – generally with an elasticity of approximately 0.10-0.20, but rising to 0.50 where we control for the impact of institutions. The impact of public-sector infrastructural investment on private-sector investment in physical capital proves particularly strong – with elasticities ranging up to 1.70.<sup>38</sup>

Further results confirm the positive impact of property rights on investment, and the negative effects of uncertainty that have been noted by other studies.

The empirical results are generally supportive of the South African fiscal authorities' renewed interest in public-sector investment since 2002. The Minister of Finance has repeatedly indicated that South Africa's level of investment should be raised from around 16% of GDP to 25% of GDP, and the public sector would have to play an important role in this regard (following an extended period of decline from the mid-1970s to 2001). Substantial efficiencies in tax revenue collections in recent years have facilitated, and continue to facilitate, a change in the

*composition* of government expenditure away from consumption towards investment without significantly compromising the *level* of consumption expenditure. South Africa's first decade of democracy was one of fiscal consolidation, including a much needed reduction in public-sector debt in relation to GDP. Subject to our observation in section 2.1 that there are limits to which increased public-sector infrastructural investment can raise economic growth, and noting that our empirical results on the infrastructural measures of the study report elasticities both above and below unity, we see an important role for infrastructural upgrading and expansion during South Africa's second decade of democracy. One of the challenges faced by the South African government in developing the country's infrastructure is the effective spending of budgeted funds. In many cases the skills and experience available at the national level are not available at municipal or other levels of government. Managing potential capacity constraints of this nature should be a priority. A more detailed projection of the country's investment needs is provided in Bogetić and Fedderke (2005)<sup>39</sup> and the National Integrated Resource Plan (2004).

In South Africa, annual economic growth has struggled to break the 3% growth ceiling since the mid-1970s. Given our econometric findings and the coinciding slowdown in growth and dramatic decline in the country's investment rate, particularly in the public sector, public investment may have an important role to play in pushing the country onto a higher long-run growth trajectory.

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Table 1 – Average annual growth rates for infrastructural goods and services

		1875-1899	1900-1919	1920-1939	1940-1959	1960-1979	1980-2001
<b>RAIL</b>	<b>Railway lines</b>	17.0	6.2	1.0	-0.3	0.6	0.1
	<b>Locomotives</b>		0.3 <sup>(a)</sup>	2.1	1.4	2.1	-1.7
	<b>Coaching stock</b>		2.4 <sup>(a)</sup>	2.7	1.4	2.9	-2.1
	<b>Goods stock</b>		1.7 <sup>(a)</sup>	3.0	3.6	3.1	-2.0
	<b>Goods stock carrying capacity</b>		3.8 <sup>(b)</sup>	4.0	4.8	3.9	-0.2
	<b>Passenger journeys</b>		3.8 <sup>(a)</sup>	4.0	4.5	4.2	-1.0
	<b>Revenue-earning freight</b>		5.4 <sup>(a)</sup>	3.8	4.2	4.8	0.8
	<b>ROADS (national &amp; provincial)</b>	<b>Total (nat. &amp; pr.)</b>			2.0	1.3 <sup>(c)</sup>	0.1
	<b>Paved (nat. &amp; pr.)</b>				15.0	5.3	1.6
	<b>Passenger vehicles</b>			12.1 <sup>(e)</sup>	5.0	5.2	2.6
	<b>Goods vehicles</b>			23.5 <sup>(e)</sup>	7.2	7.5	2.8
<b>AIR TRAVEL</b>	<b>SAA passengers</b>				9.1 <sup>(f)</sup>	12.9	2.3
	<b>Passengers on international flights at SA airports</b>					13.0 <sup>(g)</sup>	5.8
<b>ELEC-TRICITY</b>	<b>Electricity generated</b>			8.8	6.0	7.5	3.9
<b>TELE-PHONES</b>	<b>Fixed lines</b>			7.8	7.9	4.2	5.9
	<b>Mobile lines</b>						120 <sup>(h)</sup>
	<b>Total lines (fixed plus mobile)</b>			7.8	7.9	4.2	10.8

Sources: raw data from Statistics South Africa and the relevant individual organizations; calculations are those of the authors.

<sup>(a)</sup> 1905–1919      <sup>(b)</sup> 1910–1919      <sup>(c)</sup> 0.5 if the 1957 inclusion of previously unclassified roads is disregarded

<sup>(d)</sup> 1980–1993      <sup>(e)</sup> 1921–1939      <sup>(f)</sup> 1950–1959      <sup>(g)</sup> 1963–1979      <sup>(h)</sup> 1993–2001

Table 2 – PSS F-tests for the relationship between real GDP and infrastructural investment

Type of infrastructure or infrastructural “service”	Relationship between GDP and infrastructural variables, both based on <i>actual</i> values unless otherwise indicated	
	GDP on LHS; * indicates GDP affected by particular infrastructural variable	Infrastructure variable on LHS; * indicates infrastructural variable affected by GDP
<b>Infrastructural investment</b>	0.93	1.76
<b>Infrastructural fixed capital stock</b>	1.83	1.67
<b>Infrastructural investment (with per capita GDP)</b>	4.71	4.66
<b>Infrastructural fixed capital stock (with per capita GDP)</b>	7.31*	3.31
<b>Infrastructural investment (both in per capita)</b>	6.39 *	0.88
<b>Infrastructural fixed capital stock (both in per capita)</b>	7.69 *	2.78
<b>Railway lines</b>	0.52	5.79 *
<b>Locomotives</b>	8.96 *	12.00 *
<b>Coaching stock</b>	4.49	9.98 *
<b>Goods stock</b>	6.61 *	6.17 *
<b>Carrying capacity</b>	5.72	4.35
<b>Passenger journeys</b>	2.60	8.33 *
<b>Freight</b>	5.30	2.40
<b>Unpaved and paved roads</b>	6.38 *	3.78
<b>Paved roads</b>	5.90 *	1.39
<b>Passenger vehicles</b>	11.05 *	5.72
<b>Goods vehicles</b>	8.96 *	7.23 *
<b>Ports (cargo)</b>	3.87	19.73 *
<b>SAA passengers</b>	4.71	6.41 *
<b>International air passengers</b>	4.00	0.75
<b>Fixed phone lines</b>	3.06	15.72 *
<b>Electricity generated</b>	11.87 *	14.33 *

\* denotes significance at the 5% level

Source: results are those generated by the authors.

**Table 3 – Augmented Dickey-Fuller Test Statistics**

Variable	~I(0)	~I(1)	~I(2)
lnYPC	-1.8207 (-2.8947)	-8.3554* (-2.8951)	
lnKPC	-1.9014 (-2.9179)	-7.5324 (-2.9190)	-5.8531* (-2.9202)
lnIFPC	-2.4769 (-2.9422)	-9.8807 (-2.9446)	-5.1622* (-2.9472)
lnRLIN	-2.7770 (-2.8851)	-3.4686* (-2.8853)	
lnRLOC	-2.3095 (-2.8915)	-6.8455* (-2.8918)	
lnRCOA	-2.1496 (-2.8915)	-3.0701* (-2.8918)	
lnRGDS	-2.1785 (-2.8915)	-3.3060* (-2.8918)	
lnRCAP	-2.2735 (-2.8939)	-5.2674* (-2.8943)	
lnRPAS	-2.6669 (-2.8851)	-5.1256* (-2.8853)	
lnRFRT	-2.5559 (-2.8851)	-5.0376* (-2.8853)	
lnTORD	-2.8529 (-2.9017)	-3.1499* (-2.9023)	
lnPARD	-2.7900 (-2.9109)	-3.9877* (-2.9118)	
lnPASV	-1.9540 (-2.8986)	-4.2086* (-2.8991)	
lnGDSV	-2.7897 (-2.8986)	-4.2086* (-2.8991)	
lnELEC	-2.2678 (-2.8972)	-5.6072* (-2.8976)	
lnPORT	.10455 (-2.8947)	-8.1051* (-2.8951)	
lnFTEL	-2.1983 (-2.8947)	-3.4864* (-2.8951)	
lnSAAP	-2.5265 (-2.9202)	-3.5108* (-2.9215)	
lnIAPA	-1.0523 (-2.9446)	-3.7264* (-2.9472)	
lnPROP	0.27274 (-2.9339)	-7.1357* (-2.9358)	
lnINST	-2.8944 (-2.9147)	-4.8333* (-2.9157)	

\* denotes rejection of the null of non-stationarity at the 5% level of significance; figures in round parentheses report 5% critical values.

Source: results are those generated by the authors.

**Table 4 – Maximal Eigenvalue and Trace Statistics under VAR=3**

Null	Alternative	Maximal Eigenvalue	Trace
r = 0	r = 1	55.9947* (33.6400)	122.6187* (70.4900)
r ≤ 1	r = 2	36.2595* (27.4200)	66.6240* (48.8800)
r ≤ 2	r = 3	17.1755 (21.1200)	30.3645** (31.5400)
r ≤ 3	r = 4	9.4431 (14.8800)	13.1890 (17.8600)
r ≤ 4	r = 5	3.7458 (8.0700)	3.7458 (8.0700)
* denotes rejection of the null at the 5% level of significance; ** denotes rejection of the null at the 10% level of significance; figures in round parentheses report 5% critical values.			

Source: results are those generated by the authors.

**Table 5 – Just Identified Structural Cointegrating Vectors under VAR=3;**

**Setting  $g_j = \text{LNTORD}$**

VAR=3 Variable	Cointegrating Vector 1	Cointegrating Vector 2	Cointegrating Vector 3
LNYPC	1.0000	-0.085018 (0.010030)	-0.13665 (0.021560)
DLNKPC	-3.1937 (0.33370)	1.0000	0.00
DLNIFPC	0.00	-0.73793 (0.026479)	1.0000
LNTORD	0.00	0.00	-3.0502 (0.17709)
LNELEC	-0.20183 (0.024139)	0.00	0.00
ECM-CV1(-1)	-0.27808* (0.11860)	-0.012621 (0.027035)	-0.096948 (0.18582)
ECM-CV2(-1)	-1.5968* (0.65703)	-0.28599** (0.14352)	0.91016 (0.55910)
ECM-CV3(-1)	0.27260 (0.21320)	-0.0041084 (0.055353)	-0.58520* (0.22004)
Figures in round parentheses report standard errors; ECM denotes the error correction term; CVi denotes cointegrating vector i			

Source: results are those generated by the authors.

**Table 6A – Just Identified Structural Cointegrating Vectors under VAR=3;  
Sensitivity of Results to Measures of  $g_j$**

<b>g<sub>j</sub>:</b>	LNTORD	LNRLIN	LNRCOA	LNRPAS	LNRFRFRT	LNPARD	LNPASV	LNGDSV	LNPORT	LNFTTEL	LNRGDS	LNRCAP
<b>CV1</b>												
DLNKPC	3.1937	2.6966	1.6141	2.7294	2.6278	2.5977	3.3233	4.5256	1.9743	2.9624	7.8011	3.2587
LNELEC	0.20183	0.20774	0.18857	0.18607	0.069862	0.088628	0.24139	0.089015	0.20185	0.10665	-0.36651	-0.02426
<b>CV2</b>												
LNYPC	0.085018	0.077114	0.13098	0.11822	0.23291	0.19424	0.070417	0.14544	0.10043	0.16132	0.38384	0.3894
DLNIFPC	0.73793	0.80148	0.8312	0.73532	0.41109	0.53942	0.75128	0.36598	0.79419	0.52156	-0.98226	-0.30006
<b>CV3</b>												
LNYPC	0.13665	0.095017	0.19191	0.86125	0.34142	0.54592	0.32091	0.2726	0.14512	0.18936	0.34753	0.32974
LNG-j	3.0502	-0.65561	-0.15795	-0.69087	-0.071711	-0.12467	-0.14401	-0.049454	-0.044405	-0.061007	-0.10571	-0.072877

Source: results are those generated by the authors.

**Table 6B – Just Identified Structural Cointegrating Vectors under VAR=3;  
Sensitivity of Results to Measures of  $g_j$ : Imputed Elasticities at Relevant Mean Variable Values**

	LNTORD	LNRLIN	LNRCOA	LNRPAS	LNRFRFRT	LNPARD	LNPASV	LNGDSV	LNPORT	LNFTTEL	LNRGDS	LNRCAP
<b>CV1</b>												
DLNKPC	0.06	0.05	0.03	0.05	0.05	0.05	0.06	0.09	0.04	0.06	0.15	0.06
LNELEC	0.20	0.21	0.19	0.19	0.07	0.09	0.24	0.09	0.20	0.11	-0.37	-0.02
<b>CV2</b>												
LNYPC	2.44	2.22	3.77	3.40	6.70	5.59	2.03	4.18	2.89	4.64	11.04	11.20
DLNIFPC	1.37	1.48	1.54	1.36	0.76	1.00	1.39	0.68	1.47	0.96	-1.82	-0.56
<b>CV3</b>												
LNYPC	3.93	2.73	5.52	24.77	9.82	15.70	9.23	7.84	4.17	5.45	9.99	9.48
LNG-j	87.72	-18.85	-4.54	-19.87	-2.06	-3.59	-4.14	-1.42	-1.28	-1.75	-3.04	-2.10

Source: results are those generated by the authors.

**Table 7 – Maximal Eigenvalue and Trace Statistics under VAR=3**

		(1)		(2)		(3)	
Null	Alternative	Maximal Eigenvalue	Trace	Maximal Eigenvalue	Trace	Maximal Eigenvalue	Trace
r = 0	r = 1	32.21* (27.42)	66.62* (48.88)	47.7426* (37.86)	113.1119* (87.17)	37.8154 (37.85)	104.43* (81.20)
r ≤ 1	r = 2	17.00 (21.12)	34.41* (31.54)	26.35 (31.79)	65.3693* (63.00)	26.7982 (31.68)	66.61* (56.43)
r ≤ 2	r = 3	10.34 (14.88)	17.41 (17.86)	18.6761 (25.42)	39.0179 (42.34)	22.6780 (24.88)	39.82* (35.37)
r ≤ 3	r = 4	7.06 (8.07)	7.06 (8.07)	13.84 (19.22)	20.34 (25.77)	17.1387 (18.08)	17.14 (18.08)
r ≤ 4	r = 5			6.4966 (12.39)	6.4966 (12.3900)		
* denotes rejection of the null at the 5% level of significance; ** denotes rejection of the null at the 10% level of significance; figures in round parentheses report 5% critical values.							

Source: results are those generated by the authors.

**Table 8 – Imputed Elasticities at Relevant Mean Variable Values**

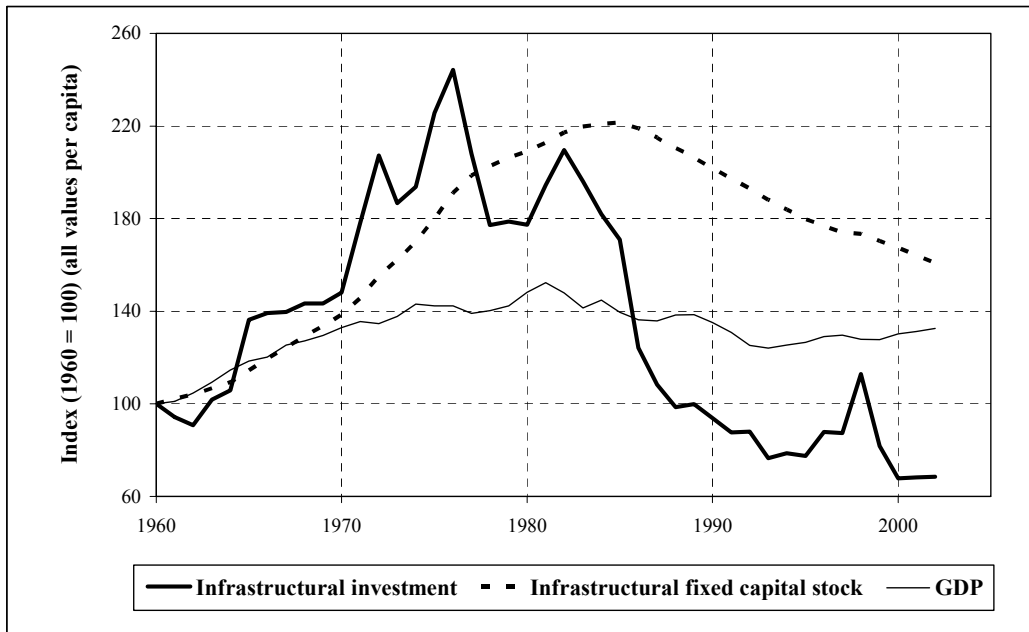
	(1)	(2)	(3)
		<b>CV1:</b>	
DLNKPC	0.05	0.03	0.04
LNELEC	0.16	0.52	0.39
		<b>CV2:</b>	
LNYPC	4.20	2.90	6.25
DLNIFPC	1.38	0.98	1.34
LNPROP	-	-	1.68
LNINSTAB	-	-0.17	-0.16

Source: results are those generated by the authors.

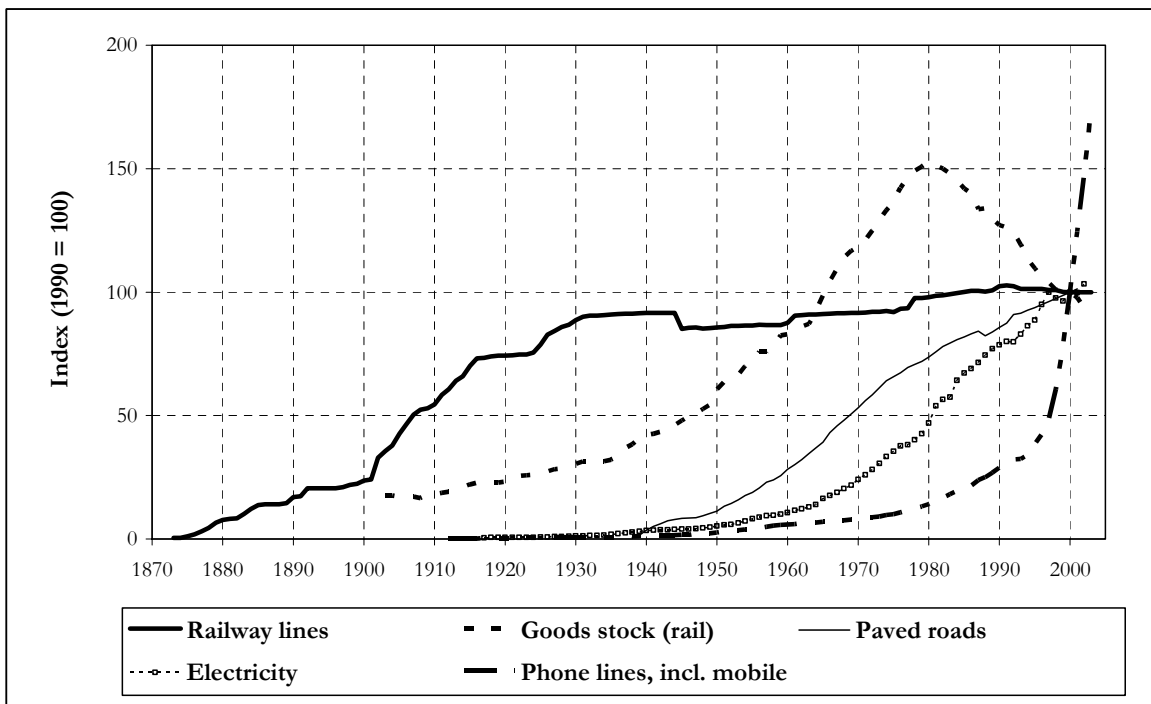
**Table 9 – Structural Cointegrating Vectors**

Variable	(1) VAR=3		(2) VAR=2		(3) VAR=1	
	Cointegrating Vector 1	Cointegrating Vector 2	Cointegrating Vector 1	Cointegrating Vector 2	Cointegrating Vector 1	Cointegrating Vector 2
LNYPC	1.000	-0.078 (0.017)	1.000	-0.054 (0.012)	1.000	-0.117 (0.020)
DLNKPC	-2.909 (0.526)	1.000	-1.482 (0.716)	1.000	-1.877 (0.52032)	1.000
DLNIFPC	0.00	-0.744 (0.048)	0.00	-0.530 (0.071)	0.00	-0.724 (0.099)
LNELEC	-0.159 (0.022)	0.00	-0.51703 (0.138)	0.00	-0.38792 (0.071770)	0.00
LNPROP	-	-	-	-	0.00	-0.031 (0.011)
LNINSTAB	-	-	0.00	0.0031 (5.617E-4)	0.00	0.003 (0.0006)
TREND	-	-	0.025 (0.007)	0.5514E-3 (0.2349E-3)	0.018871 (0.0049965)	0.0011106 (0.00040121)
ECM-CV1(-1)	-0.33* (0.09)	0.488* (0.209)	-0.500* (0.127)	-0.053* (0.012)	-0.173* (0.060)	-0.071 (0.051)
ECM-CV1(-2)		-0.501* (0.211)				
ECM-CV1(-3)		0.036 (0.043)				
ECM-CV2(-1)	-1.004 (0.75)	1.433* (0.641)	0.590 (0.545)	-1.731* (0.327)	0.561 (0.452)	-0.906* (0.301)
ECM-CV2(-2)		-1.426* (0.666)				
ECM-CV2(-3)		-0.165 (0.163)				
Figures in round parentheses report standard errors; ECM denotes the error correction term; CV <sub>i</sub> denotes cointegrating vector <i>i</i>						

Source: results are those generated by the authors.



**Figure 1 – Real GDP and public-sector economic infrastructural investment (gross) and fixed capital stock**



**Figure 2 – Phases of infrastructural development in South Africa**

### APPENDIX 1: Testing for the Direction of Association Between Variables

In order to explore the directions of association between the variables included in this study, we employ the test statistic proposed by Pesaran, Shin and Smith (1996, 2001) (hereafter PSS) F-statistics.<sup>40</sup> Suppose that the question is whether there exists a long-run relationship between the set of variables  $y_t, x_{1,t}, \dots, x_{n,t}$ . Univariate time series characteristics of the data are not known for certain. The PSS approach to testing for the presence of a long-run relationship proceeds by estimating the error correction specification given by:

$$\Delta y_t = \alpha_0 + \sum_{i=1}^p \beta_i \Delta y_{t-i} + \sum_{j=1}^n \sum_{i=1}^p \gamma_{j,i} \Delta x_{j,t-i} + \left( \delta_1 y_{t-1} + \sum_{k=2}^{n+1} \delta_k x_{k,t-1} \right) + \varepsilon_t$$

The order of augmentation,  $p$ , is determined by the need to render the error term white noise, and is chosen from the set of all feasible lag structure combinations by means of an information criterion.<sup>41</sup> The test proceeds by computing the standard F-statistic for the joint significance of  $\delta_1 = \delta_2 = \dots = \delta_{n+1} = 0$ . While the distribution of the test statistic is non-standard, and influenced by whether the  $x_{i,t}$  are  $I(0)$  or  $I(1)$ , the critical values are tabulated by Pesaran, Shin and Smith (1996, 2001), with  $x_{i,t} \sim I(0) \forall i$  providing a lower bound value, and  $x_{i,t} \sim I(1) \forall i$  providing an upper bound value to the test statistic. The test statistic is computed with each of the  $y_t, x_{1,t}, \dots, x_{n,t}$  as the dependent variable. Where the estimated test statistic exceeds the upper bound value, we reject  $\delta_1 = \delta_2 = \dots = \delta_{n+1} = 0$ , and infer the presence of a long-run equilibrium relationship. Where the estimated test statistic lies below the lower bound value, we accept  $\delta_1 = \delta_2 = \dots = \delta_{n+1} = 0$ , and infer the absence of a long-run equilibrium relationship. The test is indeterminate either where the computed test statistic lies between the upper and lower bound values (in which case it is not clear whether a long-run relationship between the variables is present), or where more than one

variable is confirmed as the outcome variable of a long-run equilibrium relationship (in which case the long-run relationships between the variables would not be unique).<sup>42</sup>

In the current application, where there is an intercept but no trend, and the relationship being tested for is between GDP and individual measures of infrastructure, the lower bound critical value of the test statistic is 4.934 and the upper bound critical value of the test statistic is 5.764, at the five per cent level of significance.

## APPENDIX 2: Glossary of Variable Names

<b>POPU</b>	Population
<b>RGDP</b>	Real GDP, R million, 1995 prices
<b>IINV</b>	Infrastructural investment (gross fixed capital formation), public sector, R million, 1995 prices
<b>IFCS</b>	Infrastructural fixed capital stock, public sector, R million, 1995 prices
<b>RLIN</b>	Railway lines, km
<b>RLOC</b>	Rail locomotives, number
<b>RCOA</b>	Rail coaching stock, number
<b>RGDS</b>	Rail goods stock, number
<b>RCAP</b>	Rail carrying capacity, tonnes
<b>RPAS</b>	Rail passenger journeys, number
<b>RFRT</b>	Rail freight, tonnes
<b>TORD</b>	Total roads (paved and unpaved, national and provincial), km
<b>PARD</b>	Paved roads (national and provincial), km
<b>PASV</b>	Passenger vehicles, number
<b>GDSV</b>	Goods vehicles, number
<b>PORT</b>	Ports: cargo handled, harbor tons
<b>SAAP</b>	South African Airways passengers, number
<b>IAPA</b>	International air passengers, number
<b>FTEL</b>	Fixed telephone lines, number
<b>MTEL</b>	Mobile telephone lines, number
<b>ELEC</b>	Electricity generated, gigawatt hours
<b>LNYPE</b>	Log of income per capita
<b>DLNKPC</b>	First difference log of <i>total</i> fixed capital stock per capita
<b>DLNIFPC</b>	First difference log of <i>public</i> -sector infrastructural fixed capital stock per capita

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<sup>2</sup> School of Economic and Business Sciences, University of the Witwatersrand.

<sup>3</sup> Graduate School of Business Administration, University of the Witwatersrand.

<sup>4</sup> Hence the frequent characterization of infrastructure as an economy's 'foundation'. See for instance Jimenez (1995: 2774).

<sup>5</sup> A legitimate question is why infrastructural goods and services provision should be public. As explanations for public-sector predominance, Aschauer (1989a: 180) cites practical difficulties with market exclusion with associated private sector under-provision, and the existence of economies of scale combined with the need to prevent monopoly pricing. Murphy et al. (1989:1024) argue that infrastructure projects may require investment outlays which are too large for private entrepreneurs or the capital markets to risk – particularly since payoffs to infrastructural investment are frequently both highly uncertain and realized only in the long term. Hence government has a coordinating and crowd-in role to play. See also Hirschman (1958:83–97). Under a Barro-type model (1990) such as that introduced here, infrastructure raises the marginal product of private-sector capital so that the private sector ceases to invest in infrastructure before the social marginal rate of return is exhausted. In the final instance, while Pollit (2002:67) notes a rising trend of privatization of infrastructure, empirically the public sector remains important. The World Bank (1994: 24) notes that private-sector participation in infrastructure was important in many countries between 1800 and 1950, but by the early 1980s the public sector was clearly dominant in electricity, telecommunications, transport by air and rail, road construction, water and sewerage. Since the relative merits of public versus private provision of infrastructure are not the focus of the present paper, we let the matter rest here.

<sup>6</sup> Incorporating, say, physical, financial and human capital.

<sup>7</sup> The generic explanation provided here leaves a number of crucial questions unanswered. Since the discussion is in terms of generic "infrastructure," this leaves moot the question of what type of infrastructure might be needed. Is it railways, roads, telecommunications or other infrastructure? Is there a sequence of these infrastructures that become relevant at different stages of development? For instance, the World Bank (1994: 4) illustrates typical differences between low-, middle- and high-income countries in the composition of their sanitation, water, irrigation, railway, telecommunication, road and power infrastructure. Sanitation, water and irrigation fall from a share of 47% of the total of these facilities in low-income countries to 26% in middle-income countries and 10% in high-income countries. Railways fall from 14% to 12% and seven per cent. Telecommunication rises from two per cent to six per cent and eight per cent, roads rise from 15% (low- and middle-income countries) to 24%, and power rises from

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23% to 40% and 52%. In individual countries such changes over time possibly reflect the transformation of their production structure (e.g. away from agriculture and mining to manufacturing and services), but they also suggest the possibility that sequences or phases of infrastructural investment are an important aspect of economic development.

<sup>8</sup> Note that the diminishing marginal product of infrastructure implies the existence of a plateau effect – with infrastructural capital reaching a maximum or socially optimal “plateau” level once the tax effect dominates the capital productivity effect. The effect is observable in South African infrastructural development – see Perkins et al. (2005).

<sup>9</sup> Kessides (1993), Jimenez (1995), Munnell (1990a), Murphy et al. (1989) and Amsden (1989) all emphasize the importance of these factors. Lee, Anas and Oh (1999) provide some empirical verification.

<sup>10</sup> See for instance the discussion in Fedderke (2001, 2004).

<sup>11</sup> Gramlich (1994) characterizes the economic research into infrastructural investment and economic growth in the late 1980s and early 1990s as a ‘speculative bubble’, precipitated by the possibility that a long-term slowdown in both infrastructure and productivity growth in the United States, starting in the early 1970s, were related. Gramlich questions the credibility of Aschauer’s results, particularly in terms of the large magnitude of the implied marginal products.

<sup>12</sup> Munnell (1990b) also finds that while public capital acts a substitute for private capital and so *discourages* private capital (crowding-out effect), it raises the rate of return on private capital and so *encourages* private capital (crowding-in effect); the crowding-in effect appears to dominate.

<sup>13</sup> Garcia-Milà et al. (1996) reject measurement error and endogeneity of private-sector capital and labor as explanations for the insignificant elasticities, but do not consider the loss of long-run information which may result from using first differences instead of levels.

<sup>14</sup> A printout of the data and their sources is available on request. Data is presented descriptively in Perkins et al. (2005).

<sup>15</sup> After 1980 government consumption expenditure increased at the expense of government investment (Merrifield, 2000: 98). Before 1980 both types of spending rose at a similar pace, but thereafter there was a sharp shift in policy, possibly reflecting the government’s desperate attempts to prop up a political system that was economically unsustainable. Growing consumption expenditure was made possible not only through investment cutbacks but by a growing fiscal deficit as well. As a proportion of GDP, the national budget deficit rose from an average of 2.9% in 1980–1986 to an average of 4.9% in 1987–1994 (fiscal years to March). In the post-apartheid period, both

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consumption and investment were constrained by the government's commitment to reducing the deficit as a proportion of GDP. It averaged 4.5% in 1995–1998 and 1.8% in 1999–2003. An analysis of government consumption expenditure and economic growth in South Africa is provided by Mariotti (2002).

<sup>16</sup> This is consistent with the World Bank's (1994: 23) view that infrastructure investment is generally 'lumpy,' with associated costly periods of over- or under-capacity.

<sup>17</sup> A fuller description of the methodology is provided in Appendix 1.

<sup>18</sup> A potential problem in understanding the relationship between infrastructural investment and economic growth is that infrastructural investment, in the heyday of Keynesian-style interventionist policies, may have been directed towards shortening the downward phases of business cycles and ensuring that recoveries, in their early stages, remained intact. This would serve to render the estimated infrastructural impact potentially spurious, with the real growth impact associated with fiscal demand-side fine tuning and management. Given the lengthy planning and lumpiness that typically characterize infrastructural investment, the characteristics of our data which show little evidence of cyclicalities, and the use of an estimator which is designed to capture long-run associations, we believe the chances of this to be remote. This is further supported by the fact that Mariotti (2002), in examining the effects of fiscal demand-management on long-run growth in South Africa, finds no positive growth impact for such intervention.

<sup>19</sup> For example, Bloom, Canning and Sevilla (2004) using a standard production function find that good health has a positive, sizeable and statistically significant impact on aggregate output through a positive labor productivity effect.

<sup>20</sup> For instance, Newman et al. (2002) argue that education projects in Bolivia may have improved school infrastructure but had little impact on education outcomes, whilst interventions in health clinics were associated with substantial declines in under-age-five mortality. Pradhan and Rawlings (2002) finds a similar mixed effect for a Nicaraguan social fund with investments in water systems being poverty-neutral, whilst education investments have a positive impact on schooling outcomes; the results of health investments are less clear.

<sup>21</sup> Fedderke et al. (2000, 2003) provide detailed evidence on the dramatic differences in access to schooling and tertiary education in South Africa across races, on data covering the 1917-1993 period. It is therefore not surprising that Fedderke and Luiz (2002) identify quite different educational production functions across racial groups in South Africa. A further complexity is that as shown by Fedderke (2005), it is the quality (as measured by maths and science performance) of human capital rather than its absolute quantity which is important for productivity growth in South Africa. As emphasized by Hall and Jones (1999), the quality of social infrastructure is crucial in explaining

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long-term productivity differences between countries. Fedderke (2005) and Fedderke and Luiz (2005) show that the peculiarities of South African institutions are vital to any understanding of the nature, quality and impact of social infrastructure on economic growth. Finally, there is relatively little work to date on the impact of health outcomes on South African growth. The examination by Arndt and Lewis (2000) on the long-run impact of AIDS in a computable general equilibrium model is an exception, but pursues a methodology distinct from that used in the present paper.

<sup>22</sup> See also the relevant cautionary discussion in Perreira (2000).

<sup>23</sup> See Johansen (1991) and Johansen and Juselius (1990).

<sup>24</sup> See Wickens (1996), Johansen and Juselius (1990, 1992), Pesaran and Shin (1995a, 1995b), Pesaran, Shin and Smith (1996).

<sup>25</sup> This finding is consistent with a number of other studies employing either dynamic panel estimators, or cointegration analysis of investment data in South Africa. See Fedderke (2004), Kularatne (2002) and Mariotti (2002).

<sup>26</sup> See Kelly, 1997; Canning and Perotti, 1994; Aschauer, 1989a; and Pereira, 2000.

<sup>27</sup> A relevant question might be whether the relevant endogenous infrastructural variable in South Africa could not be LNELEC. This possibility is excluded since the expansion of electricity generating capacity in South Africa was undertaken for strategic rather than economic considerations under the Apartheid dispensation. Thus endogeneity here is less plausible.

<sup>28</sup> Although electricity generation is not a direct measure of power station generation capacity, electricity generated may be considered a reasonable proxy for 'useful' generation capacity during the estimation period.

<sup>29</sup> Note that infrastructural investment accounts for approximately 16% of total investment in physical capital stock. Hence, by construction we would expect some relationship between aggregate and infrastructural investment. nevertheless the strength of the elasticity is greater than we would expect given the mere definitional link.

<sup>30</sup> The figure is an estimate, including the cost of bridges, raised carriageways and tunnels, and averaged across single and dual carriageways - personal communication with civil engineering firm.

<sup>31</sup> Full attendant diagnostic statistics are available from the authors.

<sup>32</sup> We note that the second cointegrating vector under the more parsimonious specification (1) is subject to some uncertainty concerning the equilibrium adjustment mechanism in the error correction specification. We obtain error correction only on inclusion of a second lag in the error correction terms – or under non-linear adjustment to the

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conditional mean value specified by the cointegrating relationship. Under the fuller specifications estimated under [11] below, error correction is immediately asymptotic.

<sup>33</sup> Both measures are obtained from Fedderke, De Kadt and Luiz (2000). See Fedderke (2004) on the inclusion of these measures in an investment relationship for South Africa. Fedderke, De Kadt and Luiz (2001) investigates the role of the institutional variables for a growth relationship. Fielding (2000), Kularatne (2002) and Mariotti (2002) all find the variables important in multiple equation representations of the growth process in South Africa. Ideally estimation would have incorporated measures of human capital also – see Fedderke (2001), Kularatne (2002) and Mariotti (2002). Unfortunately, available relevant measures of human capital terminate in 1992 – significantly reducing our sample period.

<sup>34</sup> We also estimated under the  $\beta_{15}=\beta_{16}=\beta_{24}=0$  identification structure, without the weak exogeneity restrictions. Long-run coefficient magnitudes were comparable to those reported in column (3) of Table 9.

<sup>35</sup> See for instance Fedderke (2004), Fielding (2000), Kularatne (2002) and Mariotti (2002).

<sup>36</sup> A general point of potential modeling significance is that authoritarian political dispensations may have a greater capacity to prioritize and implement infrastructure than democratic dispensations. We also tested for the impact of a measure of political rights but were unable to confirm statistical significance.

<sup>37</sup> Of course, readers should bear in mind that such impacts may be subject to significant lag effects.

<sup>38</sup> Though readers should recall that the definitional link will bias this measure upward and the final output impact is more muted.

<sup>39</sup> The study projects an expenditure need in electricity of US\$0.5 billion per annum, and of US\$1.98 billion per annum in telecommunications for South Africa. The study also further explores the differential impacts of different types of infrastructure on productivity.

<sup>40</sup> See also the discussion in Pesaran (1997) and Pesaran and Shin (1995a, 1995b).

<sup>41</sup> For instance Akaike.

<sup>42</sup> The test is analogous to a Granger causality test, but in the presence of non-stationary data. Of course, there exist an array of tests designed to establish the univariate time series characteristics of the data. The tests are not always conclusive, however. This renders the PSS F-test suitable in the current context.