Infrastructure Development and Economic Growth in South Africa: A Review of the Accumulated Evidence

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Abstract

This paper provides a broad overview of the relationship between infrastructure and growth, focusing on the South African case. The paper develops an intuitive theoretical framework in which to analyse this relationship, identifying five specific channels through which infrastructure may effect growth: as a factor of production, a complement to other factors of production, a stimulus to factor accumulation, a stimulus to aggregate demand and a tool of industrial policy. A framework is developed for evaluating empirical analyses of this relationship, which explores the implications of different definitions and measures of infrastructure and of potential data and estimation challenges. The empirical literature on South Africa is then assessed against this framework.

1 Introduction

The relationship between infrastructure and economic growth has, in recent years, become one of the most important economic topics in both academic and policy circles. The Accelerated and Shared Growth Initiative - South Africa (ASGI-SA) has identified inadequate infrastructure as one of the six most important constraints to growth in South Africa. The National Treasury has allocated R416 billion to spending on infrastructure development and maintenance, broadly defined, in the current three-year budget cycle (National Treasury, 2007). This after a period from 1976 to 2002 when annual infrastructure investment fell from 8.1% to 2.6% of GDP, with per capita expenditure falling from R1 268 to R356 (Fedderke and Bogetic, 2006a).

At the same time, academic journals have seen a flurry of infrastructure-related publications, beginning to correct a historical paucity of South African empirical research into the growth-infrastructure relationship. This research has followed the international trend of deploying increasingly advanced and more appropriate statistical techniques. Early international studies by Aschauer (1989a, 1989b, 1989c) and Munnell (1990) found a strong positive relationship between infrastructure and growth, sparking considerable academic interest in the study of this relationship. However, their findings have been widely criticised as relying on inappropriate techniques (Gramlich, 1994) and more attention is now paid to more recent studies, which use more appropriate statistical methodology, such as those of Calderón and Servén (2004) and Estache, Speciale and Veredas (2005). Similarly, South African empirical work has progressed in the last decade from overly simplistic, often inappropriate statistical techniques to more advanced and appropriate tools, particularly in the past three years.

This paper provides a broad overview of the relationship between infrastructure and growth, focusing on the South African case. Section 2 begins by briefly exploring some questions around the

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definition of infrastructure. Section 3 introduces the theoretical relationship between infrastructure and economic growth. A basic model of the determinants of economic growth is developed and is used to explore five potential channels of effect from infrastructure to growth. Section 4 develops a framework within which to evaluate empirical research, presenting the available indicators, discussing the challenges facing the applied researcher and exploring some means of overcoming these challenges. Using this framework, the empirical evidence from South African studies is reviewed in section 5. Section 6 explores the policy implications of this evidence, with particular emphasis on the funding needs and implications on infrastructure projects, building off work by Bogetic and Fedderke (2006). Section 7 concludes.

2 Defining Infrastructure

A formal and detailed definition of infrastructure is not necessary for the purposes of this paper. (For a discussion of such definitions, see Fourie, 2006.) However, it is important to develop an intuitive understanding of the characteristics and types of infrastructure. This section develops such an understanding, while at the same time introducing some issues of infrastructure measurement that will assume a central role in sections 4 and 5.

Infrastructure spending was historically defined as consumption expenditure by either government or the private sector but is now near-universally defined as capital expenditure, as infrastructure has been recognised as a capital good (Gramlich, 1994).[1] Furthermore, infrastructure often possesses at least some characteristics of a public good. The owner or developer may struggle to exclude others from using it (*non-excludability*) and the benefits accruing to the economy as a whole typically exceed those accruing directly to the owner and even to the users (called *positive externalities*) (Hirschman, 1958). These are not, however, necessary characteristics of infrastructure and some specific infrastructure items may be pure private goods.

In economic terms, infrastructure may legitimately be examined as a "stock" or a "flow" variable. In the former case, attention focuses on the stock of infrastructure at a given point in time. In the latter case, attention focuses on net infrastructure creation or loss over a given time period. Whether infrastructure is measured in terms of stocks or flows, it is important that this be compared with the appropriate measure of aggregate economic performance. Both infrastructure stocks and aggregate output (typically measured by GDP) are cumulative measures and thus possess marked time trends. Infrastructure flows and economic growth, however, are non-cumulative measures and are unlikely to possess such time trends. Infrastructure stock is thus generally compared to GDP and infrastructure flows to GDP growth, as the differing time trends may otherwise obscure genuine relationships in the data.

By convention, infrastructure is broadly divided into two categories: economic and social. The former conventionally includes transport, communications, power generation, water supply and sanitation facilities, while the latter includes educational and health-care facilities, though some authors include cultural and recreational facilities (DBSA, 1998). This classification is largely *ad hoc*, as many forms of infrastructure may be considered as either economic or social. Educational facilities, for example, are widely defined as social infrastructure, but play an important role in generating human capital, which is certainly also an economic function and carries important growth implications.

The two major approaches to measuring infrastructure are physical and financial. Financial measures simply calculate the depreciated value of the accumulated investment in a particular piece of infrastructure such as a road, school or power grid. Physical measures vary across different infrastructure measures: total length of paved roads, number of classrooms or total number of

[1] Economists divide all expenditure between the categories of "consumption" and "capital." Very generally speaking, consumption expenditure yields immediate benefits whereas capital expenditure yields delayed benefits in the future. The classification of infrastructure speaking as capital expenditure thus reflects economists' expectations that the bulk of the benefits arising from infrastructure spending accrue in the future.

containers processed by a port. Constructing a single index of the physical characteristics of widely varying types of infrastructure is a difficult task, so it is common practice to use physical measures only when examining specific types of infrastructure. When examining aggregate infrastructure stocks or flows, it is more common to use financial measures. Some studies, however, use financial measures for infrastructure data disaggregated by type (Gramlich, 1994).

In the theoretical discussion that follows in section 3, issues surrounding measurement of infrastructure are abstracted away from. In section 4, however, problems of measurement are explicitly addressed, as are some of the responses available to the empirical researcher.

3 A Basic Theoretical Model

Economic theory identifies five channels through which infrastructure can positively impact on economic growth. To contextualize these channels, a brief diversion into basic growth theory is necessary. Economists typically describe growth in terms of a production function for goods and services, where aggregate economic output is a function of a collection of production inputs or "factors of production."[2] Models differ with respect to which factors of production they regard as the key determinants of aggregate output. Physical capital (machinery, equipment, etc.) is present in almost all models, while the size of the labour force, the level of human capital (the skills level of the workforce) and technology also make frequent appearances. Some models also include government policy, geographic features and institutions (such as judicial independence, protection of property rights and bureaucratic efficiency) as determinants of growth.[3]

Most factors of production are positive determinants of aggregate output. Increases in the stock of physical capital, for example, are typically associated with increases in aggregate output. Thus, economic growth occurs when more factors of production become available and are put to use. However, it is also possible that some factors may exert a negative impact of aggregate output. Political instability, for example, has been shown to negatively effect aggregate output in South Africa (Fedderke, *et al*, 2001).[4] Furthermore, decreasing marginal product arguments apply here directly.

Discussion to date has focused on "supply-side" accounts of economic growth, in which aggregate output is modeled as the outcome of a production process. Some alternative models are "demand-side" or consider both demand and supply sides of the economy. These models regard aggregate output as the result of interacting supply and demand factors - implicitly assuming that output will only be produced if consumers (domestic or international) wish to purchase it.

Demand-side explanations of economic growth have experienced periods of popularity but have become increasingly uncommon in recent years. A relative consensus now exists amongst economists that demand-side considerations are important in determining short-run fluctuations in economic performance but play little role in determining medium- and long-run patterns of economic growth (Romer, 2001). In line with this relative consensus, this paper focuses primarily on supply-side linkages between infrastructure and growth.

Having developed a basic analytical framework within which to consider the infrastructure-growth relationship, discussion now proceeds to the five potential linkages between infrastructure and economic growth.

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[2] Mathematically, the production function can be expressed as $Y = f(X_1, X_2, X_3, \ldots)$, where Y represents aggregate output, the X_i terms represent the stock of particular factors of production and f takes on a specific functional form for each model.

[3] Sala-I-Martin, *et al* (2004), conduct a meta-study attempting to establish the most robust determinants of economic growth through time and across countries. They find that the most robust determinants are measures of education, investment and initial per capita GDP.

[4] We could equally conceive of political *stability* as a positive determinant of aggregate output. The intention of this example is simply to illustrate that there is no general requirement that factors of production be positively related to aggregate output.

3.1 Infrastructure as a factor of production

Infrastructure may simply be regarded as a direct input into the production process.[5] As infrastructure could otherwise be placed under the broader heading of physical capital, this approach assumes that infrastructure may be related to growth in a manner different to other forms of physical capital (Gramlich, 1994). Theory holds that an increase in the stock of infrastructure would increase the output of the economy as a whole, directly inducing economic growth.

The role of power generation infrastructure provides a concrete example of this channel. It is a necessary input into many production processes for both goods and services and so unreliable power supplies render these processes either more expensive or entirely impossible. This renders what economists call "marginal" transactions unprofitable - transactions that were previously just profitable, become unprofitable. Both South African and international firms have fewer profitable opportunities for investments and may thus choose not to undertake investments that they would otherwise have undertaken. The net result is a decrease in the sum total of economic activity in South Africa.

3.2 Infrastructure as a complement to other factors

Alternatively, infrastructure may be regarded as a complement to other inputs into the production process, in two senses. In the first sense, improvements in infrastructure may lower the cost of production. Inadequate infrastructure creates a number of costs for firms, who may have to develop contingency plans against infrastructure failure or even build infrastructure themselves. Inadequate transport infrastructure, for example, incurs potentially massive costs for firms who must seek alternative means of transporting both inputs and finished goods. Collier and Gunning (1999) find that this is an important contributor to Africa's poor growth performance in recent decades. The total cost of individual firms providing transport infrastructure may also be far higher than the equivalent cost of state provision of such infrastructure, as the latter is able to achieve significant economies of scale.[6] A similar analysis can be made in the context of the example of power generation infrastructure introduced in the previous subsection.

Conversely, good infrastructure generally raises the productivity of other inputs in the production process. In examining this linkage, different papers adopt different approaches and consider a range of factors of production, including capital (Barro, 1990), labour and total factor productivity (Fedderke and Bogetic, 2006a).[7] The intuition behind each of these linkages is relatively straightforward. The productivity of capital such as machinery or electronic equipment is clearly raised by reliable power supplies, while the productivity of labour will be far higher if good education and health-care infrastructure produce a well-educated and healthy workforce. "Total factor productivity" is a term economists use to describe output growth over and above that which can be ascribed to the accumulation of factors of production - it is perhaps best thought of as the efficiency with which factors of production are combined (Barro, 1998). Infrastructure may influence this measure by, for example, providing the transport facilities necessary to operate decentralised production processes.

These two effects together allow greater output for a given level of input and lower the cost of that given level of inputs. Returning to the notion of marginal transaction introduced in the previous subsection, transactions that were previously just unprofitable, become profitable. This increases the range of available profitable investment opportunities and may thus encourage both domestic and foreign investment, boosting aggregate economic activity in South Africa.

At the extreme, inadequate infrastructure may render some production processes nearly impossible. International trade, for example, is dependent on relatively sophisticated transport and communications infrastructure (Elbadawi, 1998). In particular, modern trade theory and empirical

[5] One of the X_i terms in the mathematical framework introduced above.

[6] Economists use this term to describe the situation in which per-unit costs of production fall as the volume of production increases.

[7] The difference foci reflect different functional forms of $Y = f(X_1, X_2, X_3, \ldots)$.

evidence emphasize the importance of linking into cross-border production networks. Industrial agglomeration, the process by which new industries locate near to existing industrial concentrations, is also of crucial importance. Mayer (2003) and Redding and Venables (2004) note the importance of adequate infrastructure provision to both of these processes. The success of the motor industry in the Eastern Cape, for example, would have been almost impossible in the absence of nearby harbours, road networks and a reliable power supply.

A related example particularly relevant to the South African case is that of tourism. The provision of tourist services to the international market is entirely dependent on transport infrastructure, while provision to the local market is severely constrained in the absence of such infrastructure (Fourie, 2006).

3.3 Infrastructure as a stimulus to factor accumulation

While the production function introduced earlier in this section considers the aggregate production taking place in an economy, each factor of production is itself the outcome of a specific production process. Human capital formation, for example, is a function of factors such as school facilities and educators' qualifications. In particular, infrastructure, in the form of schools, roads used to access schools and electricity provided to schools, is likely to be an important factor in the human capital production function.[8]

More generally, infrastructure is a determinant of many factors of production in a typical economy. Thus, infrastructure may influence growth indirectly, by boosting the accumulation of other factors of production or by boosting the productivity of these factors of production. These first three channels are captured in the diagram overleaf.

3.4 Infrastructure as a stimulus to aggregate demand

The first three channels focus purely on the supply side of the economy, while the fourth considers the potential role of the demand side. Large infrastructure projects typically involve significant expenditure during construction and potentially also during maintenance operations, increasing aggregate demand. Governments have, for example, often used large-scale infrastructure projects as stimulus policies during recessions or in order to achieve particular growth targets.

While the first three channels are relatively widely accepted in the literature, this fourth is more widely contested. Critics of demand-side interventions in general charge that the effects of such interventions are limited to the short-run: as productive capacity remains unaffected, the economy cannot actually produce more output. In an open economy, the result is likely to be rising imports and a potential trade deficit. In both open and closed economies, rising demand for the same output may spark price inflation. Mariotti (2002) finds that large-scale government expenditure in South Africa provides only a temporary stimulus to output (approximately two years) but produces long-term inflation. While infrastructure spending may well increase the economy's productive capacity, its primary impact on growth would then be through one of the first three channels, rather than through the demand side of the economy.

3.5 Infrastructure as a tool of industrial policy

Another somewhat controversial channel focuses on the potential for infrastructure spending by government to act as a tool of industrial policy. Government might attempt to activate this channel by investing in specific infrastructure projects with the intention of guiding private-sector investment decisions. A road construction project in a rural area may be intended to facilitate integration of

[8] Mathematically, we can represent this example in a more detailed production function: $Y = f(H, I, X_1, X_2, X_3, \ldots)$ where $H = g(I, Z_1, Z_2, Z_3, \ldots)$, I represents infrastructure stock or investment and the Z terms represent the determinants of human capital accumulation other than infrastructure.

that area into the regional economy and hence promote private sector investment and economic growth. This thinking has been a key element of the rationale behind the Maputo Corridor and the Coega Development Corporation. Here again, however, many critics charge that such interventions do not actually succeed in stimulating economic growth, as they fail to boost economic growth or simply divert resources that could be better spent elsewhere.

Despite disagreement regarding the relative importance of some of these theoretical channels of effect, there is widespread agreement that there is a generally positive relationship between infrastructure and growth. Nonetheless, specific infrastructure projects may exert a negative impact on growth, particularly when they involve effective over-provision of infrastructure (Canning and Pedroni, 2004). Empirical evidence around this issue, however, is more ambiguous. As section 4 explains, there are significant methodological and measurement challenges facing any empirical investigator. Many of these challenges revolve around issues relating to infrastructure quality and usage, which have been deliberately postponed until now.

3.6 Growth as a determinant of infrastructure spending

Discussion to date has focused on the theoretical channels through which infrastructure may effect growth. However, there is also a theoretical argument holding that growth may effect infrastructure investment decisions. On the one hand, rising aggregate output may generate demand for more infrastructure. In particular, improved infrastructure may be needed in order to transport this output, communicate with potential buyers of this output and train more skilled workers to produce this output in the future. On the other hand, mechanisms also exist in order to supply this rising infrastructure in demand. Private sector firms may invest directly in infrastructure (though this has been relatively uncommon in South African history) or they may lobby government to engage in particular infrastructure investments. This channel is depicted in figure 2 and poses a significant challenge to empirical researchers, as is discussed in section 4.

4 A Framework for Empirical Analysis

Empirical testing of the theoretical linkages identified in section 2 has posed a significant challenge to both South African and international researchers. This section begins by exploring the available indicators of the infrastructure-growth relationship and briefly discussing their relative merits and demerits. Discussion then proceeds to the empirical challenges facing these investigations, with respect to both data limitations and estimation challenges. The section concludes with an outline of the empirical tools available to researchers to overcome these challenges.

4.1 Indicators

The first of the four indicators of the growth impact of infrastructure is the most direct: a calculation of the *correlation* between infrastructure stock and aggregate output or between infrastructure investment and economic growth. This may be either a simple correlation or *partial correlation*, which calculates the relevant correlation while holding constant a range of other factors. Researchers might, for example, wish to calculate the correlation between infrastructure stock and aggregate output while controlling for the general level of physical capital. This allows them to calculate the infrastructure-growth relationship for each of a set of observed levels of physical capital (R100 million, R200 million, etc.). This allows researchers to avoid the possibility of calculating a biased measure of the infrastructure-growth relationship because part of this relationship is obscured by a physical capital-growth relationship. (And potentially a range of other relationships for which controls would also be needed.)

The second indicator, called a *growth elasticity*, is a slightly modified correlation indicator. The growth elasticity essentially measures the sensitivity of output to infrastructure, showing percentage change in the former in response to a one per cent change in the latter (through time or across different cross-sectional observations). There are several means of calculating such elasticities but discussion here focuses on one particular method: *regression* analysis.[9]

An explanation of the mechanics of regression analysis falls well beyond the scope of this paper[10] but several important features of this form of analysis are worth noting. Firstly, regression analysis attempts to "estimate" the relationship between several different variables - in this context, infrastructure, growth and any other variables for which the researcher may wish to control. Secondly, growth elasticities can be readily calculated in a regression framework, using some simple transformations of the data. Thirdly, there are a wide range of "estimation techniques" available to the applied researcher and these may produce radically different results, as may different specifications of the "regression model." Selection of the appropriate estimation techniques and regression model is thus of crucial importance, as is discussed in detail in subsection 4.3. Until recently, most South African studies employed "ordinary least squares" or "OLS" estimation, which is unable to address many of the estimation challenges outlined below.

The third and fourth options, *factor productivity gains* and *cost reductions*, are indirect measures, each entailing a two-step calculation. Firstly, the relationship between infrastructure stock and factor productivity (or cost) is calculated, typically using a regression framework. Secondly, the impact on aggregate output of the gain in factor productivity (or reduction in cost) is calculated. A useful feature of these measures is that they may allow identification of the specific channel through which infrastructure effects economic growth. If, for example, there is a strong positive relationship between infrastructure stock and output, but no significant relationship between infrastructure stock and factor productivity, it suggests that the second theoretical linkage identified above (subsection 3.2) is not operative.

The final measure used in the empirical literature is that of the *economic rate of return*. This measure compares the growth elasticity of infrastructure with the cost of that infrastructure, obtaining a measure of economic return on infrastructure expenditure.

4.2 Data limitations

Accurate empirical research requires accurate and comprehensive data but in practice this requirement is seldom satisfied. The available infrastructure data, both South African and international, suffer from a number of significant limitations, which this section highlights. Before elaborating on these limitations, it is important to understand that there are broadly three types of data that may be available to empirical researchers: cross sectional, time series and panel. Cross sectional data measures infrastructure at a given point in time across different industries, regions or countries, while time series data measures infrastructure in a given industry, region or country through several periods in time. Panel data measures infrastructure across industries, regions or countries through several periods in time.

Firstly, the data available to researchers may be neither comprehensive nor accurate. Measuring nationwide infrastructure stocks (such as length of paved roads or number of classrooms) presents a massive logistical challenge and there may be inaccuracies in even the most painstakingly compiled datasets. Furthermore, it is not implausible that there may be a systematic component to these inaccuracies. Data on rural infrastructure, for example, may be more difficult to collect and to check than data on urban infrastructure. If this is indeed the case, inaccurate data may introduce systematic bias into any comparison of the infrastructure-growth relationship in urban and rural areas. More generally, some types of infrastructure may be easier to measure than others. Tracking the number of flights leaving South Africa's airports each year is considerably less difficult than

[9] Growth elasticities can also be calculated using the formula *(%?Y / Y) / (%?I / I)*, where Y and I represent, respectively, the level of output and stock of infrastructure (or rate of economic growth and rate of infrastructure investment).

[10] For such a discussion, see Gujarati (2003).

tracking the total length of paved roads across South Africa. Such systematic data inaccuracies may bias any comparison of the growth-enhancing impact of different types of infrastructure.

The challenges involved in physical measurement of the infrastructure stock lead some researchers to instead use financial measures, as discussed in section 2. Infrastructure expenditure, however, provides at best a “noisy” indicator of the outputs of the infrastructure-creation process, as the efficiency with which investment is converted into actual infrastructure may vary considerably across different projects. To examine one particularly telling context: a given value of expenditure on infrastructure development may yield significantly greater infrastructure outputs in rural than in urban areas, due to the higher transport costs and relative shortage of construction subcontractors characterising rural areas. Using expenditure as a measure of infrastructure would then systematically overstate the “true” amount of infrastructure in rural areas relative to that in urban areas. Furthermore, falling infrastructure expenditure due to improvements in construction technology may be incorrectly interpreted as a fall in effective infrastructure investment. The choice of depreciation method also assumes crucial importance, particularly for older infrastructure, and it is highly unlikely that a single depreciation method will be applicable to widely varying forms of infrastructure. Gravel roads, for example, deteriorate far faster than asphalt roads and would thus need to be depreciated at a faster rate (Ross, 2006).

The second component of the measurement problem may be even more serious. Infrastructure data, whether physical or financial, typically incorporates many “quantity” indicators and few, if any, “quality” of “usefulness” indicators. Even if, for example, the total length of roads or number of classrooms in South Africa is perfectly measured, this provides no information about the quality of those roads or classrooms. Furthermore, there may be an inverse relationship between the quantity and usefulness of infrastructure. Fedderke and Bogetic (2006a), for example, hypothesise that some historical reductions in road length in South Africa may actually have reflected the construction of shorter and straighter roads, which would have exerted a beneficial impact on growth (Hall and Jones, 1999).

This concern assumes even greater significance when attention shifts to a comparison between the growth impact of investment in new infrastructure and that of investment in infrastructure maintenance. If investigators cannot quantify the quality of infrastructure, they cannot compare the growth impact of new infrastructure to that of old, potentially decaying infrastructure. Furthermore, “quality” may have different meanings in different contexts. A gravel road of a given state of repair in a high rainfall area, for example, is of substantially less use than a gravel road in the same state of repair in a dry area, where it will be swamped and flooded significantly less often. Factors such as these render it impossible to determine a growth-maximising expenditure allocation between maintaining existing infrastructure and building new infrastructure.

Furthermore, data on infrastructure usage is seldom available, which might provide a measure of the “usefulness” of infrastructure or the actual service provided. Some infrastructure may simply not be economically useful, perhaps because it is poorly located or replicates a service already provided by other infrastructure. The World Bank has recently conducted a series of international surveys of (subjective) infrastructure quality, usefulness and access, but these provide only highly aggregated, country-level data (Estache and Goicoechea, 2005).

4.3 Estimation challenges

Even if accurate data were available that captured exactly the relevant characteristics of the infrastructure stock, challenges would remain for the applied researcher. Fedderke and Bogetic (2006a) provide a detailed exposition of these challenges and this subsection presents a brief précis of the five key challenges that they identify.

Firstly, the relationship between infrastructure and growth may be non-linear (i.e. not directly proportional). In particular, an increase in the infrastructure stock may be growth-enhancing when the existing infrastructure stock is small, while an increase of the same magnitude may have little impact on growth when the existing infrastructure stock is small (Canning and Pedroni, 2004). This is essentially a case of zero or negative "marginal productivity" at high levels of infrastructure, as introduced in section 2. Effectively, this means that new infrastructure is growth-enhancing where it is under-provided and growth-neutral where it is adequately or over-provided.[11] Calculating any of the indicators introduced in section 4.1 becomes problematic under these circumstances and researchers may obtain misleading results.

Secondly, the relationship between infrastructure and growth may be indirect. Several of the channels identified in section 2 suggest that infrastructure impacts on aggregate output *via* some intermediate measure, such as the productivity of physical capital. If this possibility is not considered, researchers may obtain inaccurate results. In particular, a researcher seeking to isolate the infrastructure-growth relationship may calculate the partial correlation, holding constant the productivity of physical capital. This study might incorrectly reject the existence of a relationship between growth and infrastructure, but only because of this central flaw in the study design.

Thirdly, isolating the role of infrastructure in determining growth patterns is a challenging task, given that many other factors influence economic growth. If, for example, the stock of physical capital in South Africa is strongly correlated with both output and infrastructure stock, an increase in physical capital stock would be accompanied by an increase in output and infrastructure. This might be incorrectly interpreted as evidence in support of a growth-infrastructure relationship, when the two increases are in fact causally unrelated. A statistical tool is therefore required that can control for the other determinants of growth and isolate the growth-infrastructure relationship.

At the same time, however, it is possible for researchers to go too far in controlling for other determinants of growth. Infrastructure spending may result in what economists refer to as "crowd-out" effects. Private or, more commonly, public infrastructure spending may reduce investment in other areas, particularly other forms of physical capital, that promote growth (Aschauer, 1989c).[12] This creates a significant problem for the applied researcher, who must control for growth determinants that are genuinely unrelated to infrastructure spending while still allowing for the possibility of such crowd-out effects.

Fourthly, inappropriate aggregation of infrastructure measures may result in misleading conclusions regarding the infrastructure-growth relationship. Imagine, for example, that investment in road infrastructure is strongly associated with economic growth but there is no such relationship between airports and economic growth (a scenario supported by some of the empirical evidence reviewed in section 5). Aggregating these two measures and comparing overall infrastructure investment to economic growth might lead researchers to incorrectly conclude that there is no relationship between infrastructure and growth. More generally, inappropriate aggregation renders it difficult or impossible to make judgments about the relative importance to growth of different types of infrastructure.

Similarly, geographical aggregation may result in misleading conclusions. Investment in rural infrastructure may have very different growth implications to investment in urban infrastructure, possibly as a result of the potential for non-linearity discussed above. Combining the two observations regarding the dangers of aggregation, it is also possible that different types of infrastructure may have different impacts on aggregate output in different regions. For example, road infrastructure may be particularly efficacious in rural areas while educational infrastructure yields the greatest growth impact in urban areas.

Fifthly, finding a strong statistical association between infrastructure and economic growth does not by itself provide any information about the direction of causality between the two variables (Calderón and Servén, 2004). The theoretical discussion in section 2 focused on infrastructure as

[11] It may even be detrimental to growth if the resources devoted to infrastructure development could be more beneficial to growth if devoted to alternative courses.

[12] This arises because large infrastructure projects are almost always at least partially funded by loans, pushing up the demand for borrowed funds. The result is an increase in the price of loan capital - a rise in commercial interest rates. This raises the effective price of any investment funded with loan capital and may deter such investments.

a positive determinant of economic growth but there are also theories that hold that the chain of causality may run in the opposite direction. It is also possible that there may be a bidirectional causal relationship and, in particular, the direction of causality may differ across different infrastructure measures.

A further challenge that Fedderke and Bogetic do not discuss, but which bedeviled early empirical work, both internationally and in South Africa, is that posed by non-stationary data. Without entering into an overly technical definitional discussion, non-stationary data is data that displays a pronounced stochastic trend or drift through time. Both infrastructure stock and output level, for example, typically increase steadily through time and this joint trend may be incorrectly interpreted as evidence of a genuine economic relationship rather than a correlation between two stochastic trends. (Economists refer to this as the "spurious regression" problem.) As discussed in section 5, early South African studies of the infrastructure-growth relationship should be interpreted with caution for precisely this reason.

4.4 Empirical tools

There are a range of empirical tools available to the applied researcher wishing to overcome some of the data and estimation challenges discussed in the previous subsections. A selection of the more appropriate and widely-used of these tools are presented below. The sequence of this discussion follows that of the previous two subsections, presenting the available tools to respond to each of these problems in turn.

The standard response to inaccurate or mismeasured data involves the use of a particular estimation technique known as "instrumental variables" estimation. This technique can, under certain circumstances, produce accurate estimates of the infrastructure-growth relationship, even in the presence of inaccurate physical or financial data. However, the circumstances in which this technique can be applied are very limited and it has in fact never been used in a study of the South African infrastructure-growth relationship.[13] There are, furthermore, no readily available techniques to address the widespread lack of data regarding the quality and usefulness of infrastructure.

There is no specific tool used to address the possibility of non-linear relationships. "Threshold autoregressions" can identify the presence of non-linearity in time-series data (Kularatne, 2006) and some regression models can be developed that allow for the possibility of non-linearity. In the South African context, however, this is unlikely to be a significant problem, given that empirical evidence has consistently found that infrastructure has been substantially underprovided for the past few decades. Furthermore, non-linearity may be a result of an indirect relationship between infrastructure and growth and allowing for such an indirect relationship may overcome the problem of non-linearity (Fedderke and Bogetic, 2006).

Indirect relationships can be captured through a multi-stage approach to regression analysis. The relationship between infrastructure, productivity of physical capital and growth is used to illustrate this approach. Firstly, a regression analysis is used to identify the relationship between infrastructure investment and the productivity of physical capital. Secondly, a separate regression analysis is used to identify the relationship between the productivity of physical capital and economic growth. The results of these two regression analyses can then be used to calculate the relationship between infrastructure investment and economic growth. Alternatively, researchers may employ a particular estimation technique known as "multivariate cointegration," which simultaneously calculates all three relationships: between infrastructure investment and the productivity of physical capital, between the productivity of physical capital and economic growth and between infrastructure investment and economic growth (Fedderke and Bogetic, 2006a).

Controlling for other determinants of growth is a relatively straightforward task in any regression analysis, provided that data regarding these determinants is readily available. However, the applied

[13] This technique has, however, been applied to overcome some estimation, rather than data, challenges, as discussed below.

researcher still faces the challenging task of identifying which variables *should* be controlled for and which capture an indirect effect of infrastructure on growth (such as the "crowd-out" effect identified above).

The problems arising from inappropriate aggregation may, to some extent, be overcome by employing disaggregated data. Early South African studies of the infrastructure-growth relationship employed national-level financial data on infrastructure stock and aggregate output (Abedian and Van Seventer, 1995; Coetzee and Le Roux, 1998), while more recent studies employ separate measures of different types of infrastructure (Fedderke, *et al*, 2006; Perkins, *et al*, 2005) and manufacturing sector or firm-level data on output (Edwards and Johnny, 2006; Fedderke and Bogetic, 2006a). However, data is not always available at a sufficiently disaggregated level. While some data regarding infrastructure stocks is available at a municipality level, for example, output data is not available at the same level of disaggregation. The future availability of such data would significantly improve researchers' ability to identify the infrastructure-growth relationship, an observation policy-makers may wish to take into consideration.

There are several estimation techniques available to identify the direction of the causal relationship between infrastructure and growth. A form of univariate cointegration, the "PSS ARDL" technique, allows researchers to explicitly test the direction of causality (Perkins, *et al*, 2005). Both "multivariate cointegration" and "instrumental variables" estimation (both introduced above in different contexts) may allow researchers to produce accurate estimates of the infrastructure-growth relationship in the presence of bicausality[14] (Fedderke and Bogetic, 2006a). While none of these techniques are entirely conclusive, they do provide a strong indication of the direction of causality and implications of that direction, whereas the techniques employed by earlier studies simply ignored this problem entirely. Because these techniques do not necessarily identify the "true" direction of causality but instead use statistical evidence to infer the direction, economists typically speak in terms "forcing" or "driving," rather than causal relationships. The remainder of the paper follows this convention.

Finally, the problem of non-stationary data can be almost entirely addressed by modern statistical techniques. The family of estimation techniques known as "cointegration" techniques allow researchers to overcome this problem. In particular, the PSS ARDL techniques allows for the possibility that some variables may not be clearly stationary or non-stationary, while multivariate cointegration allows for regression models in which some variables are stationary and others non-stationary.

5 A Survey of the Empirical Literature

Despite a surge of academic attention in the last two years, the infrastructure-growth relationship in South Africa remains understudied. Only three studies were undertaken prior to 2003, all of those in the mid-1990s. Furthermore, some of the early studies used relatively inappropriate statistical techniques and their findings must be treated with a considerable degree of caution.

This section begins by reviewing the early empirical literature (pre-2003) and then focuses on more recent studies. These studies can be broadly divided into two categories: those that directly measure the infrastructure-growth relationship and those that indirectly measure the relationship, by analysing the connection between infrastructure and another determinant of growth. Of the more recent literature, the direct studies are considered first, followed in turn by those focusing on the relationship between infrastructure and productivity, exports and skills development. Finally, a paper considering issues of infrastructure quality and usage is considered.

Unfortunately, almost all empirical analysis has focused on economic infrastructure to the exclusion of social infrastructure. This is broadly consistent with international trends and may also, as

[14] "Bicausality" describes the situation in which there is a causal relationship between two variables in both directions.

Kularatne (2006) suggests, be a result of the limited South African data on most forms of social infrastructure. Furthermore, most studies focus purely on infrastructure developed by parastatals and the government. Private-sector infrastructure, which has come to constitute a significant portion of total infrastructure expenditure and stock, is seldom considered.

5.1 Early studies of the infrastructure-growth relationship

Both Abedian and Van Seventer (1995) and Coetzee and Le Roux (1998) focus on financial measures public-sector infrastructure in analysing the relationship between infrastructure and growth. The former paper finds output elasticities between 0.17 and 0.33 and economic rates of return between 0.2 and 0.23 (depending on the definition of the infrastructure stock). The latter study obtains relatively similar results, calculating an output elasticity of 0.3 and an economic rate of return of 0.24. These results, however, like many international findings from the same time period, do not take into account the stochastic time trends in both infrastructure stock and output measures. The calculated elasticities are thus likely to be biased and so should be treated with a high degree of caution.

The 1998 DBSA Development Report also focused on public sector infrastructure stock, measured financially. Using the same statistical techniques employed by earlier studies, the report found output elasticities between 0.15 and 0.3 and economic rates of return between 0.11 and 0.9. Using a more appropriate statistical technique that took explicit account of stochastic time trends, the calculated elasticities were between 0.25 and 0.3, with economic rates of return between 0.17 and 0.33. Perhaps surprisingly, the result obtained under the two estimation techniques are not substantially different. This does not, however, mean that inappropriate statistical techniques will in general produce reasonably accurate results. The findings of these three reports are summarised in table 1.

Thus, at the end of the 20^{th} century, the available South African empirical literature firmly supported the notion that infrastructure positively affected economic output. However, these results were characterised a failure to take into account many of the estimation challenges discussed in the previous section. They did not take into account the possibility of non-linear relationships, indirect relationships or crowd-out effects, used highly aggregated data and did not attempt to explore the direction of causality. Furthermore, only the DBSA report used an estimation technique appropriate for non-stationary data. Table 2 provides a "check list" of the empirical challenges (not) addressed by the studies reviewed in this subsection and in subsections 5.2 and 5.3.

5.2 Recent studies of the infrastructure-growth relationship[15]

Perkins, *et al* (2005), was the first of a series of studies attempting to address these particular challenges. This study used the *PSS ARDL* technique to focus specifically on the question of causality, while taking into account the time trends in the data. They find that the direction of forcing varied across different infrastructure measures:

- aggregate public sector investment and public sector fixed capita stock drive GDP;
- roads (total road length, paved road length, number of passenger vehicles) drive GDP;
- GDP drives ports' freight handling levels and airports' passenger levels;
- the direction of forcing is ambiguous for measures of railway, power generation and telecommunication infrastructure.

These findings are presented graphically in figure 3.

Fedderke, *et al* (2006), build off this result by investigating the relationship between GDP and a range of infrastructure measures between 1875 and 2001. They allow for the possibility of time trends

[15] These studies all make use of time-series data for the entire South African economy as a single unit.

in the data, directly address the issue of causality and explicitly consider both direct and indirect channels of effect. They find that aggregate infrastructure investment and infrastructure stock drive GDP, as do measures of road infrastructure. Telecommunication, port and airport infrastructure and some railway infrastructure, however, are driven by GDP. The direction of the relationship is ambiguous for electricity generation and some other railway infrastructure. These results are broadly consistent with those obtained by Perkins, *et al*, (2005) and so are not presented in a separate table.

In calculating the magnitude of the relationship between output and infrastructure, they adopt a multivariate cointegration model that examines the long-term interaction between several variables, allowing for the possibility of ambiguous causal relationships. In this model they include GDP, fixed capital stock, public sector fixed capital stock (a financial measure of infrastructure), total road length and electricity generation capacity. Their results are depicted in figure 4. They find that there is a relationship between infrastructure stock and GDP but that this relationship is indirect, with rising infrastructure stock encouraging investment in fixed capital and thereby boosting GDP. The elasticity of GDP with respect to fixed capital stock is 0.06 and that of fixed capital stock with respect to infrastructure is 1.37. This means that a one percent increase in infrastructure increases fixed capital stock by 1.37%, while a one per cent increase in fixed capital stock increases GDP by 0.06%. Furthermore, electricity generation directly effects GDP with an elasticity of 0.2 (i.e. a one per cent increase in electricity generation capacity directly increases GDP by 0.2%). Some of these results, however, are not robust to the replacement of total road length by other infrastructure measures.

They also introduce a control for property rights to test for the role of institutions in the infrastructure-growth relationship. With this control included, the indirect relationship *via* fixed capital stock is maintained and a significant direct positive relationship is also found, with an elasticity between 0.4 and 0.5.

A further paper by Kularatne (2006) looks at both economic and social infrastructure. He also uses both the *PSS ARDL* approach to test the direction of causality and a *VECM* model to examine the relationship between his two measures of infrastructure, private investment and gross value added (GVA). By including the private investment variable, he allows for the possibility that the infrastructure-growth relationship is direct or indirect, *via* private investment.

Using physical measures of economic and social infrastructure (constructed from road and classroom data, respectively), he finds that social infrastructure directly drives economic infrastructure, private investment and GVA. Ambiguous causal relationships exist between economic infrastructure on the one hand and both private investment and GVA on the other hand. Using the *VECM* model, he finds that GVA responds to social infrastructure spending with an elasticity of 0.06, while the private investment rate responds to economic infrastructure spending with an elasticity of 0.02. (GVA in turn responds to private investment with an elasticity of 2.5.)

While he finds a positive infrastructure-growth relationship, he also tests explicitly for the possibility that this relationship may be non-linear: that infrastructure spending initially enhances growth but then stunts growth beyond some sufficiently high level. He finds that the relationship is positive for both economic and social infrastructure for all values of infrastructure investment recorded in South Africa in the last thirty years.[16] This finding is of substantial importance when interpreting the other South African empirical studies, as it suggests that their results are not compromised by the fact that they do not take into account the possibility of a nonlinear relationship between infrastructure and growth.

Having considered both the recent and slightly older empirical evidence, a number of conclusions can be drawn. Perhaps most importantly, the early finding of a positive infrastructure-growth relationship has been borne out by the subsequent application of more sophisticated techniques. However, these latter studies have identified two important features of this relationship that was

[16] This paper does not, however, consider the interaction of human capital and institutions. Fedderke (2005) finds, albeit in a different context, that the relationship of interest, between human capital and economic growth in South Africa, is strongly influenced by institutions such as political stability and political rights.

not investigated by the early relationships. Firstly, while aggregate infrastructure stock and investment appear to drive output, there are feedback effects from output to some specific forms of infrastructure. Secondly, much of the relationship appears to be indirect, with expanding infrastructure increasing fixed capital stock and productivity, which in turn increases output. Furthermore, the next subsection demonstrates that there may be a further indirect channel through which the relationship between infrastructure and growth operates.

5.3 Infrastructure and productivity

Fedderke and Bogetic (2006a) focus their attention on the relationship between infrastructure and productivity, measured by both labour and total factor productivity. Unlike the papers examined above, which employed time-series data on the South African economy as a whole, this paper considers a panel of 24 South African manufacturing sectors between 1975 and 2000. Their findings are summarised in table 3.

They find that aggregate infrastructure stock and investment impact positively on labour productivity, with elasticities of 0.19 and 0.2, respectively. Aggregate infrastructure investment impacts positively on total factor productivity with an elasticity of 0.04, while aggregate infrastructure stock has no significant relationship with total factor productivity.

They also go on to investigate the relationship between infrastructure and productivity for physical measures of particular types of infrastructure. They find that electricity (elasticity 0.05), railway (elasticities between 0.32 and 1.04), air transport (elasticities between 0.05 and 0.25) and particularly road (elasticities between 0.35 and 2.95) infrastructure positively impacts on labour productivity. The results for total factor productivity are broadly consistent with an elasticity of 0.04 for electricity, 0.04 for air and ports, 0.07 for telecommunications and elasticities between 0.03 and 0.18 for railways.

While there are some negative and some insignificant infrastructure measures, the picture is overwhelmingly one of a positive relationship between productivity and infrastructure, which in turn suggests a positive relationship between infrastructure and growth. These results, however, are heavily dependent on statistical techniques that control for the possibility of a bicausal relationship between infrastructure and productivity. In the absence of these controls, a substantial number of these measures have insignificant or negative relationships to either or both productivity measures. This again highlights the potential for inappropriate statistical techniques to produce wholly inaccurate conclusions.

5.4 Infrastructure and export performance

As noted in section 2, there are strong theoretical reasons to believe that improvements in infrastructure positively impact trade. Edwards and Johnny (2006) test this hypothesis and find that:

- firm-level data reveals greater dissatisfaction with transport and communications infrastructure amongst exporting than non-exporting firms, suggesting that infrastructure is limiting firms' ability to export;
- regression analysis of export performance suggests that total public sector infrastructure stock (in particular, rail carrying capacity, paved roads and power generation capacity) positively impact export performance; and
- *PSS ARDL* analysis suggests that infrastructure stock drives export performance, rather than *vice versa*.

There is a broad, though not universal, consensus that the relationship between export performance and economic growth is broadly positive (see, for example, Rodrik, 1997). While most studies find a strong positive relationship between the two variables, the causal process underlying this relationship is not entirely clear. However, there is significant evidence to support the view that export performance exerts a positive impact on growth. If this is indeed the case, then the results above suggest a further indirect impact of infrastructure on growth.

5.5 Infrastructure and skills development

Employment generation and skills development may also be key considerations of public sector infrastructure policies - such policies are often justified in the language of job creation and skills development, instead of or in addition to the language of economic growth. In terms of the theoretical model developed in section 2 skills acquisition constitutes an increase in the stock of human capital, so such acquisition may in fact positively impact on economic growth.

Yet the available empirical evidence in South Africa does not provide significant support for this hypothesis. McCord (2003) finds that the performance of public sector infrastructure projects with respect to skills transfer (and employment generation) has not met the expectations of policy-makers, due to the short period of employment and the low-skilled nature of the available work. This suggests a limited or negligible scope for infrastructure to positively impact on economic growth through this channel.

5.6 Infrastructure quality and usage

Bogetic and Fedderke (2006) provide the only macroeconomic analysis of the quality and usefulness of South Africa's infrastructure, using a database of subjective indicators recently released by the World Bank (Estache and Goicoechea, 2005). The data was collected through a nationwide survey and attempted to assess infrastructure quality, affordability and accessibility. As only one wave of the survey is currently available, the only meaningful comparison is cross-sectional, with other countries. The authors compare South Africa's performance with that of upper middle income countries, sub-Saharan Africa as a whole and the entire world.

They find that:

- electricity provision scores favourably in quality[17] and affordability but poorly in accessibility (though with improvements visible in this area);
- water and sanitation provision is of a high quality where it is available but is very inaccessible in rural areas, while affordability data is unavailable;
- telephone and postal communication infrastructure is widely accessible (particularly cellphones) and is of varying quality (good for cellphones, mediocre for landlines and poor for postal services) and affordability (domestic landline pricing is expensive but international and cellphone calls are inexpensive); and
- transport infrastructure quality is high, but is reported as relatively inaccessible due to low road densities.

The finding regarding transport infrastructure is, however, disputed by the authors. Firstly, the data for paved roads may be inaccurate and, secondly, the low total road density may reflect South Africa's extensive geographical area but high industrial concentration in specific areas.

South Africa's infrastructure thus generally performs well relative to the chosen benchmark, suggesting that quality is high. However, the quality and particularly accessibility of infrastructure varies considerably between urban and rural areas. The impact on national economic growth of rural underprovision of infrastructure is not necessarily significantly negative but the implications for the quality of life of citizens in rural areas are unambiguously damaging.

[17] This data was gathered prior to the extensive power outages early in 2006.

6 Policy Implications

The available empirical evidence for South Africa thus suggests that the relationship between infrastructure and growth is broadly positive. However, this does not necessarily imply that wholescale increases in the provision of infrastructure are appropriate. There are a range of important policy issues that must be considered in addition to the broad empirical evidence reviewed in section 5. This penultimate section of the paper briefly discusses five of these issues. In all cases, however, further research is required before robust policy implications can be drawn. Discussion is thus restricted largely to an "issues to consider" form, rather than providing concrete recommendations.

6.1 Public versus private provision

The first issue requiring attention is the division of infrastructure provision between the public and private sectors. Infrastructure provision was historically seen as largely the province of the state, in part due to the economies of scale implicit in this area that were introduced in section 2 (Kessides, 2004). Since the late 1970s, however, increasing attention has been paid to the role of the private sector (Noll, 1999). In contemporary South Africa, this is an important issue, with several key parastatal infrastructure providers having been partially privatised in the past decade (such as the Airports Company of South Africa and Telkom) and several private providers having entered infrastructure markets (such as Cell-C and Neotel).

There are a wide range of complex issues implicit in any discussion of the relative merits of public, private and mixed provision of infrastructure and related services. A comprehensive discussion of these issues falls beyond the scope of this paper and would indeed constitute a separate report in its own right. A detailed exposition of this debate can be found in Kessides (2004) and Guasch (2004). In this paper, discussion is limited to highlighting a few of the most crucial issues.

Firstly, the international consensus amongst economists is increasingly moving toward the view that private sector infrastructure provision should generally be preferred to public sector, except potentially in cases where the industry in question is a "natural monopoly" (Kessides, 2004). This describes an industry in which provision is only profitable if one firm controls the entire market. Eskom is often cited as the quintessential example of a natural monopoly, as the cost of constructing and maintaining a nationwide electricity grid is so high that it may not be profitable for two firms to construct separate grids. A similar argument might potentially be advanced in the cases of the Portnet, Spoornet and the Airports Company of South Africa.

Secondly, however, there are no one-size-fits-all rules regarding the appropriate ownership structure for infrastructure provision. While the majority of evidence points to public provision as relatively inefficient and unreliable (and hence detrimental to growth), there are cases in it remains preferable to private provision (Newbery, 2001).

In particular, appropriate regulation of private providers is important. At minimum, this means that government regulators must have the organisational capacity (Stern, 2000) and political will (Estache, 2002) to enforce regulations. Attempts should be made wherever possible to ensure that privatised infrastructure provision is subject to competitive pressures, rather than simply replacing a state-owned monopoly with a privately-owned monopoly (Noll, 2000).

6.2 Funding

Whether infrastructure investment is funded by the public or private sector, the source of funds for this investment is of crucial importance, as funding decisions may have significant and sometimes detrimental macroeconomic effects. Borrowing from overseas sources requires significant interest and capital repayments in foreign currency, which may push down the value of the rand. Domestic borrowing, on the other hand, may make it more expensive for firms to borrow capital for other investment projects and thereby "crowd-out" other investments by the private sector, as noted in section 4 (and in particular in footnote 11). Frankel, *et al*, (2006) express concern that the magnitude of the infrastructure investment proposed by the ASGI-SA strategy may have damaging macroeconomic effects. Ultimately, policy-makers must carefully consider the available funding schemes and attempt to choose that which has the least disruptive effect on the economy as a whole.

This consideration is particularly important in view of the findings of Bogetic and Fedderke (2006b), who forecast the value of investment required to meet particular infrastructure development targets. By modeling the relationship between infrastructure investment and GDP growth across a panel of 52 countries between 1980 and 2002 they are able to predict the value of infrastructure investment needed to maintain 3.6% and 6% GDP growth per annum between 2006 and 2010. They find that the 3.6% growth target requires an investment of approximately 0.2% of GDP in electricity infrastructure and 0.7% of GDP in telecommunication infrastructure. The 6% growth target requires a doubling of these values and a significant increase in budgeted infrastructure expenditure. Their findings may in fact understate the extent of infrastructure investment needed, given that they cannot examine the quality of existing infrastructure and that this appears to be a particularly pressing problem in the electricity sector. This points to the importance of carefully selecting the most appropriate form of generating the available funding.

6.3 Location

It is immediately apparent to even a casual observer that the location of new infrastructure projects is a crucial determinant of their growth impact. Fedderke and Wollnik (2007), for example, find that transport costs are a crucial determinant of industry location decisions in South Africa, with higher transport costs resulting in greater geographical concentration. This was one of the many considerations ignored by the apartheid-era designers of the "border industry" strategy, where political considerations won out over economic sensibility. While it is clear that location is an important consideration in infrastructure investment decisions, there is relatively little available empirical evidence regarding the criteria upon which locational decisions should be made - pointing to the need for further research in this area. At minimum, policy-makers need to be aware that infrastructure location is an important determinant of growth in and of itself and plan accordingly.

6.4 Type

The studies reviewed in section 5 provide clear evidence that not all infrastructure types are equal when it comes to growth effects. The most consistent finding across all the available papers is that road infrastructure exerts a far more robust impact on growth than other forms of physical infrastructure (Perkins, *et al*, 2005; Fedderke, *et al*, 2006; Fedderke and Bogetic, 2006). Furthermore, the only paper considering both economic and social infrastructure finds that educational infrastructure appears to exert a greater impact on growth than road infrastructure (Kularatne, 2006).

These studies thus provide some guidance to policy-makers regarding the relative importance of different types of infrastructure. Furthermore, Perkins *et al*, (2005) note that sequencing may be of crucial importance - particular types of infrastructure may be particularly important at particular times. More generally, interaction effects between different types of infrastructure may be of relevance. Integrating a rural area into a national transport grid while leaving it without electricity or telecommunications infrastructure, for example, may yield very poor growth returns. The issue of interaction is one requiring further investigation in the South African context.

6.5 Maintenance versus expansion

As noted in sections 3 and 4, it is exceptionally difficult for economists or policy-makers to compare the growth effect of investment in new infrastructure on the one hand and maintenance of existing infrastructure on the other. This challenge arises because there have been no successful attempts worldwide to develop a technique to measure the quality of infrastructure on a large scale (Kessides, 2007). Further research in this area is thus urgently required, perhaps building off more general work already conducted into measuring the "quality depreciation" of physical capital (Hulten, 1990; Hulten and Wykoff, 1981). This could potentially be applied equally to both social and economic infrastructure.

7 Conclusion

Both theoretical and empirical evidence thus point to the existence of a robust positive relationship between infrastructure and economic growth. In particular, it appears that:

- aggregate infrastructure stock and investment drive economic output;
- the driving relationship between economic output and infrastructure varies significantly across different types of physical infrastructure; and
- infrastructure impacts on output both directly and indirectly, via increased private sector investment, improved productivity and rising exports.

However, this does not amount to a general argument in favour of infrastructure investment by either government or the private sector. As Perkins, *et al* (2005), emphasize, different types of infrastructure may be particularly beneficial for growth at different times and under different circumstances. It is thus important that the proposed infrastructure spending under ASGI-SA is subject to thorough cost-benefit analysis and carefully takes into account the areas in which infrastructure is in greatest need of upgrading. Infrastructure plans must also take into careful consideration the forecasted investment levels required to sustain particular growth targets. Finally, the relationship between infrastructure maintenance and economic growth remains almost entirely unknown, both internationally and in South Africa (Kessides, 2007), and this issue requires considerable attention in order to develop a comprehensive understanding of the infrastructure-growth relationship.

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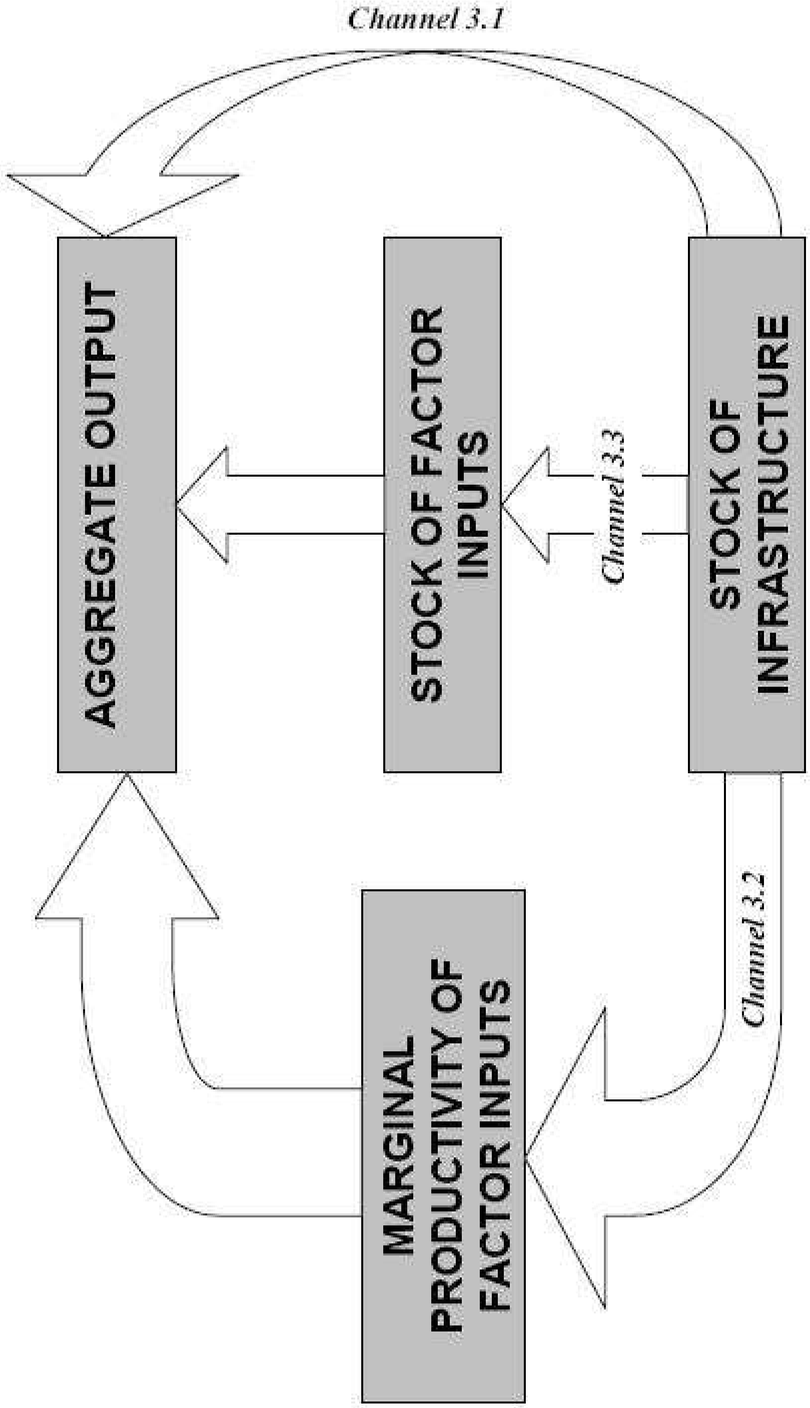

Figure 1: Graphic representation of the channels in 3.1, 3.2 and 3.3.

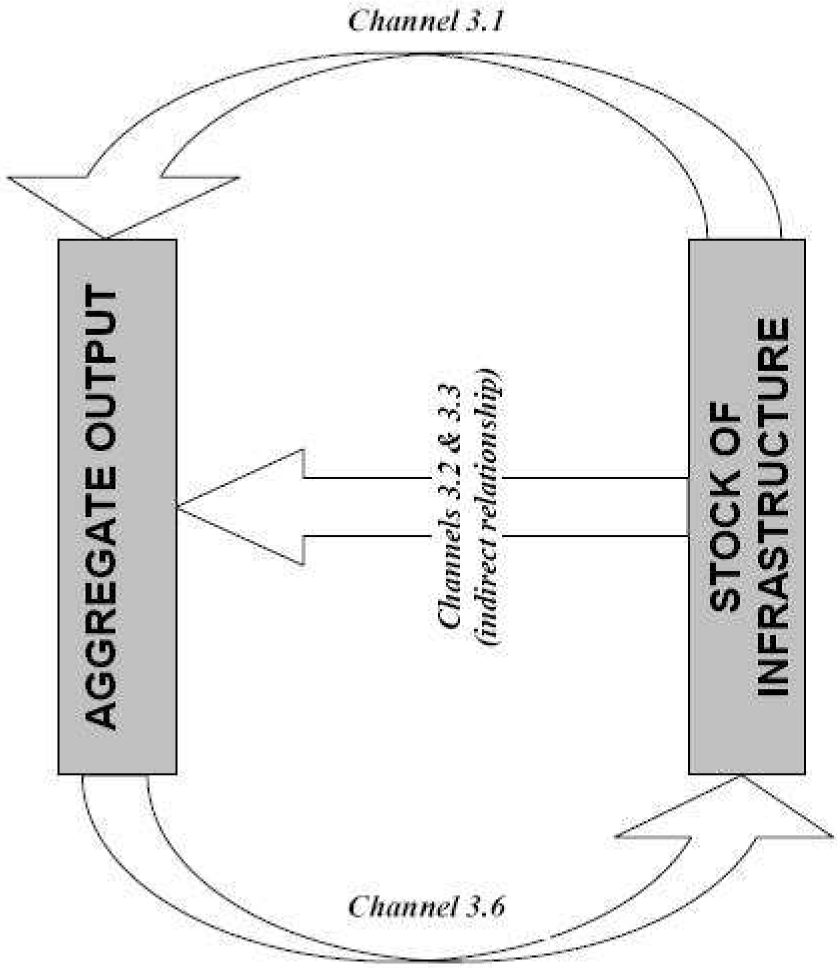

Figure 2: Graphic representation of the channels in 3.1, 3.2, 3.3 and 3.6.

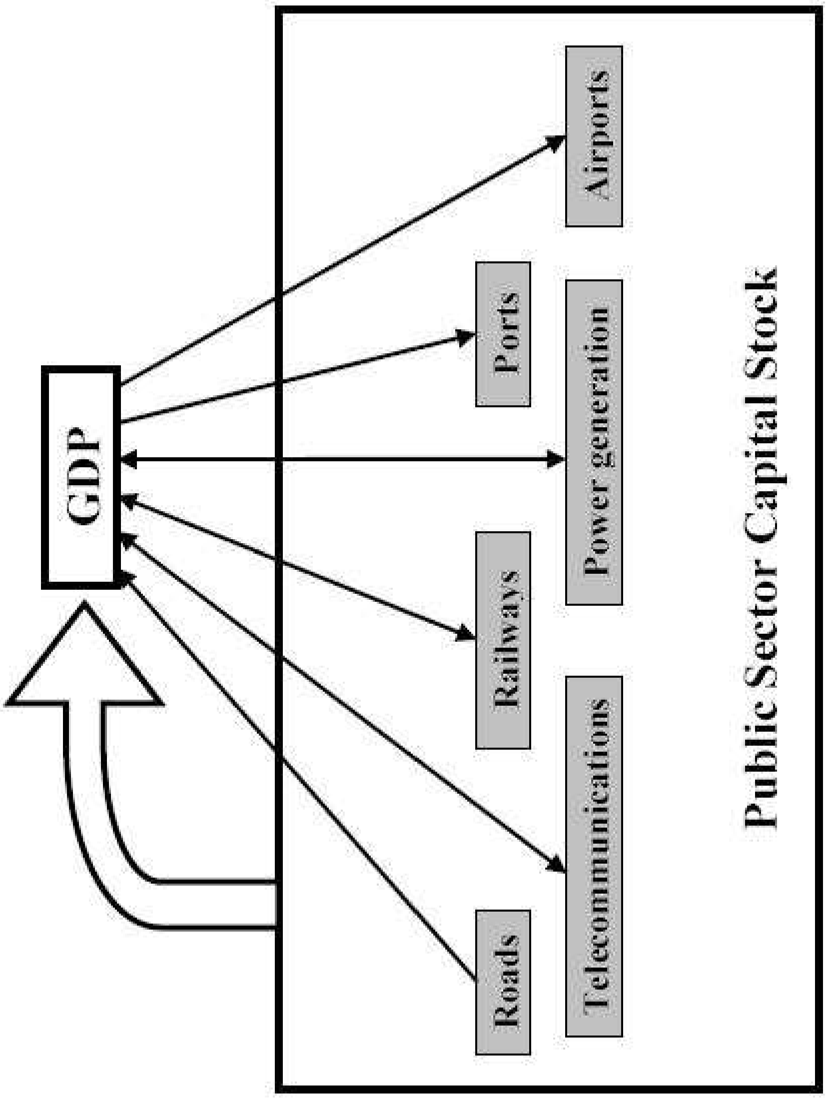

Figure 3: Graphic representation of the "forcing" relationships in Perkins, et al *(2005).*

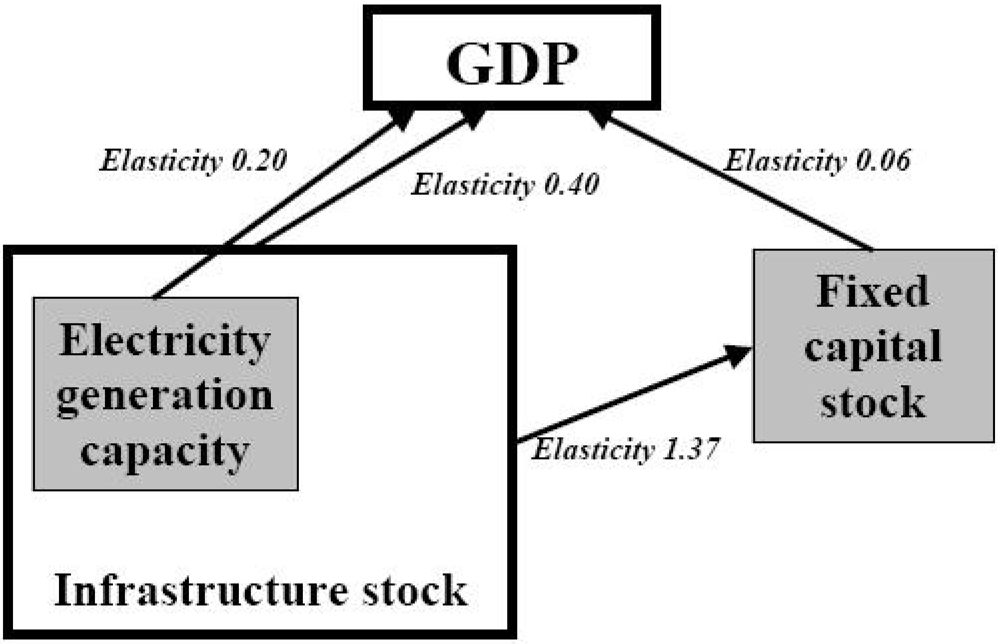

Figure 4: Graphic representation of the finding of Fedderke, et al *(2006). Note that the direct relationship between infrastructure stock and GDP is operative only when a control is introduced for property rights.*

Study	Tests for a non-linear relationship?	Allows for an indirect relationship?	Allows for crowd-out effects?	Allows for non-stationary data?	Uses disaggregated data?	Tests for causality?
Abedian & Van Seventer (1995)						
Coetzee & Le Roux (1998)						
DBSA (1998)				Y		
Fedderke, et al (2006)		Y	Y	Y	for infrastructure only	Y
Fedderke & Bogetic (2006)		Y	Y	Y	for infrastructure and output	Y
Kularatne (2006)	Y	Y	Y	Y	for infrastructure only	Y

Table 1: Direct measures of infrastructure-growth elasticities. Adapted from Fourie (2006).

Study	Infrastructure measure(s)	Growth indicator(s)	Econometric technique	Elasticity
Abedian & Van Seventer (1995)	Public authorities capital stock	GDPpc	OLS	0.33
	Public sector capital stock	GDPpc	OLS	0.17
Coetzee & Le Roux (1998)	Public sector infrastructure stock	GDPpc	OLS	0.30
DBSA (1998)	Public authorities capital stock	GDPpc	OLS	0.25
	Public authorities capital stock	GDPpc	Cointegration	0.30
	Public sector capital stock	GDPpc	OLS	0.15
	Public sector capital stock	GDPpc	Cointegration	0.28
	Public sector infrastructure stock	GDPpc	OLS	0.17
	Public sector infrastructure stock	GDPpc	Cointegration	0.25

Table 2: Empirical strategies employed in South African studies of the infrastructure-growth relationship.

Infrastructure measure	Labour productivity elasticity	Total factor productivity elasticity
Aggregate stock	0.19	≈ 0
Aggregate investment	0.20	0.04
Roads	0.34 – 2.95	-0.45 – 2.80
Railways	0.32 – 1.04	0.18
Air	0.05 – 0.25	0.04
Ports	≈ 0	0.04
Power generation	0.05	0.04
Telecommunications	0.05	0.07

Table 3: Productivity elasticities with respect to various infrastructure measures from Fedderke and Bogetić (2006a). All elasticities shown here are calculated allowing for the possibility of bicausality.