Competitio 2026. XXV. évfolyam
doi: 10.21845/comp/2026/1-2/1

Is the clamour for infrastructure investment justifiable for economic development? An investigation into an emerging economy. A case from South Africa

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A critical challenge in South Africa today is the absence of consistent economic growth and job creation, both of which are necessary to reduce poverty and increase the standard of living of its citizens. The South African government continues to commit and spend billions of rands annually on infrastructure in an attempt to address social ills. We analyse this type of investment using long term statistical methods to determine its effects on income per capita over the period 1996–2021. We applied three estimation methods to assess the various econometric approaches to investigate this relationship. These methods included Pooled OLS, OLS with Fixed Effects, the and the one step system GMM method The analysis demonstrated a long-term link between infrastructure investment and income per capita. Specifically, transport and ICT investments have a significant positive effect on earnings. On the contrary, labour has a long-term negative impact. Capital investment projects should not be developed, constructed, or implemented haphazardly. But must be coordinated with education and vocational development programs to improve labour efficiency to counter its negative impact on GDP per capita.

Keywords: panel data analysis, infrastructure, regional economic development, income inequality
JEL classifications: C33, O18, R11

1. Introduction

South Africa faces challenges in sustaining economic growth and creating jobs, crucial for reducing poverty and enhancing living standards (Lewis, 2002). Improved living standards involve better access to quality-enhancing goods and services and improved social and economic status (Bolganbayev et al., 2022). Regional development is about improving welfare via human resource and capacity development (Bolganbayev et al., 2022). South Africa, with its apartheid history and economic disparities, illustrates these issues. Economic growth has significantly slowed: GDP growth declined from over 6% in the 1960s to about 3% in the 1970s, 2% in the 1980s, with fluctuating rates in the 1990s (Lewis, 2002). During the 1990s, formal employment fell, and unemployment rose, affecting 37% of the working age population, including discouraged job seekers (Lewis, 2002). From 1990 to 1994, growth averaged 0.1% annually, increasing to 2.6% from 1995 to 1999 (Hodge, 2009). Growth averaged 4.3% from 2000 to 2007 (Hodge, 2009). The 2008–2009 financial crisis hit South Africa, causing GDP to drop to −1.5% in 2009 from 3.2% in 2008 (World Bank, 2024), which hurt investor confidence and economic recovery (Lewis, 2002). From 2010 to 2022, growth averaged 1.82% (World Bank, 2024), insufficient to resolve economic exclusion.

This research investigates the role of infrastructure investment in driving economic development within South Africa and examines its spatial distribution. Infrastructure investment has been recognized as a fundamental catalyst for economic growth as it enhances productivity, facilitates trade, and generates employment opportunities (Aschauer, 1989; Romp and de Haan, 2005; Fedderke and Garlick, 2008; Estache and Fay, 2009; Heintz et al., 2009; Calderon and Serven, 2010 and Kumo, 2012). Nevertheless, the effectiveness of infrastructure investment is contingent upon its allocation, quality, and maintenance.

Infrastructure investment in South Africa is unevenly distributed, favouring affluent regions like Gauteng and the Western Cape, while areas such as Limpopo and the Eastern Cape fall behind (Statistics South Africa, 2023). This disparity worsens socioeconomic inequalities and hinders economic growth. South Africa also faces structural issues like high unemployment, low skill levels, and poor governance. This study examines infrastructure investment's role in economic development across nine provinces, providing policy recommendations. It highlights the need for targeted investment in underdeveloped areas, better governance, and structural reforms to address systemic challenges. The South African government, under the National Development Plan (NDP), seeks to reduce income inequality from 0.70 to 0.60 and increase the infrastructure investment percentage of GDP to 20% by 2030. Severe income disparity has persisted throughout the previous century, highlighting the importance of broad economic reforms, whether by policy or legal mandates. Existing policies and frameworks are inadequate in the face of rising income disparity, necessitating a rethinking of the variables that contribute to income inequality Seabela et al. (2024). The ongoing increasing trend in income inequality underlines the difficulty of resolving its fundamental causes by policy and intervention strategies, despite the extensive adoption of social expenditure programs (Seabela et al., 2024).

The theoretical underpinning of this study is founded upon infrastructure theory. Infrastructure theory, as articulated by Samuelson (1954), Aschauer (1989) and Munnell (1992), underscores the significance of public infrastructure in augmenting productivity and fostering economic growth. Employing panel data econometric models, this research investigates the impact of infrastructure investment on GDP per capita across South Africa's provinces. The study is guided by the research questions: Is the South African government's substantial strategic commitment to infrastructure yielding benefits in terms of economic development and spatial equity? What positive and negative effects does infrastructure investment have on economic development in South Africa over the period 1996-2021? These questions are interrogated through the application of econometric modelling and analysis, commencing with panel unit root testing, progressing to a Pooled Ordinary Least Squares (OLS), OLS with Fixed Effects, and the one step system Generalised Method of Moments (GMM) method. All econometric analyses within this study were executed using STATA and EViews 12 software. The subsequent sections of the paper are structured as follows: Section 2 reviews the pertinent theoretical literature and model, while Section 3 delineates the data, econometric methodologies applied, and the analysis along with the results. Section 4 delivers the discussion and conclusions of the study.

2. Theoretical Background

Infrastructure is divided into public and private categories, distinguished by funding sources: public is government-funded, and private is funded by individuals (Eberts, 1990). This study focuses on public infrastructure, further split into economic overhead capital (EOC) and social overhead capital (SOC). EOC supports economic activity through transport, energy, and telecom networks (Eberts, 1990). Fedderke and Garlick (2008) view infrastructure investment as capital expenditure. SOC aids human capital via healthcare, education, and cultural amenities (Eberts, 1990; Fedderke and Garlick, 2008). Sahoo et al. (2010) highlight infrastructure as key to economic growth, especially in emerging nations. Public infrastructure has two traits: it underpins economic activity and generates societal benefits, or positive spillovers, that surpass any actor's payment capacity (Eberts, 1990; Fedderke and Garlick, 2008; Sahoo et al., 2010). These spillovers are mainly non-excludable, meaning one's usage doesn't diminish availability to others. Infrastructure like pollution control and communication networks offers scale economies (Eberts, 1990).

Paul A. Samuelson's (1954) work on public expenditure forms the basis for public good theory, distinguishing between private and community consumption goods. The theory argues that markets inadequately provide public goods, which benefit all, unlike private goods limited to individual use. Instead of questioning government existence, Samuelson asks, "How should the government decide?" (Samuelson, 1954:388). Infrastructure, as a non-exclusive and non-rival public good, should be supplied by the government (Fourie, 2006). Research into public infrastructure's role began in the late 1980s (Munnell, 1992; Bougheas et al., 1999; Calderón and Servé, 2010). Munnell (1992) credits David Aschauer for inspiring regression analysis to assess public capital expenditure impact on production. Aschauer found reduced public capital spending significantly contributed to U.S. productivity declines in the 1970s. Early econometric studies show public capital investment crucially affects private sector output and productivity (Munnell, 1992). Aschauer's early research indicates a 1% rise in public capital spending increases private production by 0.39% (Munnell, 1992). Some estimates face critique for exaggerated coefficients and variable endogeneity (Munnell, 1992; Aaktar et al., 2017).

Egberts (1990) argues that economic progress depends on location advantages. Firms seek locations with economic potential and sufficient infrastructure. Ascani et al. (2012) support this, stating that globalisation leads to economic growth in specific local clusters and highlights the importance of local actors. They claim globalisation started the concept of regional development.

Despite supportive evidence, several studies highlight challenges in both developed and developing economies (Erenburg, 1993; Gramlich, 1994; Flyvbjerg et al., 2003; Rioja, 2003; Kenny, 2007). Gramlich (1994) argues public infrastructure investment can lead to inefficient resource allocation if projects are prioritized for political instead of economic reasons, resulting in low returns or neglect of urgent needs. Governments may choose projects based on politics, like voter support, rather than maximizing societal benefits. Erenburg (1993) asserts this can "crowd out" private investment due to higher interest rates from government spending, limiting funds for private sector, reducing total investment, and slowing economic growth.

Rioja (2003) explains that governments underinvest in maintaining infrastructure, leading to deterioration and higher long-term costs. They often prioritize new projects over maintaining existing ones, resulting in further infrastructure decline. Kenny (2007) notes that political influence and corruption can negatively impact infrastructure projects, causing poor investment and resource misallocation. Political decisions can prioritize funding based on politics rather than economics, while corruption like bribery and kickbacks can lead to poor project choices and resource mismanagement.

Numerous studies (Romp and de Haan, 2005; Fedderke and Garlick, 2008; Estache and Fay, 2009; Heintz et al., 2009; Kumo, 2012; Marais, 2025) show a strong positive link between infrastructure investment and economic growth. Heintz et al. (2009) used ARDL to assess the U.S. production from 1951 to 2006, finding long-term ties between public capital investment and private productivity, with infrastructure boosting private investment. Romp and de Haan (2005) state that 32 of 39 OECD studies found infrastructure positively affecting output, efficiency, productivity, private investment, and employment. In developing countries, 9 of 12 studies noted a significant positive impact (Estache and Fay, 2009). Bougheas et al. (2000) showed infrastructure investment relates to growth, using OLS and IV models to classify infrastructure as a cost-reducing technology. Ferreira and Araujo (2006) found infrastructure investments in Brazilian roads, telephones, and energy from 1960 to 1996 supported long-term economic growth, with a 10% increase in public infrastructure boosting long-term productivity per capita by 2.2–3.3%.

Bose et al. (2007) found a positive correlation between government capital expenditure and income per capita growth in 30 developing countries from 1970 to 1980. Establishing this link is difficult due to varied methodologies and econometric challenges like common trends, poor data quality, reverse causation, and omitted variable bias (Estache and Fay, 2009; Gramlich, 1994). Public infrastructure boosts private sector productivity, offering direct benefits as explained by Aschauer (1989) and Barro (1990). An increase in public capital stock enhances productivity of all inputs (Dissou and Didic, 2013.7). Lower production costs increase private output. Additional mechanisms include complementarity and crowding out, with the former supporting growth through private capital formation (Dissou and Didic, 2013.7).

Agenor and Moreno-Dodson (2006.9) state that public infrastructure increases the productivity of private inputs, enhancing returns on private capital and potentially boosting private sector demand for physical capital. The concept of crowding out is noted, where rising public expenditure may initially reduce private investment, potentially causing long-term negative effects. Fourie (2006), Fedderke et al. (2006), and Richaud et al. (1999) found that public infrastructure investment offers positive externalities like increased competitiveness, trade, foreign investment, and profitability, which raise income per capita. Kumo (2012) emphasizes infrastructure's direct impact on manufacturing, reducing costs and aiding human capital development, thereby raising demand through spending on construction and operations. It can direct industrial strategy by influencing private sector investment through targeted projects (Fedderke and Garlick, 2008; Kumo, 2012).

In studies on infrastructure investment and economic development, GMM estimations in first difference and system forms address variable endogeneity (Zhou et al., 2021). The GMM System Estimator uses both difference and level equations: lagged level variables as instruments in the difference equation, and first differences as instruments in the level equation. These equations are jointly estimated with GMM. Monte Carlo simulations by Blundell and Bond (1998) find the system estimator most effective. Overidentification is tested with the Hansen test and Arellano and Bond's second-order correlation test, confirming instrument validity and no second-order correlation. White's method corrects coefficient standard deviations to handle heteroskedasticity.

2.1. Theoretical model

The primary objective of this research is to augment the extant body of knowledge by employing econometric methods to analyse South Africa's economic development. This research is executed in two phases. The first phase scrutinizes the economic performance across South Africa's nine provinces, assessing the impacts of infrastructure investment, whether beneficial or detrimental, over the period from 1996 to 2021, and determines the spatial distribution of economic development. Data for this phase was sourced from the South African Reserve Bank database, encompassing seven variables for each province, including the national average, and was transformed into panel data. To mitigate potential data distortions, the Covid-19 pandemic is considered an exogenous shock and has been excluded, as it led to a global cessation of economic activities from March 2020 for approximately two years. The relationship is tested using the series level values the logical framework is shown Equation 1 for the provincial analysis.

$$LnGDP = \beta_0 + \beta_1 LnGDP_{t-2} + \beta_2 LnEMP_{t-2} + \beta_3 LnGFCF_{t-2} + \beta_4 LnCON_{t-2} + \beta_5 LnICT_{t-2} + \beta_6 LnTRA_{t-2} + \beta_7 LnElec_{t-2} + u_t \quad (1)$$

Examination into the relationship between the dependent variable real GDP per capita and the independent variables employment, domestic investment, ICT investment, construction investment, electricity investment and transport investment are commonly performed through long and short run analysis. We applied three estimation methods to assess the various econometric approaches to investigate this relationship. These methods included Pooled OLS, OLS with Fixed Effects, the and the one step system GMM method (Blundell and Bond, 1995). Our analysis mainly relies on the latter, as it has been widely used in recent studies on the topic (Santo, 2015; Kitonyo and Kathanje, 2018; Zhou et al., 2021; Asanta et al., 2022 and Dao and Le, 2024). Initially, the estimations were conducted using the Least Squares method, adept at handling country-specific heterogeneity. Furthermore, it undertakes the examination of the hypotheses.

H_1. *Infrastructure investment has a long-term, significant positive effect on aggregate output, i.e. real GDP per capita.*
H_2. *A significant relationship exists between infrastructure investment and real GDP per capita.*
H_3. *Income disparity in South Africa has increased.*

Static panel models use methods like Pooled OLS, fixed effects (FE), and random effects (RE). The RE estimator was excluded after the Hausman test favored FE. Thus, coefficients are estimated with FE. Dynamic models incorporate lagged dependent variables, reflecting past behaviors' influence on current values, like GDP persistence, showing endogeneity and dynamics missed by static models. The diversity of South Africa's 9 provinces requires considering specific effects over the 25-year study (1996–2021). The System GMM, a common growth literature method, addresses issues like serial correlation, heteroskedasticity, and endogeneity (Leitao, 2010), as tackled by Arellano and Bond (1991) and Blundell and Bond (1998, 2000). The dynamic model uses Blundell and Bond's methodology (1998, 2000). For infrastructure investment and economic development analysis, RGDP is the dependent variable, with investment subcategories: construction, transport, ICT, and electricity. The study employs one-step System GMM estimators as introduced by Holtz-Eakin et al. (1990), Arellano and Bond (1991), and Arellano and Bover (1995).

$$Y_{it} - Y_{it-1} = (\propto - 1)Y_{it-1} + \beta_0 X_{it} + \mu_i + \varepsilon_{i,t} \tag{2}$$

Where is the logarithm of the real GDP per capita, is the rate of income per capita growth, is the initial level of income per capita, represents a vector of explanatory variables, is an unobserved country-specific effect, is the error term and the subscripts and represent country and time period respectively. Rewriting (2), we obtain:

$$Y_{it} = \alpha Y_{it-1} + \beta_0 X_{it} + \mu_i + \varepsilon_{i,t} \tag{3}$$

To eliminate the province specific effects, we take the first differences of (3):

$$Y_{it} - Y_{it-1} = a(Y_{it-1} - Y_{it-2}) + \beta_0 (X_{it} - X_{it-1}) + \varepsilon_{it} - \varepsilon_{it-1} \tag{4}$$

Levine et al. (2000) advocate for the utilization of instruments for two principal reasons: firstly, to address the probable endogeneity between infrastructure investment variables and economic growth; and secondly, due to the correlation of the newly formulated error term $(\varepsilon_{it} - \varepsilon_{it-1})$ in equation 12 with the lagged dependent variable $(Y_{it-1} - Y_{it-2})$. The GMM panel estimator employs the subsequent moment conditions.

$$E[Y_{it} - s(\varepsilon_{it} - \varepsilon_{it-1})] = 0 \text{ for } s \geq 2; t = 3,\ldots,T$$

$$E[X_{it} - s(\varepsilon_{it} - \varepsilon_{it-1})] = 0 \text{ for } s \geq 2; t = 3,\ldots,T$$

Assuming the error term, , lacks serial correlation and the explanatory variables, *X*, exhibit weak exogeneity, the authors designate this as the difference estimator. Notwithstanding, there exist statistical limitations associated with this estimator. Alonso-Borrego and Arellano (1996) and Blundell and Bond (1998) indicate that, in instances where the explanatory variables exhibit persistence over time, the lagged levels of these variables serve as weak instruments for the regression equation formulated in differences. To mitigate the potential biases attributed to the difference estimator, the authors employ an innovative estimator that integrates within a systematic framework the regression in differences with the regression in levels. The authors adopt a GMM estimator which utilizes lagged differences of Y_{it} as instruments for the equation in levels, alongside lagged levels of Y_{it} serving as instruments for equations in first differences. Blundell and Bond (1998) propose that Monte Carlo simulations and calculations of asymptotic variance demonstrate that this expanded system GMM estimator provides efficiency improvements in contexts where the first-difference GMM estimator is inadequately performing. The aforementioned instruments are deemed suitable under the assumption that, while there may exist a correlation between the levels of the right-hand side variables and the country-specific effect in the level equation, there is no correlation between the differences of these variables and the province-specific effect. The additional moment conditions pertinent to the second component of the system, which is the regression in levels, are:

$$E\left[(Y_{it-s} - Y_{it-s-1})\left(\mu_{it} - \varepsilon_{i,t}\right)\right] = 0 \text{ for } s = 1$$

$$E\left[(X_{it-s} - X_{it-s-1})\left(\mu_{it} - \varepsilon_{i,t}\right)\right] = 0 \text{ for } s = 1$$

Considering that the lagged levels serve as instruments within the difference's specification, solely the most recent difference is utilized as an instrument within the level's specification. Employing additional lagged differences would lead to superfluous moment conditions [see Arellano and Bover (1995)]. The authors apply the aforementioned moment conditions and implement a System GMM procedure to produce parameter estimates that are both consistent and efficient.

3. Methodology

3.1. Research Goal

The research aimed to examine the beneficial and detrimental effects of infrastructure investment on economic development in South Africa from 1996 to 2021. It is anticipated that the allocation of domestic capital towards infrastructure will enhance the country's per capita income.

3.2. Data

In this empirical study the panel dataset comprises of a sample of South Africa's 9 provinces is regarded as one population in Table 1. The macroeconomic variables for this investigation are summarised in Table 2 below. The choice of these variables was guided by the literature as mentioned in section 2. The extracted data from the South African Reserve Bank database was manually converted into a balanced panel dataset which resulted in a sample of 234 observations for the period 1996–2021 as seen in the descriptive statistics in Table 3. The investigation period for this analysis was originally planned to commence from 1980 to coincide with the convergence analysis but was amended to 1996 due to a lack of data. South Africa's 9 provincial boundaries were legally designated when the country became a democratic republic in 1994. Prior to this the country had four provinces namely, the Cape of Good Hope, Orange Free State, Transvaal and Natal (Mabin et al., 2024).

Table 1. 9 Provinces in South Africa

Code	Province	Provincial Capital City
EC	Eastern Cape	Bhisho
FS	Free State	Bloemfontein (national constitutional capital)
GAU	Gauteng	Pretoria (national administrative capital)
		Johannesburg (national economic centre)
KZN	Kwa-Zulu Natal	Pietermaritzburg
LP	Limpopo	Polokwane
MP	Mpumalanga	Mbombela
NC	Northern Cape	Kimberly
NW	North-West	Mahikeng
WC	Western Cape	Cape Town (national legislative capital)

Source: Author's construction (2024).

Table 2. Study variables

Macroeconomic variable	EViews reference	Measurement	Source
real GDP per capita	Real GDP	Millions in ZAR	South African Reserve Bank
Employment	Emp	Millions of persons	South African Reserve Bank
Domestic investment	GFCF	Millions in ZAR	South African Reserve Bank
Construction investment	Cons	Millions in ZAR	South African Reserve Bank
Transport investment	Transp	Millions in ZAR	South African Reserve Bank
ICT investment	ICT	Millions in ZAR	South African Reserve Bank
Electricity investment	ELEC	Millions in ZAR	South African Reserve Bank

Source: Author's construction (2024).

The dependent variable GDP per capita is defined as an important economic metric that measures the average economic production per capita in a certain geographic location. It is computed by dividing the total GDP by the population (Samuelson and Nordhaus, 2009; Mankiw, 2020). This metric provide insight into the country's economic performance and is oftentimes used to assess the standard of living and economic welfare of its citizens. Real GDP per capita is the total production value adjusted for inflation, and it is applied in this analysis. GDP per capita purchasing power parity (PPP) is an inappropriate measure to consider using as this is an investigation of 9 provinces within the borders of a single country. The PPP measure is more appropriately applied when comparatively analysing a cross section of countries as in the case of the second part of this study.

Six independent variables were investigated; employment or the number of people employed is defined as "working for at least one hour per week for some payment, either for a wage or profit, or commission, or without pay in a family business" (Junankar, 2004:42). This salary or compensation is the individual's remuneration for services done, with the total indicated as a proportion of GDP (Rogerson and Rogerson, 2010; Dissou and Didic, 2013; Zeng, 2015; Kanó and Lengyel, 2021; Bolganbayev et al., 2022).

The OECD (2022) defines domestic investment, or gross fixed capital formation, in real terms as the acquisition of newly produced, purchased, and second-hand assets, including the production of such assets by producers (industries, producers of government services, and producers of private non-profit services to households) for their own use, minus assets that have been sold or written off. These assets are inputs into the manufacturing process of other commodities and services with an economic life of more than a year.

Construction investment refers to the allotment of monetary resources particularly aimed at the development, upgrading or maintenance of physical structures. This investment includes a wide range of activities, including residential, non-residential and infrastructure construction (Richaud et al., 1999; Bougheas et al., 2000; Romp and de Haan, 2005; Fedderke et al., 2006; Ferreira and Araujo, 2006; Fourie, 2006; Banister, 2008; Fedderke and Garlick, 2008; Glaeser and Gyourko, 2008; Estache and Fay, 2009; Heintz et al., 2009; Sahoo et al., 2010; Kumo, 2012; Zeng, 2015; Litman, 2017; Ouattara and Zhang, 2019).

Transport investment is defined as the allocation of monetary resources to develop, advance and maintain transportation infrastructure and services. These investments are crucial to promote the movement of people and goods and include various means of transportation such as road, rail, air and sea transport (Richaud et al., 1999; Bougheas et al., 2000; Romp and de Haan, 2005; Fedderke et al., 2006; Ferreira and Araujo, 2006; Fourie, 2006; Banister, 2008; Fedderke and Garlick, 2008; Estache and Fay, 2009; Heintz et al., 2009; Sahoo et al., 2010; Kumo, 2012; Zeng, 2015; Litman, 2017; Ouattara and Zhang, 2019).

Information and communication technology (ICT) investments are monetary resources allocated to the procurement, advancement and maintenance of technologies that promote communications and information management. This investment includes a broad scope of technologies, including hardware, software, telecommunications and related services (Brynjolfsson and Hitt, 1998; Bougheas et al., 2000; Ferreira and Araujo, 2006; Sahoo et al., 2010; Szirmai, 2012; Lavopa and Szirmai, 2014; Zeng, 2015; Rodrik, 2016; Lambregts et al., 2017; Ouattara and Zhang, 2019; Mitra and Raghunathan, 2020; Szanyi, 2021).

Lastly, investment in energy generation infrastructure, hereafter referred to as electricity investment, is defined as the allocation of financial capital into initiatives, enterprises, and technologies involved in the production, distribution, and utilization of energy. It includes conventional energy sources, such as fossil fuels, as well as renewable energy sources, encompassing solar, wind, and hydropower (Sustainability Directory, 2025).

Table 8 summarises the descriptive information of the 9 provinces from 1996 to 2021. The table outlines the descriptive data for central tendency and variability. The mean values represent the average value of the variables in the overall model. The standard deviation represents the dispersion of data around the mean value. It also indicates the data's proximity to the average value throughout the specified period. The range of data can be assessed by the highest and minimum values in each model. The range indicates the amount of variance in variables. Variables with broader range values exhibit more variance and vice versa. This study conducts all panel data econometric analysis using STATA and EViews 12 software.

Table 3. Descriptive Statistics for SA's 9 Provinces

Variable	N	Mean	Median	Maximum	Minimum	Std. Dev
real GDP per capita	234	4.8185	4.8061	5.1026	4.5355	0.1347
Employment	234	6.0445	6.0062	6.7111	5.3478	0.3275
Total investment	234	4.5417	4.6173	5.4287	3.4665	0.4255
Construction investment	234	2.7285	2.7428	3.8296	1.3821	0.5369
Transport investment	234	3.6347	3.6433	4.5211	2.6097	0.4354
ICT investment	234	3.3278	3.3369	4.3003	2.2529	0.4057
Electricity investment	234	3.3987	3.4325	4.5015	2.2053	0.5622

Source: Author's construction from EViews 12 output (2025).

3.3. Analysis and Results

This section provides the outcomes of both static and dynamic Ordinary Least Squares (OLS), and Generalized Method of Moments (GMM) regressions based on empirical assessments of the link between infrastructure investment and economic growth. The optimal lag selection was cross checked by applying the Vector Autoregression model which determine it to be VAR(2) and supports the GMM procedure as summarised in Table A1 in the Appendix. The preliminary stage in the estimation process of this dissertation entails evaluating the presence of cross-sectional dependence (CD) among the analytical units (provinces). As illustrated in Table 4, all of the variables display cross-sectional dependence, thus the null hypothesis of panel homogeneity is not accepted.

In light of the observed cross-sectional dependence among all of the selected variables, the ensuing step entails the verification of stationarity or the order of integration by employing second-generation unit root tests, which adeptly manage cross-sectional dependence within the models being estimated. This investigation employed two panel unit root tests, those developed by Levin et al. (2002), known as LLC, and Im et al. (2003), referred to as the IPS test. These stationarity assessments prove highly effective in short panels characterized by a limited temporal dimension (T). The justification for selecting panel unit root tests (IPS and LLC) over first-generation unit root tests (ADF and PP) resides in their enhanced robustness, which is especially beneficial for short panels, as is the case in this study. The results from the stationarity tests align with the null hypothesis, indicating the presence of a unit root within the variables. According to the results presented in Table 10, the null hypothesis is rejected for construction, transport,

Table 4. Cross sectional Dependence Results

Test	real GDP per capita	Cons	Elect	Trans	ICT	GFCF	Emp
Breusch-Pagan LM	80.212 (0.000)	927.042 (0.000)	930.332 (0.000)	929.442 (0.000)	924.547 (0.000)	930.617 (0.000)	790.265 (0.000)
Pesaran scaled LM	90.299 (0.000)	105.010 (0.000)	105.398 (0.000)	105.293 (0.000)	104.716 (0.000)	105.431 (0.000)	88.891 (0.000)
Bias-corrected scaled LM	90.1190 (0.000)	104.830 (0.000)	105.218 (0.000)	105.113 (0.000)	104.536 (0.000)	105.251 (0.000)	88.711 (0.000)
Pesaran CD	28.239 (0.000)	30.447 (0.000)	30.501 (0.000)	30.486 (0.000)	30.406 (0.000)	30.505 (0.000)	28.019 (0.000)

Source: Author’s construction from EViews 12 output (2025).

ICT investment and employment at the level form, denoted as I(0) under all tests. The exception of the variables concerning real GDP per capita, GFCF and electricity investment. For these exceptions, the null hypothesis is only rejected at the first difference, indicated as I(1), suggesting the lack of non-stationary characteristics.

3.3.1. Dynamic Pooled OLS and Fixed Effect OLS Estimation

Employing the logarithm of real GDP as the dependent variable, the results derived from the static panel estimation, pooled OLS and the fixed effects estimator in Table A2 in the Appendix exhibit positive and highly statistically significant outcomes. The coefficient relating to the infrastructure investment variables remains consistent, exhibiting no systematic alterations upon the inclusion of control variables within the model as reported in Table A2. These coefficients persist as positive and highly statistically significant, substantiating a long-term positive correlation between infrastructure investment and economic growth as postulated by the majority of theoretical models. The outcomes are congruent with previous scholarship, which identifies a significant positive relationship between infrastructure investment and economic growth (Romp and de Haan, 2005; Fedderke and Garlick, 2008; Estache and Fay, 2009; Heintz et al., 2009; Kumo, 2012; Zhou et al., 2021). However, this does not consider any time effects in the dataset. Therefore, dynamic panel estimation was applied which accounts for time and provincial fixed effects. Table 6 presents the results and diagnostics

Table 5. Panel Stationarity Unit Root Test Results

Variable	Method	t-statistics	p-value	Order of integration	Cross sections
Real GDP	LLC	-2.512	0.00	I(1)	9
	IPS	-2.996	0.00	I(1)	9
Emp	LLC	-6.385	0.00	I(0)	9
	IPS	-4.668	0.00	I(0)	9
GFCF	LLC	-5.466	0.00	I(1)	9
	IPS	-3.569	0.00	I(1)	9
Cons	LLC	-9.043	0.00	I(0)	9
	IPS	-4.806	0.00	I(0)	9
Trans	LLC	-5,377	0.00	I(0)	9
	IPS	-2,232	0.00	I(0)	9
ICT	LLC	-5.565	0.00	I(0)	9
	IPS	-2.322	0.00	I(0)	9
Elect	LLC	-2.385	0.00	I(1)	9
	IPS	-3.092	0.00	I(1)	9

Source: Author's construction from EViews 12 output (2025).

of the dynamic Pooled OLS and Fixed Effect OLS analyses. The model's fitting adequacy is demonstrated by the F-statistic values of 2696.73 (0.000) for the Pooled OLS and 14646.44 (0.000) for the Fixed Effects OLS, along with their respective probability values, which meet the model stability requirements, thus affirming the results' credibility. The lagged GDP (L.lnrGDPpc) illustrates persistence, with a coefficient of 0.979 (0.000) in the Pooled OLS and 0.929 (0.017) in the Fixed Effect OLS, denotive of significant persistence where GDP shocks display near-perfect continuation. This finding substantiates the path dependence in the regional GDP of South Africa. The subsequent findings from the Pooled OLS analysis indicate that the independent variables exhibit a negligible impact on real GDP per capita. These assessments are unable to comprehensively account for the lagged effects these variables may impose on the dependent variable. A similar pattern is observed in the Fixed Effect OLS analyses. The utilized tests are insufficient for a comprehensive examination of the relationship between these variables.

Table 6. Dynamic Panel Estimation

Dependent variable: lnrGDPpc

Variable	Pooled OLS	FE OLS
L.lnrGDPpc	0.979 (0.000)	0.929 (0.017)
LnCon	0.003 (0.577)	0.026 (0.023)
LnElect_con	0.002 (0.651)	0.006 (0.017)
LnTrans	0.002 (0.691)	-0.019 (0.026)
LnICT	0.022 (0.147)	0.022 (0.147)
LnEmp	-0.148 (0.355)	-0.031 (0.022)
LnGFCF	-0.147 (0.201)	0.006 (0.020)
F-statistic	9696.73 (0.000)	14646.44 (0.000)
Constant	0.171 (0.043)	0.000 (0.000)
R-squared	0.998	0.998
Observations	225	225
Cross sections	9	9
Lag	2	2
Year FE	YES	YES
Province FE	YES	YES

Source: Author's construction (2025).

3.3.2. Dynamic Panel Estimation

Table 7 delineates the outcomes and diagnostics of the one-step system GMM analysis. The adequacy of the model fit is evidenced by the F-statistic, 2.77e+07 (0.000), along with its associated probability value, fulfilling the model stability prerequisites, thereby deeming the results credible. It is imperative to underscore that the system GMM modelling procedure adjusts the variable nomenclature and elucidates the lag effect of each independent variable (instruments) on the dependent variable, namely real GDP per capita. The lagged GDP (L.lnrGDPpc) encapsulates persistence, with a coefficient of 0.998 (0.000) indicating pronounced persistence where shocks to GDP exhibit near-perfect continuation. This finding corroborates the path dependency in the regional GDP of South Africa. An augmentation in investment in the built environment (L1_LnCon) by 1% precipitates a 0.088% (0.001) increase in GDP, demonstrating the catalytic role of physical infrastructure investment in fostering growth. A 1% escalation in electricity investment (LnElect_con) engenders a 0.054% (0.000) increase in GDP, underscoring that energy access and supply constitute a growth multiplier, rendering them indispensable for economic advancement. A 1% enhancement in transport infrastructure investment (L1_LnTrans) induces a 0.040% (0.036) increase in GDP, reflecting gains achieved through augmented efficiency in logistical networks and the facilitation of goods movement within the nation. The statistically insignificant impact of a 1% increase in ICT investment, 0.006 (0.218), indicates that investment in digital infrastructure should not be implemented in isolation but instead in conjunction with complementary elements such as research and development activities. A 1% rise in employment level (L1_LnEMP) results in a 0.054% (0.021) increase in GDP, suggesting an economy driven by labour expansion in South Africa. An unanticipated result pertains to the impact of total domestic investment on the national GDP, wherein a 1% increase in gross fixed capital formation (L1_LnGFCF) results in a -0.266% decrease in GDP. This phenomenon may be attributed to the crowding out effect of private capital by public investment or potentially to capital depreciation, illustrating the phenomenon of reverse causality.

A general guideline suggests that the number of instruments should be lower than the number of groups. However, in the present findings, the number of instruments (27) surpasses the group count (9). The Hansen test p-value (1.000) confirms the exogeneity assumption, while the AR(2) tests p-value (0.285) assures the absence of autocorrelation. These results demonstrate robustness against alternative specifications. The robust Hansen test 0.28 (1.000) does not reject the null hypothesis regarding the validity of the instruments. The elevated p-value (1.000) is a consequence of the proliferation of instruments, which can render the Hansen test less potent and result in a p-value of 1. Nevertheless, in this instance, the issue is not problematic as the test fails to reject the null hypothesis.

When examining the Difference-in-Hansen tests, the following observations are made: For the GMM instruments applied to levels, the Hansen test excluding a group result in a chi-square statistic (chi2) of 18 with a value of 0.28, and the difference is chi2(1)=0.00 with a p-value of 1.000. This indicates an inability to reject the hypothesis that the level instruments are exogenous. For the GMM applied to gmm(L.lnrGDPpc, collapse lag(2 2)), the Hansen test excluding a group yields chi2(17)=1.08, with a difference reported as chi2(2)=-0.80. The negative value is attributed to an artifact of the generalized inverse; nonetheless, the reported p-value remains 1.000, indicating the validity of the subset of instruments for the lagged dependent variable.

Upon examination of the Arellano-Bond tests for autocorrelation it demonstrates that AR(1), the test yields z = -2.52 and Pr > z = 0.012, indicating significance.

Table 7. Dynamic Panel Estimation Results and Diagnostics, One-Step System GMM

Dependent variable: lnrGDPpc

Variable	Coefficient	p-value
L.lnrGDPpc	0.998	0.000
L1_LnEmp	0.112	0.021
LnElect_con	0.054	0.000
L1_LnICT	0.006	0.218
L1_LnCon	0.088	0.001
L1_LnTrans	0.040	0.036
L1_LnGFCF	-0.266	0.000
F-statistic	2.77e+07	0.000
Constant	0.141	0.772
Hansen test	0.28	(1.000)
AR(1)	-2.52	(0.012)
AR(2)	-1.07	(0.285)
AR(3)	-0.93	(0.350)
Observations	225	
Instruments	27	
Cross sections	9	
Lag	2	
Year FE	YES	
Province FE	YES	

Source: Author's construction (2025).

This result aligns with expectations for first differences, given that errors in levels are likely to exhibit serial independence, thus their differences should manifest correlation at the first order. Now turning to AR(2), z = -1.07 and Pr > z = 0.285, indicating non-significance. This is pivotal, as it denotes the absence of second-order serial correlation in the first-differenced errors, thereby affirming the validity of the instruments. In AR(3), z = -0.93 and Pr > z = 0.350, again indicating non-significance, thus confirming the absence of higher-order autocorrelation.

As indicated in Table 7, there is an absence of significant second-order autocorrelation, except for the GMM-System in the estimated model lacking control variables. Overall, our test statistics suggest a properly specified model. This finding aligns with Zhou et al. (2021), who investigated the relationship between infrastructure investment and economic growth across 29 Chinese provinces using the dynamic panel method. The authors concluded that a statistically significant relationship exists between infrastructure investment and economic growth.

4. Discussion and Conclusions

The study investigated South Africa's nine provinces, focusing on economic performance, infrastructure investment, and economic development distribution. It employed Pooled OLS, OLS with Fixed Effects, and the one-step system GMM to assess infrastructure investment's impact on economic development from 1996 to 2021. From 2011 to 2022, South Africa's population grew by 51.7%, with Gauteng, KwaZulu-Natal, and the Western Cape being the most populated. Internal migration is prevalent in Gauteng and the Western Cape, while out-migration occurs in Limpopo, Eastern Cape, and Free State. Gauteng contributes 33% to national GDP, KwaZulu-Natal 16.2%, and Western Cape 14%. Although the Northern Cape is the largest in area, it contributes only 2.3% to GDP. Eastern Cape and Limpopo face high unemployment and rely on remittances. Economic structures vary by natural resources and industry, with Gauteng as a finance and manufacturing centre, and Free State and Limpopo depending on mining and agriculture.

H_1: Infrastructure investment has a long term significant positive effect on aggregate output i.e. real GDP per capita.

The hypothesis posits infrastructure investment positively impacts real GDP per capita over the long term. The findings partly support this: a 1% increase in construction investment boosts GDP by 0.088% (p=0.001), electricity by 0.054% (p=0.000), and transport by 0.040% (p=0.036), all significant. However, ICT investment results in only a 0.006% GDP increase (p=0.218), which is not significant. The positive results in construction, electricity, and transport align well with Infrastructure Theory (Aschauer, 1989; Munnell, 1992) and support the theory that infrastructure enhances productivity and reduces costs (Liu and Liu, 2011; Asturias et al., 2019). These outcomes also agree with studies from various countries (Romp and de Haan, 2005; Ferreira and Araujo, 2006; Fedderke and Garlick, 2008; Estache and Fay, 2009; Heintz et al., 2009; Kumo, 2012; Marais, 2025). Infrastructure types differ in benefits: Construction and Transport reduce costs and improve logistics; Electricity powers economic activities. ICT's lack of significance suggests a complex relationship requiring: (i) Complementary investments in skills, research, and processes (Brynjolfsson and Hitt, 1998). (ii) Longer or harder-to-measure returns. (iii) Inefficient use of ICT investments (Kenny, 2007).

H_2: A significant relationship exists between infrastructure investment and real GDP per capita.

A considerable relationship is evident between infrastructure investment and real GDP per capita. The empirical results provide substantial support for the acceptance of this hypothesis. The principal finding of the GMM analysis indicates a statistically significant relationship. Three out of the four infrastructure variables exhibit a positive and significant coefficient. The System GMM model, constructed to account for endogeneity and persistence, corroborates a robust causal link between infrastructure investment and economic output. This finding serves as the primary empirical substantiation of the thesis articulated in section 2. It offers tangible evidence for the extensive body of literature asserting that public capital is a crucial driver of growth. It directly supports the contributions of Aschauer (1989), Munnell (1990, 1992), Bougheas et al. (1999), and other works referenced in the theoretical synopsis. It substantiates the South African government's policy stance (as articulated in the NDP 2050, NIP 2030) that emphasizes infrastructure investment for economic development. The advanced econometric technique (System GMM) effectively disentangles the impact of infrastructure investment from other factors and reverse causality. The highly significant coefficients for most types of infrastructure, together with strong model diagnostics (Hansen test, AR tests), assure that this relationship is not spurious.

H_3: Income disparity in South Africa has widened.

The analysis shows evidence supporting the hypothesis. Gauteng and Western Cape were the only provinces with GDP per capita above the national average over 25 years. Free State was around the average, while six provinces were below it. Investment heavily favoured Gauteng, KwaZulu-Natal, and Western Cape, as detailed in Figures 19-30. This mirrors South Africa's historical inequalities from apartheid and colonialism and supports theories that investment is often politically, not economically, driven (Gramlich, 1994; Kenny, 2007). Wealthier areas attract more investment, worsening inequality (Bourguignon & Morrisson, 1998; Piketty, 2006). Reasons include Path Dependency: Investments follow historical economic patterns from apartheid. Political Economy: Political factors influence infrastructure decisions (Kenny, 2007). Market Forces: Investment goes to areas with higher returns—generally urban areas like Gauteng and Western Cape.

The study also found that a 1% increase in GFCF leads to a 0.266% GDP decline. This supports the notion that public investment may crowd out private investment (Erenburg, 1993) due to high costs and inadequate management (Flyvbjerg et al., 2003; Rioja, 2003). This issue arises when investments fail to produce quality results, often due to corruption and inefficiency, especially in state-run entities like Eskom.

The provincial analysis furnishes a nuanced and critical elucidation of the research inquiry. It substantiates that infrastructure investment (H_2/H_3) holds a significant positive correlation with economic growth; however, this correlation is not consistent across all infrastructure categories. Significantly, the advantages of this growth have been geographically concentrated, resulting in an expansion of provincial income disparities (H_3). The disconcerting negative correlation between total investment and GDP indicates that the inefficiency and allocation of investment are profound issues, corroborating numerous criticisms directed at infrastructure-led growth strategies within the South African milieu. This research on South Africa's provincial economies indicates considerable differences in economic development and infrastructural investment. While some provinces grow, such as Gauteng and the Western Cape, others struggle owing to a lack of investment and restricted economic prospects. To solve these difficulties, the government has to take a comprehensive approach that includes infrastructure investment, regional development, and equitable growth policies. South Africa may achieve more balanced and sustainable economic growth by focussing on undeveloped regions, improving ICT and transport infrastructure, encouraging public-private partnerships and education. Long-term planning and consistent policy execution will also be critical in ensuring that infrastructure investments benefit all provinces in the long run.

Compliance with ethical standards

Funding

I, the author, declare that no funding was received for this study.

Conflict of interest

I, the author, declare that I have no conflict of interest.

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Appendix

Table A1. VAR lag order selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	165.0836	NA	0.010109	-1.756484	-1.632313	-1.706138
1	548.0414	731.8751	0.000145	-6.000460	-5.858551	-5.942922
2	550.7140	5.077861	0.000142*	-6.019044*	-5.859397*	-5.954314*
3	550.7736	0.112662	0.000144	-6.008596	-5.583210	-5.936673
4	550.7769	0.006131	0.000146	-5.997521	-5.802396	-5.918406
5	550.8384	0.114869	0.000147	-5.986094	-5.774230	-5.900787
6	550.8533	0.027503	0.000149	-5.976147	-5.745545	-5.882648
7	553.9009	5.621199*	0.000145	-5.998899	-5.750558	-5.898207
8	553.9012	0.000566	0.000147	-5.987791	-5.721711	-5.879907

Source: Author's construction (2025). *Indicates the lag order selection by the criterion. LR: sequential modified LR test statistic (each test at 5% level), FPE: final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion.

The results demonstrate that the VAR(2) model is the optimal choice as it has the greatest number of asterisk symbols (*) shown in Table A1 and confirms the GMM procedure has selected the optimum lag for modelling.

Table A2. Static Panel Estimation

Dependent variable: lnrGDPpc		
Variable	Pooled OLS	FE OLS
LnCon	-0.248 (0.000)	0.031 (0.739)
LnElect_con	0.142 (0.001)	0.057 (0.240)
LnTrans	0.102 (0.068)	0.062 (0.393)
LnICT	0.533 (0.000)	1.475 (0.000)
LnEmp	-0.122 (0.035)	-1.397 (0.000)
LnGFCF	-0.217 (0.058)	-0.122 (0.366)
F-statistic	27.79 (0.000)	14.21 (0.000)
Constant	5.075 (0.058)	9.151 (0.000)
R-squared	0.384	0.589
Root MSE	0.107	0.092
Observations	234	234
Cross sections	9	9

Source: Author's construction (2025).