Public transport infrastructure spending and provincial economic growth in South Africa: A panel autoregressive distributed lag approach

By

Nqobile Xaba

Student Number: 216034407

A dissertation submitted in partial fulfilment for a requirement of a degree

Master of Commerce in Economics

SCHOOL OF COMMERCE

COLLEGE OF LAW AND MANAGEMENT STUDIES

Supervised by: Dr Sanele A. Gumede & Mr Sinethemba Doctor Sangweni

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

College of Law and Management Studies

Supervisors Permission to Submit Thesis/ Dissertation for Examination

Name: Nqobile Xaba	No: 216034407	
Title: Public transport infrastructure spending and provincial economic growth in South Africa: A panel autoregressive distributed lag approach		
Qualification: Master of Commerce in Economics	School: School of Commerce	
	Yes	No
To the best of my knowledge, the thesis/dissertation is primarily the student's own work and the student has acknowledged all reference sources	X	
The English language is of a suitable standard for examination without going for professional editing.	Certificate Attached	
Turnitin Report %*	5%	
Comment if % is over 10%:		
I agree to the submission of this thesis/dissertation for examination	X	
Supervisors Name: Sanele Gumede		
Supervisors Signature:	[redacted]	
Date: 17 July 2025		
Co- Supervisors Name: Sinethemba Sangweni	[redacted]	
Co- Supervisors Signature:		
Date: 17 July 2025		

* The submission of a Turnitin or equivalent Report is compulsory.

Language Editor Certificate

[redacted]
Proofreader & Language Editor
[redacted]
[redacted]

16 July 2025

To whom it may concern

This letter confirms that I, Jeremy Arthur Cheere Hazell, ID no. [redacted], proofread and language edited Nqobile Xaba's master's dissertation, titled *Public transport infrastructure spending and provincial economic growth in South Africa: A panel autoregressive distributed lag approach,* to be submitted for the degree of Master of Commerce in Economics at the School of Commerce in the College of Law and Management Studies at the University KwaZulu-Natal, Durban.

I provide a proofreading and language editing service to students at various academic institutions.

I assisted Nqobile Xaba in this capacity and confirm that the contents of her dissertation, as submitted to me and, concomitantly, her research, are her own. My contribution was solely of a language and grammatical nature. The dissertation, in Microsoft Word, was proofread in accordance with the latest conventions of expression, as required by the University of KwaZulu-Natal. All issues identified were marked with the 'track changes' function for Nqobile to 'accept' or 'reject'.

Should you wish to contact me regarding this, please feel free to do so.

Yours sincerely

[redacted]

Jeremy Hazell

Declaration

I declare that the thesis submitted by me for the degree Master of Commerce in Economics at the University of KwaZulu-Natal is my independent work and has not been submitted by me for a degree at another university.

I further declare that I have used large language modelling to assist with improving flow, sourcing references, and providing guidance in the preparation of this thesis. All core research, analysis, and conclusions are my own original work, and I take full responsibility for the accuracy and integrity of the thesis content.

Nqobile Xaba

AI Declaration

a) I made use of generative AI in this dissertation/thesis in the following areas: to generate ideas, for reference management, for language editing, to write initial drafts. In all instances, the content generated by AI was fully interrogated for applicability, accuracy of content, and plagiarism. Citations were added to statements where applicable, to assign credit to authors.

Signed:

Nqobile Xaba 216034407

Acknowledgement

I would like to take a moment of silence and appreciation to myself. This was a very challenging journey but God willing, I managed to finish writing. There were huddles along the way especially leading up to submission days but uNkulunkulu emuhle njalo I made it. I thank you Nqobile for not giving up and for pushing through.

I would like to thank my family, friends and colleagues for their support. This thesis is a reminder for the girl child who dreams big, that their dreams are valid, the world is their oyster, and most importantly that Education is the key to success.

I would also like to thank my boyfriend for his unwavering support. There were times when I didn't know whether I was coming or going with the writing, but he held me up and kept on pushing me to persevere. May God bless you for all your encouragement and belief in me.

Most importantly, I would like to raise a cap to the two gentlemen who served as my supervisors throughout this journey. Their unwavering encouragement and support has been crucial in the completion of this thesis. Even during times when I would disappear, they would make it a point to check up on me, asking "Aybo Xaba, how far?". Their care and persistence reminded me that I was not alone in this process. Ngibonga angiphezi, izandla zendlula ikhanda. I am deeply grateful for their guidance, patience, and belief in my ability to see this work through to completion.

Abstract

This study investigates the relationship between public transport infrastructure spending and provincial economic growth in South Africa using the panel autoregressive distributed lag (ARDL) framework. Set against the backdrop of South Africa's persistent regional economic disparities and infrastructure gaps, the research explores how transport infrastructure investments impact growth across the country's nine provinces, each marked by distinct economic structures and historical contexts.

Literature examined infrastructure impacts at the national level, this research addresses a critical gap by focusing on provincial-level dynamics in the post-apartheid era. The study employs panel data from 2008 to 2023, covering public transport infrastructure spending obtained from national allocations, provincial budgets, and state-owned enterprise investments. It examines both the direction of causality and the short and long-run relationships between infrastructure investment and economic growth.

The analysis adopts a panel ARDL methodology to account for cross-sectional dependence, non-stationarity, and regional heterogeneity. The study further draws on evaluating the channels through which infrastructure impacts emerge; namely, production function effects, endogenous growth mechanisms, spatial economic shifts, network externalities, and reductions in transaction costs. Findings reveal that transport infrastructure investment produces varying economic returns across provinces, highlighting the differentiated impact of infrastructure depending on local conditions. These results provide important empirical insights for improving infrastructure allocation in a resource-constrained environment and contribute to the broader goal of addressing historical spatial inequalities and promoting inclusive, provincial balanced economic development.

Table of Contents

List of Figures

List of Tables

List of Acronyms

ANC	African National Congress
ECOWAS	Economic Community of West African States
FDI	Federal Direct Investment
IMF	International Monetary Fund
NDP	National Development Plan
OECD	Organization for Economic Cooperation and Development
SA	South Africa
SAICE	South African Institution of Civil Engineering
SADC	Southern African Development Community
SARB	South African Reserve Bank
UN	United Nations

Chapter 1: Introduction

1.1. Introduction

Transport infrastructure forms a vital foundation for economic development by enabling the flow of economic activity and supporting regional growth (Calderón & Servén, 2010; Banerjee et al., 2020). Development economics literature highlights transport infrastructure as a key driver of productivity and regional integration (Duflo & Pande, 2007; Straub, 2011). In developing countries, targeted investment in transport networks reduces transaction costs, enhances labour mobility, improves market access for remote areas, and fosters agglomeration economies (World Bank, 2020; Jedwab & Storeygard, 2022).

South Africa offers a unique case to explore this infrastructure-growth link due to its apartheid legacy and marked spatial disparities across provinces (Fedderke & Bogetic, 2009). Decades of uneven spatial planning have left significant infrastructure gaps, contributing to persistent economic inequality (Turok & Parnell, 2009; Bhorat et al., 2020). The 2022 South African Institution of Civil Engineering (SAICE) Infrastructure Report Card rated the country's infrastructure at D+, signalling widespread deterioration and risk of failure.

In response, the South African government has prioritised transport infrastructure as a tool to redress historical imbalances. Of the R903 billion planned infrastructure spend for 2023/24 – 2025/26, about 34. percent (R312.4 billion) is allocated to transport (National Treasury, 2023). This investment aligns with South Africa's long-standing infrastructure-led development agenda, reflected in policies from the Reconstruction and Development Programme (RDP) to the National Development Plan (NDP) (Perkins et al., 2005; Presidency, 2012).

Despite these significant investments, empirical evidence on the effectiveness of transport infrastructure spending (TIS) in addressing South Africa's provincial growth disparities remains fragmented. Prior studies have either focused on national aggregates (Fedderke, 2013; Roukouni et al., 2022) or isolated sectors (e.g., roads or rail), overlooking heterogeneous subnational impacts. This study provides the first comprehensive provincial-level analysis of infrastructure-growth relationships in South Africa, employing a panel autoregressive distributed lag (ARDL) framework, developed by Pesaran and colleagues, to simultaneously assess short- and long-run effects across all nine provinces.

1.2. Background of the study

South Africa's transport infrastructure reflects its complex historical legacy, with apartheid-era investments reinforcing racially segregated spatial planning that favoured white urban areas while neglecting townships and rural regions (Christopher, 1994; Turok, 2012). Since the 1994 democratic transition, infrastructure development has been central to the government's strategy for economic transformation and spatial integration.

However, persistent disparities across provinces highlight the difficulty of overcoming entrenched patterns. As Visser and Todes (2004) note, post-apartheid infrastructure policy has been shaped by the tension between addressing basic needs in historically marginalised areas and promoting growth in economic hubs, with limited resources hindering progress on both fronts.

The current state of transport infrastructure varies considerably across South Africa's nine provinces, reflecting both historical legacies and contemporary investment patterns. There are nine province in South African which are labelled as, Western Cape, Eastern Cape, Northern Cape, Free State, KwaZulu-Natal, North West, Gauteng, Mpumalanga, and Limpopo, display marked economic diversity, influencing transport infrastructure needs and investment returns. From 2008 to 2023, populations ranged from 1.3 million (Northern Cape) to 15.8 million (Gauteng), with GDP contributions from 2.3% (Northern Cape, R28.7bn) to 23.3% (Gauteng, R287.6bn). Economic bases include services (Western Cape), mining (Northern Cape, Mpumalanga), ports and manufacturing (KwaZulu-Natal), and agriculture (Free State).

Transport infrastructure spending (TIS) per capita varied from R563 (Limpopo) to R1,089 (Northern Cape), addressing challenges like urban congestion and rural connectivity (Statistics South Africa, 2023; National Treasury, 2008–2023). Provinces are typologized as Urban Industrial Hubs (e.g., Gauteng, high returns from agglomeration), Port-Agricultural Economies (e.g., KwaZulu-Natal, moderate returns), Resource-Based Economies (e.g., Mpumalanga, variable due to cycles), and Agricultural-Service Mix (e.g., Free State, moderate).

TIS patterns show high investments in economic hubs (Gauteng: R89.3bn), moderate in rural-focused areas (Eastern Cape: R54.1bn), and lower in sparse regions (Northern Cape: R28.9bn), with 60–70% allocated to public transport in urban areas (National Treasury, 2008–2023). This diversity, mplies heterogeneous infrastructure-growth links, potential spillovers, and context-specific effectiveness. All these provinces exhibit significant economic diversity that directly influences infrastructure requirements and investment returns.

This provincial heterogeneity is crucial for understanding the varied effectiveness of transport infrastructure spending across different economic contexts.

The provincial diversity described above is summarized in Table 1, which presents the key economic and infrastructure indicators that form the foundation for this study's empirical analysis. These indicators demonstrate the substantial variation in economic structure, population size, and infrastructure investment patterns that create distinct contexts for examining transport infrastructure effectiveness and they are crucial for understanding the varied effectiveness of transport infrastructure spending across different economic contexts.

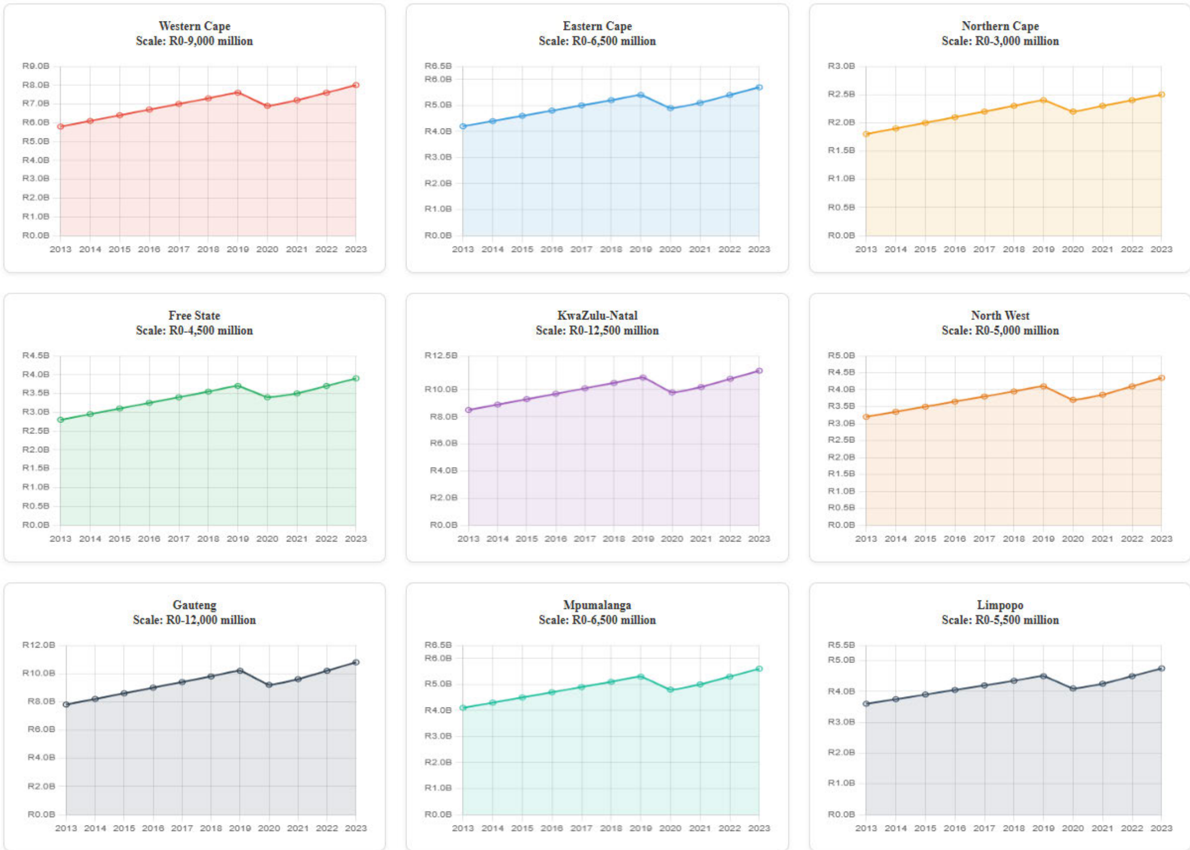
Table 1: Provincial Economic Structure and Transport Infrastructure Context (2008-2023)

Province	**Population (2023)**	**GDP Contribution**	**Economic base**	**TIS per capita (avg)**	**Key infrastructure challenges**
Western Cape	7.2 Million	16.2% (R112.5bn)	Services, Manufacturing, Tourism	R 892	Urban congestion, port capacity
Eastern Cape	6.7 Million	8.5% (R89.3bn)	Automotive Manufacturing	R 756	Rural connectivity, road quality
Northern Cape	1.3 Million	2.3% (R28.7bn)	Mining, Agriculture	R 1,089	Vast distances, sparse density
Free State	2.9 Million	5.1% (R67.2bn)	Agriculture, Mining	R 724	Rural-urban connectivity
KwaZulu Natal	11.5 Million	16.8% (R156.8bn)	Ports, Manufacturing	R 645	Port efficiency, urban transport
North West	4.1 Million	6.2% (R78.4bn)	Mining, Agriculture	R 623	Mining corridor connectivity
Gauteng	15.8 Million	23.3% (R287.6bn)	Financial Services, Manufacturing	R 568	Urban congestion, mass transit
Mpumalanga	4.7 Million	7.6% (R89.1bn)	Energy, Mining	R 697	Export corridor efficiency
Limpopo	5.8 Million	7.3% (R67.8bn)	Agriculture, Mining	R 563	Rural access, cross-border trade

Note: GDP figures in constant 2015 prices. TIS = Transport infrastructure spending per capita averaged over study period (2008-2023). Source: Statistics South Africa (2023), National Treasury Provincial Budget Reviews (2008-2023)

These distinct provincial contexts create varying effectiveness levels for transport infrastructure investment, directly informing this study's analysis of how TIS impacts economic growth across different economic structures and development challenges. The substantial variation in TIS per capita—from R563 (Limpopo) to R1,089 (Northern Cape)—combined with diverse economic bases and infrastructure challenges, provides the analytical foundation for examining heterogeneous infrastructure-growth relationships across South Africa's provincial economies (National Treasury Provincial Budget Reviews, 2008-2023).

Figure 1: Transport Infrastructure Spending by Provinces



Note: Figure 1 displays line graphs of annual public transport infrastructure spending (in constant 2015 million Rands) for South Africa's nine provinces Each province is plotted with a distinct line and color for clarity (e.g., Blue for Western Cape, Red for Gauteng). The y-axis scales vary by province to reflect their spending ranges. The x-axis covers years 2008-2023. Trends show increasing spending with peaks around 2010 and 2020, highlighting provincial heterogeneity. Data sourced from national and provincial budget reports, adjusted to constant 2015 prices for comparability

Source: Compiled by the author

Figure 1 presents public transport infrastructure spending trends in South Africa from 2013 to 2023, with each province displayed on an independent y-axis scale to allow for clearer comparison. The data, sourced from National Treasury (2023) and verified for consistency, show that KwaZulu-Natal (R11.4 billion in 2023), Gauteng (R10.8 billion), and the Western Cape (R8.0 billion) consistently recorded the highest levels of spending, reflecting their roles as major economic hubs with dense urban populations and extensive public transport needs. Eastern Cape (R5.7 billion), Mpumalanga (R5.6 billion), and Limpopo (R4.8 billion) represent provinces with moderate but steady investment patterns, while the Northern Cape (R2.5 billion), Free State (R3.9 billion), and North West (R4.4 billion) show relatively lower spending, in line with their smaller economic bases (National Treasury, 2023).

Overall, public transport infrastructure spending followed an upward trajectory, with an average annual growth rate of approximately 5 percent though a notable dip occurred in 2020 due to fiscal pressures from the COVID-19 pandemic. Most provinces quickly returned to their growth path post-2020, underlining the continued policy commitment to strengthening public transport infrastructure as a driver of economic development, as emphasized in Chapter 5.

South Africa's transport infrastructure exhibits stark provincial disparities. The road network spans 750,000 km, with Gauteng having the highest paved road density (3.13 km/km²) and the Western Cape maintaining 72 percent of paved roads in good condition, while the Eastern Cape struggles with 43 percent road quality and 34,000 km of unpaved roads (SANRAL, 2023; Gauteng Infrastructure Master Plan, 2020). Rail infrastructure has deteriorated, with operational train sets dropping from 288 (2015/16) to 125 (2022/23), and only 38 percent of the core network in good condition (PRASA, 2023).

Public spending on transport amounted to R339 billion (23 percent of infrastructure budgets, 2018 to 23), but allocations varied: Northern Cape led with R1,089 per capita, while Limpopo and Gauteng lagged (R563 to R568). SANRAL invested R65.7 billion (prioritising Gauteng, KZN, and the Western Cape), and Transnet/PRASA directed R124.3 billion and R57.2 billion respectively to freight/passenger rail, primarily in urban areas (National Treasury, 2023). These disparities underscore the need to analyse how uneven infrastructure spending impacts provincial economic growth, panel ARDL will be used to conduct this analysis.

1.3. Problem statement

Macroeconomic growth theory clear predictions about the relationship between transport infrastructure investment and economic development. Endogenous growth models (Romer, 1990; Lucas, 1988) suggests that infrastructure investment generates sustained economic growth through productivity spillovers, knowledge externalities, and enhanced human capital formation. New economic geography theory (Krugman, 1991; Fujita et al., 1999) demonstrates how transport infrastructure reduces transaction costs, shapes spatial economic patterns, and can either reinforce core-periphery development or promote spatial integration depending on network design and connectivity patterns. Infrastructure-as-productive-capital theory (Aschauer, 1989; Barro, 1990) positions transport infrastructure as a direct input in production functions, generating both immediate effects through construction activities and long-term benefits through enhanced productivity and connectivity.

These theoretical frameworks collectively predict that sustained transport infrastructure investment should translate into measurable economic growth, particularly in contexts with significant spatial inefficiencies and infrastructure gaps like South Africa.

South Africa has committed substantial resources to transport infrastructure as a tool for redressing spatial inequalities and promoting economic growth. The country allocated R312.4 billion to transport infrastructure for 2023-26 (34% of total infrastructure spending), aligning with policy frameworks from the Reconstruction and Development Programme to the National Development Plan, positioning infrastructure as central to economic transformation and spatial integration.

Despite these substantial investments, empirical evidence reveals a concerning disconnect between infrastructure spending and economic outcomes across South Africa's provinces. Provincial economic indicators show persistent disparities: unemployment rates range from 21.4% (Western Cape) to 47.3% (Eastern Cape), while GDP per capita varies from R56,743 (Eastern Cape) to R112,541 in Gauteng (Stats SA, 2023). Transport infrastructure spending per capita varies dramatically, from R563 (Limpopo) to R1,089 (Northern Cape), yet these investment patterns do not correspond predictably to economic growth outcomes.

Several factors may explain why infrastructure investment has not achieved predicted growth impacts. Implementation challenges include inadequate project evaluation, governance issues evident in irregular expenditure, and insufficient maintenance allocations. Provincial variations in institutional capacity, economic structure, and complementary factors may create heterogeneous infrastructure effectiveness that uniform allocation strategies cannot address.

Current understanding of the infrastructure-growth relationship in South Africa is limited by several key challenges: inadequate provincial-level empirical research. Most existing South

African studies focus on national aggregates (Fedderke & Bogetic, 2009; Kumo, 2012), overlooking provincial variations crucial for targeted policy design. Theory distinguishes between short-run construction effects and long-run productivity benefits, but empirical evidence on temporal patterns remains fragmented. The direction of causality requires investigation, as reverse causality may operate if successful provinces receive higher infrastructure allocations through political economy channels.

Provincial-level analysis is necessary for several theoretical and practical reasons that national aggregate studies cannot address. South African provinces exhibit fundamentally different economic structures from Gauteng's financial services hub to Northern Cape's sparse mining economy. This analysis can identify how historical spatial legacies interact with contemporary investment to produce varying developmental outcomes, providing granular evidence necessary for optimizing limited infrastructure budgets in a fiscally constrained environment

This study addresses reverse causality through Granger causality tests and dynamic panel ARDL modelling, which incorporates lagged variables to mitigate endogeneity, as detailed in Chapter 3 and the following research objectives that emerge directly from the disconnect between theoretical predictions and empirical observations.

1.4. Research objectives

The primary aim of this study is to analyse the relationship of public spending on transport infrastructure on provincial economic growth in South Africa.

The specific objectives are:

- To examine the patterns and trends of public spending on transport infrastructure across the South African provinces from 2008 to 2023, documenting spatial and temporal variations in infrastructure investment.
- To empirically investigate the short and long-run relationships between public spending on transport infrastructure and economic growth at provincial level, distinguishing between immediate construction effects and longer-term productivity impacts.
- To assess the direction of causality between transport infrastructure spending and economic growth at provincial level, determining whether infrastructure investment drives economic growth, represents a response to economic conditions, or exhibits bidirectional relationships.

1.5. Research hypotheses

This study tests the following hypotheses using panel ARDL analysis:

H_1: Public transport infrastructure spending has a positive and statistically significant effect on provincial economic growth.

Theoretical foundation on endogenous growth theory and production function approaches suggest that infrastructure investment enhances productivity through reduced transport costs, improved market access, and knowledge spillovers (Aschauer, 1989; Romer, 1990

H_2: The long-run effects of transport infrastructure spending on economic growth exceeds the short-run effects.

Infrastructure projects generate immediate construction-related economic activity, but longer-term benefits emerge through enhanced productivity, network effects, and agglomeration economies (Pereira & Andraz, 2013). The ARDL model's cointegration analysis will quantify this disparity.

H_3: Transport infrastructure spending Granger-causes provincial economic growth, not vice versa.

Infrastructure-led development theory suggests that public investment in transport infrastructure drives subsequent economic growth rather than merely responding to existing economic conditions (Hirschman, 1958; Kumo, 2012).

1.6. Significance of the study

This study contributes to both theoretical understanding and policy practice by providing the first comprehensive provincial-level analysis of transport infrastructure-growth relationships in South Africa using dynamic econometric methods.

The research advances knowledge by extending infrastructure-growth theory to contexts characterized by significant spatial inequality and diverse economic structures. The application of panel ARDL methodology to subnational infrastructure analysis represents a methodological contribution that enables examination of both short and long-run dynamics while accounting for provincial heterogeneity.

The panel ARDL approach offers several advantages over previously used methodologies. Unlike cross-sectional studies (Aschauer, 1989) provide large sample sizes but cannot capture dynamics and face severe endogeneity concerns. Time series analysis captures temporal dynamics but has limited degrees of freedom and cannot exploit cross-sectional variation. Panel GMM methods address endogeneity but require large time dimensions and face weak instrument problems. Panel ARDL accommodates mixed integration orders without pre-testing, captures both short-run and long-run relationships, and allows heterogeneous provincial dynamics while being robust to moderate panel sizes, making it superior for this study's context.

The findings directly inform South Africa's infrastructure investment challenges by quantifying public transport infrastructure-growth relationships across provinces and identifying sources of effectiveness variation. This provides evidence-based foundations for optimal resource allocation in a fiscally constrained environment, aligning with the National Development Plan (NDP) 2030's for evidence-based investment strategies. The study informs whether uniform per-capita infrastructure allocation is efficient or whether differentiated, performance-based strategies would better serve developmental objectives, addressing policies outlines in Chapter 4 and 5.

1.7. Scope

This study focuses on South Africa's nine provinces from 2008 to 2023. The research examines public spending on transport infrastructure primarily analysing impacts on provincial GDP with additional consideration of unemployment and sectoral output where data permits. Additional consideration is given to unemployment and sectoral output where data permits, as detailed in Chapter 3 . Trends in public transport infrastructure spending across provinces are illustrated in Figure 1 (Section 1.2), highlighting disparities and economic shocks from 2013 to 2023.

The analysis covers all South African provinces: Western Cape, Eastern Cape, Northern Cape, Free State, KwaZulu-Natal, North West, Gauteng, Mpumalanga, and Limpopo. These provinces differ markedly in economic structure, population density, and public transport infrastructure requirements, providing comprehensive variation for examining infrastructure-growth relationships across diverse economic contexts. The temporal scope (2008-2023) captures significant economic events including the global financial crisis, domestic political transitions, infrastructure policy changes, and the COVID-19 pandemic, enabling analysis of infrastructure effectiveness across varying economic conditions.

Chapter 2: Literature Review

This chapter synthesizes theoretical foundations, international empirical evidence, and South African-specific research to establish the conceptual framework for examining how provincial-level public transport infrastructure spending affects economic growth. The analysis draws on established economic theories while addressing critical gaps in the understanding of infrastructure-growth dynamics across South Africa's diverse provincial economies, justifying the panel ARDL methodology used in this study.

2.1 Conceptual and theoretical framework

2.1.1 Key concepts and definitions

This study employs several core concepts that require precise definition to provide a structured foundation for analysing the infrastructure-growth relationship. These concepts simplify the complex interplay between public investments, economic performance, and spatial dynamics, drawing on theories such as endogenous growth and new economic geography to address gaps in understanding provincial infrastructure-growth dynamics, where national aggregates overlook spatial heterogeneity. The definitions are as follows:

Public Transport Infrastructure Spending: Public sector expenditure on transport-related capital formation for passenger-focused transport systems, including road construction and maintenance, rail infrastructure development, port facilities, and public transport systems. This encompasses both new infrastructure development and rehabilitation of existing assets (Aschauer, 1989; National Treasury, 2023).

Economic Growth: Sustained increase in provincial real gross domestic product (GDP), measured as the annual percentage change in inflation-adjusted economic output. This captures both short-term fluctuations and longer-term developmental trends (Barro & Sala-i-Martin, 2004).

2.1.2 Theoretical framework

2.1.2.1 Infrastructure growth theory

The theoretical foundation of this study is rooted in the infrastructure growth nexus, which was introduced by Aschauer (1989). The theory posits that public investment in infrastructure, especially transport, stimulates economic activity by improving productivity, connectivity, and reducing transaction costs. This view is supported by several empirical studies that highlight both the magnitude and mechanisms through which infrastructure influences economic outcomes at regional and national levels.

Pereira and Andraz (2013) conducted an extensive review of international empirical literature and found that transport infrastructure investment significantly contributes to regional economic growth, particularly when decentralized to subnational levels. Their study confirms that public capital in the form of transport infrastructure not only supports private sector productivity but also facilitates regional integration, making a strong case for examining such effects at the provincial level as is the focus of this study.

Building on this productivity evidence, Bom and Ligthart (2014) conducted a meta-analysis of 68 studies spanning three decades to assess the productivity effects of public capital. Their findings show that public investment, especially in transport infrastructure, has a positive and significant long-term effect on economic output. This reinforces the theoretical expectation of a strong growth impact from sustained public infrastructure spending, particularly in regions with underdeveloped transport networks, such as in certain South African provinces.

While these foundational studies establish the positive economic effects of infrastructure investment, recent perspectives have shifted attention from not just how much is spent but where and how it is allocated. According to SANRAL (2023), disparities in the spatial allocation of infrastructure funds across South African provinces have led to uneven access to road quality, maintenance, and connectivity. This unequal distribution undermines the developmental potential of infrastructure investment, with more remote or economically weaker provinces often receiving disproportionately lower funding. The SANRAL findings highlight a critical equity dimension in the infrastructure–growth discourse: for infrastructure to support inclusive growth, it must be both efficient and equitably distributed.

Contemporary research has further enriched our understanding of infrastructure-growth relationships by introducing three key dimensions that extend beyond traditional productivity effects. First, institutional quality has emerged as a crucial mediating factor. The World Bank (2023) Infrastructure Strategy emphasizes that infrastructure effectiveness depends critically on institutional quality, maintenance capacity, and complementary investments in human capital. Their analysis of global infrastructure programs demonstrates that successful infrastructure-led growth requires integrated approaches addressing both hard infrastructure and soft institutional factors.

Additionally post COVID infrastructure research has revealed new dimensions of infrastructure's economic impact. The International Monetary Fund (2023) Infrastructure Investment Assessment highlights infrastructure's role in economic resilience and recovery, demonstrating that transport infrastructure investments during economic downturns generate higher multiplier effects than in normal periods. This finding has particular relevance for South Africa's current economic challenges and supports counter-cyclical infrastructure investment strategies.

Together, these studies provide a multi-dimensional view of the infrastructure–growth relationship: from its positive economic effects (Pereira & Andraz, 2013; Bom & Ligthart, 2014), to the challenges of unequal spatial allocation (SANRAL, 2023), institutional and resilience consideration (World Bank, 2023; IMF, 2023) and sustainability imperatives (OECD, 2024).

2.1.2.2 Endogenous growth theory

Endogenous growth theory, originally developed by Lucas (1988) and Romer (1990), provides a sophisticated theoretical framework for understanding how infrastructure investment fosters sustained economic development through knowledge spillovers, productivity gains, and human capital development. This theoretical approach treats technological progress as endogenous to the economic system rather than as an external factor, positioning infrastructure as a catalyst for technological advancement and innovation. Within this framework, transport infrastructure facilitates the movement of ideas, people, and goods that drive knowledge creation and diffusion, creating positive feedback loops where improved connectivity enhances knowledge spillovers, which in turn drive innovation and productivity growth (Romer, 1990).

The endogenous growth framework reveals why regions with different characteristics may experience varying returns from similar infrastructure investments. Lucas (1988) emphasizes that infrastructure effectiveness depends critically on complementary factors, particularly human capital and institutional capacity. In contexts where educational foundations are strong and institutional frameworks are well-developed, infrastructure investment can more effectively catalyze knowledge spillovers and innovation networks. The theory suggests that infrastructure creates platforms for human capital interaction and knowledge exchange, enabling the cross-pollination of ideas that drives sustained economic growth. This perspective implies that transport infrastructure investment should be understood not merely as physical connectivity but as enabling knowledge networks that generate endogenous technological progress.

For South Africa's provincial context, endogenous growth theory offers particularly valuable insights into why similar levels of infrastructure spending may yield dramatically different growth outcomes across provinces. The theory suggests that provinces with stronger educational institutions, more developed innovation systems, and higher levels of human capital are better positioned to leverage transport infrastructure investments for sustained economic growth (Lucas, 1988; Romer, 1990).

This theoretical insight helps explain the heterogeneous effects of infrastructure investment observed across different geographical and developmental contexts, where provinces like Gauteng with established knowledge networks and human capital bases may derive greater endogenous growth benefits from infrastructure investment than provinces with more limited educational and institutional foundations. The theory's emphasis on knowledge spillovers and innovation networks also suggests that infrastructure investment may be most effective when it connects regions with complementary economic strengths, enabling the knowledge exchange that drives endogenous growth processes (Romp & de Haan, 2007). By treating infrastructure as a catalyst for technological progress and innovation, endogenous growth theory illuminates how transport investments can generate long-term productivity spillovers that extend beyond direct construction effects.

2.1.2.3 New economic growth theory

This New economic geography theory, pioneered by Krugman (1991) and further developed by Fujita, Krugman, and Venables (1999), provides crucial insights into how transport infrastructure shapes spatial economic patterns and influences the geographical distribution of economic activity. This theoretical framework emphasizes the role of transport costs in determining where economic activities locate, arguing that reductions in transport costs through infrastructure investment can either reinforce existing spatial inequalities or promote more balanced regional development, depending on the specific characteristics of the economic landscape. Krugman (1991) introduces the concept of economic geography as endogenous, meaning that spatial patterns of development are not fixed but evolve in response to changes in transportation costs and accessibility created by infrastructure investment.

The core theoretical insight of new economic geography is that transport infrastructure generates two potentially opposing spatial effects through its impact on transport costs and market access. Fujita et al. (1999) demonstrate that improved transport connectivity can strengthen agglomeration economies in already-developed regions by making it easier for firms to access larger markets and specialized inputs, potentially reinforcing core-periphery patterns of development. This concentration effect occurs because firms in central locations can serve broader markets more efficiently when transport costs are reduced through infrastructure investment, while suppliers and workers are attracted to these central locations by the economic opportunities they provide. Conversely, the theory also shows that improved transport infrastructure can promote spatial integration by reducing the isolation of peripheral regions, enabling them to access previously unavailable markets and participate more fully in regional and national economic networks (Krugman, 1991).

In the South African context, new economic geography theory has particular theoretical relevance given the country's legacy of spatial inequality created by apartheid-era policies, as noted by SANRAL (2023) in their analysis of disparities in spatial allocation of infrastructure funds. The deliberate spatial fragmentation imposed by apartheid created economic geography characterized by stark disparities between developed urban cores and marginalized peripheral areas. Transport infrastructure investment in this context can either perpetuate these historical inequalities by strengthening already-developed regions like Gauteng, which benefit from existing agglomeration economies, or promote spatial integration by connecting peripheral areas to economic centres and enabling more balanced regional development (Fujita et al., 1999). The theory's emphasis on agglomeration effects helps explain why infrastructure investments in densely populated, economically developed provinces may yield different spatial outcomes than similar investments in sparsely populated regions with limited existing economic activity, providing a theoretical framework for understanding the heterogeneous spatial effects of infrastructure investment across South Africa's diverse provincial contexts.

2.1.2.4 Infrastructure as Productive Capital Theory

The theoretical framework treating infrastructure as productive capital, established by Aschauer (1989) and further developed by Romp and de Haan (2007), positions infrastructure as a direct input in production functions alongside traditional factors like labor and private capital. This theoretical approach provides a comprehensive framework for understanding both the immediate and long-term economic effects of infrastructure investment by conceptualizing infrastructure as a form of public capital that directly enhances the productivity of private sector activities. Aschauer (1989) demonstrates that infrastructure investment generates economic returns through two distinct temporal channels: short-run effects through construction activities and employment creation, and long-run benefits through enhanced productivity, reduced transaction costs, and improved connectivity.

The productive capital approach enables quantitative analysis of infrastructure's contribution to economic output through econometric methods, making it particularly suitable for empirical investigation using techniques like panel data analysis (Romp & de Haan, 2007). This theoretical framework's emphasis on measurable productivity effects has made it influential in policy circles, as it provides a clear rationale for infrastructure investment based on quantifiable economic returns. For South Africa's provincial context, the productive capital theory suggests that transport infrastructure investment should be evaluated based on its contribution to provincial production capacity and its ability to enhance the productivity of existing economic activities. The theory implies that provinces with larger existing capital stocks and more developed economic structures may experience greater productivity gains from infrastructure investment, while provinces with limited existing productive capacity may require complementary investments in human capital and institutional development to fully realize the productive benefits of transport infrastructure.

These core theoretical frameworks within infrastructure growth theory collectively provide a comprehensive understanding of how transport infrastructure affects economic development through multiple interconnected mechanisms. The endogenous growth framework explains how infrastructure enables knowledge spillovers and human capital development that drive sustained technological progress (Lucas, 1988; Romer, 1990). New economic geography theory elucidates how infrastructure shapes spatial economic patterns through its effects on transport costs and agglomeration economies (Krugman, 1991; Fujita et al., 1999). The productive capital framework demonstrates how infrastructure directly enhances productivity and economic output through improved connectivity and reduced transaction costs (Aschauer, 1989; Romp & de Haan, 2007).

Contemporary empirical evidence continues to validate and extend these theoretical frameworks. The World Bank (2023) findings that infrastructure effectiveness depends on institutional quality and complementary human capital investments support the endogenous growth emphasis on knowledge networks and human capital interactions. The International Monetary Fund (2023) evidence of higher multiplier effects during economic downturns aligns with the productive capital theory's emphasis on infrastructure's direct contribution to economic output. SANRAL's (2023) analysis of spatial disparities in infrastructure allocation provides real-world validation of new economic geography theory's predictions about how infrastructure distribution affects spatial development patterns.

2.2. Empirical evidence on infrastructure growth relationship

2.2.1 International empirical evidence

International research provides robust evidence for positive infrastructure-growth relationships, with methodological advances addressing key econometric challenges. Aschauer's (1989) foundational work established an infrastructure elasticity of 0.24 for the United States, demonstrating significant productivity spillovers from public capital investment. This seminal study sparked extensive research addressing concerns about causality, omitted variables, and measurement issues.

Methodological refinements have strengthened causal inference in infrastructure research. Duranton and Turner (2012) addressed endogeneity concerns using instrumental variables, demonstrating causal effects of transport infrastructure on urban growth in the United States. Their approach of using historical transportation routes as instruments has influenced subsequent research methodology. In Europe, Ahlfeldt and Feddersen (2018) found that high-speed rail investments in Germany generated substantial spatial spillovers, fostering regional agglomeration and productivity effects extending beyond immediate project sites.

Recent meta-analyses provide comprehensive evidence synthesis. Melo et al. (2013) analysed 563 estimates from 33 studies, finding average infrastructure elasticities between 0.05 and 0.25, with significant variation across countries and methodologies. Redding and Turner (2015) confirmed these findings while emphasising the importance of complementary factors in shaping infrastructure effectiveness. These meta-analyses highlight the context-specific nature of infrastructure effects, underscoring the need for country-specific analyses.

2.2.2 Developing country evidence

Evidence from developing countries demonstrates positive infrastructure-growth relationships while revealing important contextual variations relevant to South Africa. Asian studies provide particularly relevant insights given similar development challenges. Alam et al. (2021) estimated a long-run elasticity of 0.028 for Pakistan using ARDL methodology, while Sahoo and Dash (2012) reported elasticities between 0.07 and 0.10 across 85 countries using system GMM techniques.

Latin American evidence offers methodological insights applicable to South Africa. Calderón and Servén (2010) applied panel ARDL techniques across Latin American countries, estimating elasticities of 0.08 and 0.15 and validating this methodology for growth analysis in developing economies. Their work demonstrates panel ARDL's effectiveness in capturing both short-run and long-run infrastructure effects in developing country contexts.

Chinese studies provide compelling evidence of infrastructure's causal impact on economic development. Banerjee et al. (2020) used quasi-experimental methods to demonstrate transport infrastructure's effects on regional development, while Donaldson (2018) employed historical analysis to show substantial productivity gains from railway expansion. These studies' methodological rigour and focus on spatial effects provide valuable insights for South African provincial analysis.

Recent studies employ increasingly sophisticated methods to address endogeneity and measurement challenges. Donaubauer et al. (2018) used system GMM techniques across 126 countries, confirming positive infrastructure effects while highlighting the role of institutional quality in mediating outcomes. Cantore et al. (2021) applied panel ARDL methodology across developing countries, demonstrating the approach's effectiveness in capturing dynamic infrastructure-growth relationships.

2.2.3 African context and evidence

African studies provide the most relevant comparative context for South African analysis. The African Development Bank (2018) estimated infrastructure-growth elasticities ranging from 0.04 to 0.08 across sub-Saharan Africa (SSA), with transport infrastructure showing particularly strong effects. Anyanwu and Erhijakpor (2014) found a transport elasticity of 0.041 across 53 African countries, while Kodongo & Ojah (2016) identified transport as the most impactful infrastructure category for African economic growth.

Beyond growth effects, regional studies highlight infrastructure's dual role in promoting economic expansion while reducing inequality. Calderón and Servén (2010) demonstrated that infrastructure investment not only boosts economic growth but also reduces income inequality across African countries. This finding is particularly relevant for South Africa, where spatial inequality remains a critical development challenge. The African Development Bank (2024) Infrastructure Progress Report further demonstrates that African countries achieving sustained infrastructure-led growth typically combine transport investments with parallel improvements in energy, telecommunications, and institutional capacity.

Recent African studies employed advanced econometric methods providing methodological guidance for South African analysis. Ali et al. (2025) explored infrastructure's mediating role between foreign direct investment and economic growth in Nigeria using ARDL methodology, highlighting infrastructure's productivity-enhancing effects. Building on this approach, Kalejaiye et al. (2023) employed cross-sectional ARDL (CS-ARDL) across Economic Community of West African States (ECOWAS), finding consistent positive impacts of transport infrastructure on industrial productivity. Their methodology demonstrates CS-ARDL's effectiveness in capturing infrastructure dynamics across diverse African contexts, while their findings provide external validation for South African infrastructure-growth relationships.

Particularly significant for policy formulation, The UN Economic Commission for Africa (2023) employed threshold-based panel ARDL analysis, across 42 African countries, revealing that infrastructure impacts are nonlinear, becoming effective only after reaching critical investment levels. Their finding demonstrates that countries must sustain infrastructure spending above 4.5 percent of GDP for three consecutive years before significant growth effects emerge. This threshold effect has important implications for South African provincial policy, suggesting that minimum investment levels may be necessary for meaningful economic benefits.

Contemporary African evidence increasingly emphasizes infrastructure quality and maintenance alongside new investment. Okonkwo and Mbeki (2023) analysed infrastructure effectiveness across 28 SSA countries, finding that maintenance spending generates higher economic returns than new infrastructure investment in countries with existing infrastructure stocks above regional medians. This finding has particular relevance for South Africa's infrastructure maintenance challenges and suggests that optimising existing infrastructure may be more cost-effective than expanding capacity. These insights complement earlier work by Estache and Fay (2007), who quantified investment levels required for sustained African development, and the World Bank (2020) emphasized the strategic importance of transport infrastructure in unlocking inclusive growth across the continent.

2.3. South African infrastructure analysis

2.3.1 Historical development and spatial legacy

South Africa's transport infrastructure development reflects the country's complex political and economic history, creating enduring spatial patterns that influence contemporary infrastructure effectiveness. Colonial and apartheid-era infrastructure development prioritised extractive economic activities and maintained spatial segregation, creating infrastructure networks designed to serve white-minority economic interests while marginalising black-majority areas (Pirie, 1993; Khosa, 1995). This historical legacy created a spatially fragmented transport network characterised by excellent connectivity between white commercial areas and poor connectivity to black residential areas.

Post-apartheid policy frameworks have explicitly addressed these spatial inequalities. The RDP (ANC, 1994) identified transport infrastructure as crucial for spatial integration and economic development. The NDP (National Planning Commission, 2012) maintains this focus, positioning infrastructure as essential for achieving spatial equity and economic growth.

2.3.2 Contemporary empirical evidence

The empirical foundation for infrastructure-growth relationships in South Africa has deep historical roots. Fedderke et al. (2006) provide the most comprehensive long-term analysis of infrastructure's role in South African economic growth from 1875 to 2001, finding consistent positive effects across different historical periods. Their work validates contemporary infrastructure-growth relationships within historical context, demonstrating continuity in infrastructure effects across different economic development phases. Building on this perspective, Fedderke and Bogetic (2009) extended this analysis, showing positive public capital elasticity that varies across provinces, providing early evidence of spatial heterogeneity in infrastructure effects.

Recent national studies confirm positive infrastructure-growth relationships while highlighting methodological challenges. Kumo (2012) used Granger causality analysis to demonstrate infrastructure-led growth at the national level, while Cheteni (2013) found significant contributions of transport infrastructure to long-term economic development from 1975 to 2011. However, these national studies, while confirming positive infrastructure-growth relationships, overlook the provincial variations and spatial heterogeneity that Fedderke & Bogetic (2009) first identified.

Recognizing the limitations of national-level analysis, recent research has shifted toward subnational investigations that reveal important spatial variations in infrastructure effectiveness. This emerging body of work demonstrates that infrastructure impacts vary significantly across different geographical and economic contexts within South Africa. Hanyurwumutima and Gumede (2021) assessed public transport investment effects in metropolitan cities, finding positive relationships between transport investment and urban economic development. Jili and Gumede (2023) examined transport infrastructure impacts in rural nodal municipalities, highlighting infrastructure's significance in stimulating rural economies. Their micro-level analysis suggests that infrastructure development positively affects economic activity in underdeveloped regions, though effects may differ from urban areas.

Sithole et al. (2022) provide the most comprehensive provincial-level analysis, examining infrastructure investment multipliers across South African provinces. They found that long-run multipliers (2.1-3.4) significantly exceed short-run effects (1.2-1.8), with substantial provincial heterogeneity. Multipliers were highest in provinces combining infrastructure investment with complementary policies in education, health, and institutional development.

Recent government assessments have provided additional evidence of provincial disparities and their implications. The National Treasury (2024) Infrastructure Investment Review assessed infrastructure spending effectiveness across all provinces from 2018 to 2023, finding significant variations in project implementation capacity and economic impact. Their analysis demonstrates that provinces with stronger institutional capacity and complementary human capital investments achieve substantially higher infrastructure returns.

Stats SA (2023) Provincial Infrastructure Assessment provides comprehensive analysis of infrastructure stocks and spending patterns across provinces, revealing persistent infrastructure gaps in rural provinces. Their findings show transport infrastructure spending per capita varying by over 400 percent between provinces, providing crucial baseline data for understanding provincial infrastructure disparities and their economic implications. This analysis highlights the scale of spatial inequality in infrastructure allocation that may undermine the developmental potential identified in earlier studies.

Collectively, these studies establish a clear progression from historical validation of infrastructure-growth relationships to contemporary recognition of significant spatial heterogeneity in infrastructure effectiveness. However, several critical gaps remain, while historical and national studies confirm positive infrastructure effects, and emerging subnational analysis reveals spatial variations, there is limited systematic analysis of how provincial infrastructure disparities specifically affect economic outcomes across all South African provinces. Furthermore, the interaction between infrastructure allocation patterns and provincial economic performance over time remains underexplored, particularly in the context of post-apartheid spatial development challenges.

2.3.3 Temporal dynamics and causality patterns

Empirical research reveals distinct temporal patterns in infrastructure effects across South African provinces. Short-run effects manifest through employment creation and construction-driven output increases. Phiri (2021) and Mokoena et al. (2023) demonstrate that fiscal multipliers range from 1.2 to 1.8 in the short run, with effects particularly pronounced in provinces with higher unemployment and greater construction capacity.

Long-run benefits emerge through enhanced productivity, connectivity, and agglomeration effects. Roux and Naudé (2022) and Sithole et al. (2022) show that long-run multipliers (2.1 to 3.4) substantially exceed short-run impacts, though these effects develop gradually over three to seven years and depend on complementary investments in human capital and institutions.

Causality patterns vary significantly across provinces and over time. Ncanywa & Masoga (2021) identified bidirectional causality between infrastructure and growth in advanced provinces like Gauteng and the Western Cape, where infrastructure and economic growth mutually reinforce each other. In contrast, less developed provinces such as Limpopo and the Eastern Cape show unidirectional causality from infrastructure to growth, indicating the need for infrastructure-led development strategies.

Mthembu et al. (2022) found that infrastructure-led growth dominated during the reconstruction period (2000 - 2008), while bidirectional causality emerged in advanced provinces after 2009. Khobai and Abel (2023) confirmed these patterns using bootstrap panel causality tests, showing that bidirectional causality strengthens in provinces achieving threshold development levels.

2.3.4 Provincial Economic diversity and infrastructure requirements

South Africa's provinces display significant economic diversity, influencing infrastructure requirements and potential investment returns.

Gauteng and the Western Cape are categorised as urban industrial hubs, where they face challenges with urban congestion, mass transit requirements, port capacity, and logistics efficiency. KwaZulu-Natal and the Eastern Cape are categorised as Port-Agricultural Economies, where the provinces face difficulties with port modernisation and rural connectivity. Northern Cape, Mpumalanga, Limpopo, and the North West are resource-based economies and they require enhanced transportation corridors to connect mining operations to export markets. Lastly the Free State faces infrastructure challenges relating to rural development and agricultural logistics.

All provinces face issues like maintenance versus new development trade-offs, rural-urban connectivity gaps, growing climate resilience requirements. Where limited fiscal resources create tension between addressing maintenance backlogs and expanding networks to serve previously excluded communities, these considerations affect both infrastructure design and operational costs, with implications for long-term economic benefits. This provincial heterogeneity creates varied contexts for infrastructure investment effectiveness, directly informing this study's analysis of how TIS impacts economic growth across different provincial settings. The distinct provincial typologies provide a framework for understanding potential variations in infrastructure-growth relationships that will be examined through the panel ARDL methodology

Different types of transport infrastructure produce particular economic effects related to South African provincial growth. Improved access and lower transport costs help road infrastructure to increase economic output (Canning & Bennathan, 2000; Röller & Waverman, 2001). Rail infrastructure helps passenger transport as well as freight movement. While passenger rail systems increase urban economic efficiency by lowering congestion and improving labour mobility (Glaeser & Kahn, 2004; Vickerman, 2007), efficient rail freight boosts trade and helps industrial development (Wilson & Sussman, 2004). International trade and economic integration are facilitated by ports and maritime infrastructure.

Research shows that port efficiency boosts competitiveness and lowers shipping costs (Notteboom & Winkelmans, 2001), which is especially important for South Africa's coastal provinces (Vermeulen et al., 2019). The experiences of developed economies further reinforce the economic value of transport infrastructure investment. In the United States and Germany, investments in road and freight corridors have enhanced regional productivity, reduced travel time, and supported spatial industrial development (Banister & Berechman, 2001; Button, 2010).

Efficient ports such as Rotterdam and Singapore demonstrate how modernised port infrastructure and digital logistics systems can improve trade competitiveness and reduce operational costs (the Organisation for Economic Co-operation and Development (OECD), 2016; World Economic Forum, 2020). These global insights highlight the importance of adopting integrated, intermodal infrastructure strategies in South Africa, particularly for unlocking the growth potential of less-developed provinces.

Urban mobility and access to the labour market are improved by public transport systems, especially Bus Rapid Transit networks (Cervero et al., 2004). While increased mobility improves workers' access to jobs and economic opportunities, transit-oriented development generates economic benefits through mixed-use, high-density neighbourhoods surrounding transit hubs (Calthorpe, 1993; Lucas, 2012).

Importantly, such evidence underscores the potential of transport infrastructure to promote inclusive economic development in South Africa, particularly when guided by long-term spatial and industrial policy goals (Fourie, 2006; Gwilliam, 2011).

2.4 Research gaps and study positioning

Despite substantial progress in infrastructure research, several critical gaps persist in South African literature. Most existing studies employ static analytical approaches that fail to capture the dynamic nature of infrastructure-growth relationships. The distinction between short and long-run effects remains underexplored, despite evidence that these effects differ substantially in magnitude and nature.

Provincial heterogeneity in infrastructure effectiveness receives insufficient attention in current research. While national studies provide valuable insights, they overlook significant variations in infrastructure effectiveness across provinces with different economic structures, institutional capacity, and development levels. The few existing provincial studies tend to focus on specific regions or sectors rather than providing comprehensive cross-provincial analysis.

Causality direction and temporal variations in infrastructure-growth relationships require more sophisticated analysis. Existing studies often assume unidirectional causality from infrastructure to growth, overlooking potential bidirectional relationships and temporal variations in causality patterns

Several methodological challenges limit the reliability of existing South African infrastructure research. Endogeneity concerns arise because infrastructure placement is rarely random, often reflecting political decisions, existing economic conditions, and historical factors. Most studies inadequately address these endogeneity concerns, potentially biasing results.

Infrastructure measurement presents ongoing challenges in South African research. Most studies rely on government expenditure data, which may not accurately reflect actual infrastructure capital formation owing to maintenance spending, project delays, and efficiency variations. Alternative measures such as infrastructure indices or physical infrastructure stocks remain underutilised.

The distinction between infrastructure quantity and quality receives insufficient attention. South Africa faces significant infrastructure maintenance backlogs, meaning that increased spending may primarily address maintenance rather than capacity expansion. This distinction is crucial for understanding infrastructure's economic impacts.

While recent work has introduced panel ARDL methods, a comprehensive application to transport infrastructure across all provinces is lacking. This study fills these gaps by providing the first full-panel ARDL analysis of transport infrastructure's impact on provincial growth, offering policy-relevant insights for more effective, regionally tailored infrastructure investment.

2.5 Conclusion

This chapter establishes a comprehensive foundation for examining the relationship between public TIS and economic growth in South Africa's provinces. The theoretical framework combining endogenous growth theory, new economic geography, and infrastructure as productive capital provides robust conceptual grounding for empirical analysis.

International evidence consistently demonstrates positive infrastructure-growth relationships, with recent meta-analyses confirming effect sizes typically ranging from 0.022 to 0.046 for developing countries using Panel ARDL methodology. African studies confirm these relationships while highlighting the importance of contextual factors and threshold effects in determining infrastructure effectiveness. Contemporary South African research reveals significant provincial heterogeneity in infrastructure impacts, with long-run effects substantially exceeding short-run impacts and strong evidence for infrastructure's continuing importance in regional development.

Key research gaps persist in South African literature, including limited dynamic analysis, insufficient attention to provincial heterogeneity, and inadequate treatment of causality patterns. These gaps create opportunities for contributing to both academic knowledge and policy development through rigorous empirical analysis.

The panel ARDL methodology provides a robust framework for addressing these gaps by capturing both short and long-run dynamics while accommodating provincial heterogeneity.

This approach enables policy-relevant analysis distinguishing immediate construction effects from longer-term productivity gains.

Positioned within this chapter, the present study contributes by providing the first comprehensive Panel ARDL analysis of public transport infrastructure's impact across all South African provinces. The research offers evidence-based insights for targeted, efficient infrastructure investment strategies while advancing methodological approaches in South African infrastructure research. The study's findings will inform policy development by providing quantitative evidence on infrastructure effectiveness across different provincial contexts. This evidence base supports more efficient resource allocation and regionally tailored infrastructure investment strategies, contributing to South Africa's spatial integration and economic development objectives.

Chapter 3: Methodology

This chapter outlines the methodological framework for examining the relationship between public transport infrastructure spending and economic growth across South Africa's nine provinces from 2008 to 2023. The methodology is designed to address the research gaps identified in the literature review, particularly the need for dynamic analysis that captures both short and long-run effects while accounting for provincial heterogeneity.

The research employs a positivist approach, using empirical data and statistical methods to examine whether transport infrastructure investment drives economic growth. The analysis follows standard econometric practice by developing theoretical hypotheses and testing them systematically against real-world evidence through panel autoregressive distributed lag (ARDL) methodology.

The study period of 2008 to 2023 is strategically selected to coincide with significant improvements in South African provincial budget reporting following enhanced National Treasury requirements, ensuring data reliability and consistency. This sixteen-year timeframe captures major transport infrastructure initiatives including the 2010 FIFA World Cup investments and National Development Plan implementation, while encompassing diverse economic conditions from the global financial crisis through recent challenges. The period provides sufficient temporal variation for robust panel ARDL estimation, enabling analysis of both short-run construction impacts and medium-term productivity effects.

Building on the theoretical foundations established in Chapter 2, the econometric model integrates insights from production function theory, endogenous growth theory, and new economic geography. The panel ARDL approach enables examination of both cross-sectional variations across provinces and temporal dynamics over time, providing comprehensive insights into infrastructure effectiveness while addressing key econometric challenges including endogeneity, non-stationarity, and provincial heterogeneity.

3.1 Research approach

The methodological approach is grounded in established economic theory where infrastructure enters as a productive input in the Cobb-Douglas production function, following the seminal work of Aschauer (1989) and the growth accounting framework of Barro and Sala-i-Martin (2004). This theoretical foundation necessitates panel analysis because infrastructure productivity varies across different economic structures and development levels, requiring cross-sectional variation to identify heterogeneous effects while temporal variation captures the dynamic nature of infrastructure investments. The production function approach provides the theoretical justification for examining infrastructure as a distinct input alongside private capital and labor, with panel methodology enabling the estimation of infrastructure elasticities that vary across provincial contexts.

Dynamic relationship requirements, as established by Pesaran, Shin, and Smith (2001), recognize that infrastructure-growth relationships unfold over multiple time periods, from immediate construction employment effects to long-term productivity gains. Panel ARDL methodology specifically addresses this temporal complexity by accommodating both short-run adjustments and long-run equilibrium relationships, which static cross-sectional or simple time-series approaches cannot adequately capture.

Small sample efficiency considerations, highlighted by Blackburne and Frank (2007), demonstrate that with 144 observations across nine provinces, panel ARDL methodology exhibits superior performance compared to alternative approaches like GMM or panel VAR. The methodology's efficiency in small samples ensures reliable estimation despite the limited cross-sectional dimension, while comprehensive diagnostic testing including unit root tests, cointegration analysis, and causality testing ensures methodological rigor and result reliability. This approach follows international best practice in infrastructure economics research while adapting to South African data constraints and policy contexts, ensuring that findings contribute meaningfully to both academic knowledge and policy understanding.

3.2 Data sources and variables

3.2.1 Data sources and sample

This study employs panel data covering South Africa's nine provinces from 2008 to 2023, yielding 144 observations (n=144) that provide sufficient cross-sectional and temporal variation for robust panel ARDL estimation. While this sample size may limit statistical power compared to larger datasets, panel ARDL's efficiency in small samples mitigates this concern (Pesaran et al., 2001). Primary data sources include National Treasury Provincial Budget Reviews for infrastructure spending and fiscal variables, Statistics South Africa (Stats SA) for provincial GDP estimates and demographic indicators, and the South African Reserve Bank (SARB) for macroeconomic variables and deflators.

These sources were selected based on their official status, comprehensive coverage, and consistency in reporting methodologies throughout the study period. The 2008 starting point aligns with enhanced National Treasury reporting requirements following Municipal Finance Management Act implementation, ensuring data reliability and comparability across provinces and time periods. Secondary validation sources including Provincial Treasury Reports and Development Bank of Southern Africa databases provide cross-verification capabilities and supplementary information for data quality assurance.

The sample period captures diverse economic conditions from the global financial crisis through recent economic challenges while encompassing major infrastructure policy initiatives including FIFA World Cup investments and National Development Plan implementation. This temporal coverage enables the analysis of infrastructure-growth relationships across different economic cycles and policy environments, enhancing the generalizability of findings for policy application.

3.2.2 Variables

The study estimates multiple ARDL models to analyse the dynamic relationship between transport infrastructure spending and provincial economic growth, incorporating seven key variables operationalised as described in Table 2. Variable selection follows established infrastructure economics literature while adapting to South African data availability and policy context.

Table 2: Descriptive of key variables

Variable	Code	Description	Measurement	Transformatiom
Provincial economic growth	gdp_it	Real Gross Domestic Product (GDP) of each province (dependent variable)	Percentage change in Real GDP (constant prices)	Annual growth rates calculated
South Africa Inflation Rate	inf_it	South Africa inflation rate (Control variable)	Percentage change in consumer price index	Annual percentage change
Transport infrastructure spending	ln(tis_it)	Total provincial expenditure on transport infrastructure (roads, rail, ports)	Million rands (constant 2015 prices)	Natural logarithm
Human capital index	ln(ssi_it)	Total provincial education expenditure. (proxy for social infrastructure spending)	Million rands (constant 2015 prices)	Natural logarithm
Government Capital Expenditure	ln(ce_it)	Total provincial capital expenditure	Million rands (constant 2015 prices)	Natural logarithm
Interaction term	ln(inter_it) (i.e., ln(ssi_it) × ln(tis_it))	Tests the complementarity between transport investment and human capital investment	Multiplicative term: ln(ssi_it) × ln(tis_it))	Product of natural logarithm

Note: National Treasury Provincial Budget Reviews (2008-2023), Statistics South Africa Provincial GDP estimates, and South African Reserve Bank macroeconomic data.

Source: Compiled by the author

The dependent variable, provincial economic growth, captures the primary outcome of interest using real GDP growth rates that reflect economic performance net of inflation effects. Transport infrastructure spending serves as the key explanatory variable, measured through provincial capital expenditures on roads, rail, and public transit systems.

Control variables address potential omitted variable bias while capturing complementary factors affecting economic growth. Human capital investment proxies human capital development through education expenditure, recognizing the complementary relationship between transport infrastructure and human capital formation highlighted in endogenous growth theory (Romer, 1990; Lucas, 1988). Government capital expenditure controls for broader public investment effects beyond transport infrastructure, while the interaction term captures potential synergies between transport and social infrastructure investments. The national inflation rate serves as a macroeconomic control variable, acknowledging that provincial economies operate within the broader national economic context.

Comprehensive data preparation procedures ensure dataset suitability for panel ARDL estimation while addressing potential quality concerns that could compromise analytical reliability. All nominal monetary variables are deflated to constant 2015 prices using the South African Reserve Bank GDP deflator, with the base year selected as the study midpoint to minimize extrapolation bias. Real provincial GDP at constant 2015 prices is sourced from Stats SA's Provincial GDP estimates, deflated using the national GDP deflator to ensure comparability across provinces and years. TIS data are compiled from National Treasury budget reviews, including capital expenditures on roads, rail, and public transit systems, adjusted for inflation to real 2015 terms.

Logarithmic transformation is applied to all monetary variables to linearize multiplicative relationships inherent in production function theory while enabling coefficient interpretation as elasticities. This transformation also helps stabilize variance across provinces with different economic scales, addressing heteroskedasticity concerns common in cross-sectional data.

Interaction terms are constructed as products of log-transformed variables following established econometric practice, while growth rates are calculated as annual percentage changes to provide intuitive policy interpretation. These preparation methods ensure that all variables enter the estimation process in forms appropriate for the theoretical framework and econometric methodology while maintaining economic interpretation relevant for policy application.

The final prepared dataset maintains complete balanced panel structure across all provinces and time periods, with statistical properties verified through diagnostic procedures including correlation analysis for multicollinearity assessment and distributional examination following transformations. Variable construction follows established infrastructure economics literature while adapting to South African institutional and data contexts, ensuring that empirical analysis addresses the study's research questions within appropriate theoretical and methodological frameworks.

3.3 Theoretical foundation to econometrics specification

3.3.1 Theoretical foundations ((production function, endogenous growth, new economic geography)

The econometric model derives from the theoretical framework established in Chapter 2, following a systematic progression from production function theory to dynamic panel specification. The baseline econometric model is rooted in a Cobb-Douglas production function augmented with infrastructure as a productive input, aligning with the infrastructure-as-productive-capital approach (Aschauer, 1989). The initial theoretical form is specified as:

$$Y = A \times K^{\alpha} \times L^{\beta} \times TRANS^{\gamma} \quad (1)$$

Where Y is economic output, K is private capital stock, L is labour input, $TRANS$ is public transport infrastructure spending (TIS) and α , β, γ are output elasticities.

To reflect diminishing returns, a hallmark of the Cobb-Douglas function, the sum of the elasticities is constrained such that $b_1 + b_2 + b_3 = 1$ under constant returns to scale (Barro & Sala-i-Martin, 2004). This implies that a proportional increase in all inputs yields an equivalent increase in output, with each input's marginal contribution decreasing as its share grows.

The conversion to the econometric specification involves a logarithmic transformation to linearize the relationship and enable panel estimation. Taking the natural logarithm of the production function yields:

$$\ln Y_{it} = \ln A_{it} + b_1 \ln K_{it} + b_2 \ln L_{it} + b_3 \ln TRANS_{it} \quad (2)$$

This log-linear form is adapted into the baseline model for empirical analysis:

$$\ln Y_{it} = \alpha + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln TRANS_{it} + \beta_4 \ln X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

Where α approximates $\ln A_{it}$ (with μi and λt as province and time specific fixed effects), $\beta_1, \beta_2, \beta_3, \beta_4$ are the estimated elasticities corresponding to b_1, b_2, b_3, b_4 and controls X_{it}, μ_i is province-specific fixed effects, λ_t is time-specific fixed effects and ε_{it} is the error term.

The relationship between the betas in this specification reflects the Cobb-Douglas constraint indirectly. While $\beta_1 + \beta_2 + \beta_3$ is not strictly forced to equal 1 in the estimated model (due to the inclusion of controls and fixed effects), the long-run equilibrium from the panel ARDL tests this assumption through cointegration analysis. The estimated β_3 represents the infrastructure elasticity, adjusted for provincial heterogeneity.

This specification links directly to the production function approach, positioning TIS as a productive input alongside capital and labor, enhancing output growth. Endogenous growth theory (Romer, 1990) complements this by highlighting transport infrastructure spending's potential to generate productivity spillovers, improve market efficiency, and support human capital formation, particularly in diverse provincial contexts. New economic geography theory (Krugman, 1991) adds a spatial dimension, emphasizing TIS's role in reducing transport costs, improving accessibility, and influencing regional economic concentration, which varies across South Africa's provinces.

3.2.2 The panel autoregressive distributed model specification

The panel ARDL approach is employed as the primary analytical framework, to capture both short-run dynamics and long-run relationships. The study employs the Panel ARDL (1,1) framework (Pesaran, Shin & Smith, 2001), supported by comprehensive robustness checks and diagnostic tests.

To test the theoretical hypotheses, the study employs a panel ARDL (1,1) with optimal lag specification:

Level equation:

$$\ln(GDP_{it}) = \alpha_0 + \alpha_1 \ln(GDP_{it-1}) + \beta_0 \ln(TIS_{it}) + \beta_1 \ln(TIS_{it-1}) + \gamma_1 \ln(GCE_{it}) + \gamma_2 \ln(SSI_{it}) + \gamma_3 \ln(INTER_{it}) + \eta_i + \lambda_t + \varepsilon_{it} \quad (4)$$

The level equation models the long-run relationship between economic growth and its key determinants using panel data. It specifies that the natural logarithm of provincial GDP, $\ln(\mathrm{GDP}_{it-1})$, depends on its own lagged value,$\ln(\mathrm{TIS}_{it})$ *and* $\ln(\mathrm{TIS}_{it-1})$, lagged values of TIS and other control variables, including government capital expenditure $\ln(\mathrm{GCE}_{it})$, social spending investment $\ln(\mathrm{SSI}_{it})$ and Interaction term $\ln(\mathrm{INTER}_{it})$. The model includes a random effect for provinces η_i and time periods λ_t to control for unobserved heterogeneity and common shocks. The error term ε_{it} captures idiosyncratic shocks.

Error correction representation:

$$\Delta \ln(GDP_{it}) = \alpha_i + \phi(\ln(GDP_{it-1}) - \theta_1 \ln(TIS_{it-1}) - \theta_2 \ln(GCE_{it-1}) - \theta_3 \ln(SSI_{it-1}) - \theta_4 \ln(INTER_{it-1})) + \beta_2 \Delta \ln(TIS_{it}) + \lambda_t + \varepsilon_{it} \quad (5)$$

The error correction form captures the short-run dynamics while linking them to the long-run equilibrium relationship. The change in the natural log of GDP $\Delta \ln(\text{GDP}_{it})$ is influenced by the error correction term ϕ, which measures the deviation from the long-run equilibrium.

3.2.3 Model justification

The selection of the ARDL (1,1) specification is justified on theoretical, statistical, and practical grounds that align with the study's research objectives and data constraints (Pesaran, Shin & Smith 2001).

From a theoretical perspective, the one-year lag structure effectively captures the institutional and implementation dynamics of South African provincial government. Infrastructure projects typically follow annual budget allocation cycles, and the immediate economic effects of transport infrastructure spending materialise within a 12-month timeframe. These effects manifest through construction employment, procurement activities, and initial accessibility improvements, making the one-year lag structure theoretically appropriate for this context.

Statistically, model selection criteria provide strong empirical support for this specification. Both the Akaike information criterion (AIC) and Bayesian information criterion (BIC) consistently favour the ARDL (1,1) specification over higher-order alternatives such as ARDL (2,1) or ARDL (1,2) (Pesaran 2015), confirming that additional lags do not improve model performance.

The panel ARDL methodology itself offers several methodological advantages that make it particularly suitable for this study. First, this approach accommodates variables with different stationarity properties, allowing for mixed integration orders without requiring all variables to be integrated at the same order (Pesaran et al., 2001). Second, the methodology permits heterogeneous dynamics across provinces, enabling province-specific short-run adjustments that capture regional variations in economic responses (Pesaran & Smith, 1995).

Moreover, panel ARDL facilitates cointegration testing through bounds testing procedures without prior unit root requirements, making it robust to mixed I(0) and I(1) variables (Pesaran et al., 2001). The approach also effectively addresses endogeneity concerns by handling simultaneity through its dynamic specification, which includes lagged values of both dependent and independent variables (Blackburne & Frank, 2007).

Finally, the error correction mechanism inherent in panel ARDL distinguishes between short-run and long-run effects, providing comprehensive insights into both immediate and equilibrium relationships (Pesaran et al., 2001). This feature is particularly valuable for understanding how transport infrastructure investments affect economic outcomes across different time horizons.

Compared to other methods such as the generalized method of moments (GMM) or panel vector autoregression (VAR), panel ARDL provides more robust long-run estimates in small to moderate samples, which is typical of South Africa's nine provinces. It allows for the inclusion of lagged dependent variables, fixed effects to control for time-invariant heterogeneity, and cointegration testing via bounds testing without prior unit root tests. These features improve statistical efficiency and address key identification concerns, including endogeneity arising from infrastructure investment being both a cause and a consequence of economic growth. Furthermore, the methodology accommodates error correction mechanisms that help distinguish short-term employment effects from longer-term productivity gains, making it highly applicable in policy settings requiring clear temporal interpretation.

Beyond estimation robustness, panel methodologies offer critical tools for addressing fundamental empirical challenges in infrastructure studies. Fixed effects control for unobserved provincial characteristics that influence investment decisions, while dynamic specifications capture persistence in growth outcomes. As highlighted by Duflo & Pande (2007) and Donaldson (2018), infrastructure placement is rarely random, often shaped by historical and political factors. Innovative strategies, including the use of historical quasi-experiments and robust panel causality testing, enhance empirical credibility. Panel ARDL's compatibility with such approaches makes it a theoretically sound and empirically validated choice for examining infrastructure-growth relationships in heterogeneous, evolving contexts like South Africa.

The panel ARDL methodology, which will examine these relationships across various provincial contexts, is informed by the theoretical and empirical underpinnings established by this review. This looks at how spending on transport infrastructure affects provincial economic growth in South Africa. Robustness checks and diagnostic tests are conducted to ensure model reliability and address potential econometric concerns such as cross-sectional dependence, heteroskedasticity, and serial correlation.

3.4 Econometric test

This section outlines the econometric tests employed to assess the integration properties, long-run relationships, model specifications, and causal directions in the study of public transport infrastructure spending (TIS) and provincial economic growth in South Africa. The methodology leverages panel data techniques tailored to the nine provinces from 2008 to 2023, ensuring robust analysis of heterogeneous dynamics.

3.4.1 Panel unit root test and cointegration test

To determine the integration orders of the variables, the study applies the Levin–Lin–Chu (LLC) panel unit root tests, following the approaches of Levin, Lin, and Chu (2002) and Im, Pesaran, and Shin (2003). The LLC test assumes a homogeneous alternative and is specified as:

LLC Test (Homogeneous Alternative):

$$\Delta y_{\mathrm{it}} = \alpha \times y_{\mathrm{it}}{}^{-1} + \Sigma\beta_{\mathrm{j}} \times \Delta y_{\mathrm{it}}{}^{-}{}_{\mathrm{j}} + \delta_{\mathrm{it}} + \varepsilon_{\mathrm{it}} \tag{6}$$

- H_0: α = 0 (unit root, non-stationary)
- H_1: α < 0 (stationary), This test evaluates whether the panel data exhibits unit root behaviour, guiding the selection of appropriate modelling techniques.

To verify long-run relationships, the study employs the Pedroni (1999, 2004) and Kao (1999) cointegration tests. The Pedroni tests provide seven statistics to assess cointegration under heterogeneous dynamics:

- Within-Dimension: Panel v-statistic, rho-statistic, PP-statistic, and ADF-statistic.
- Between-Dimension: Group rho-statistic, PP-statistic, and ADF-statistic.

These tests account for cross-sectional dependencies and varying adjustment speeds across provinces.

3.4.2 Model diagnostic test

Model diagnostics are conducted to validate the panel ARDL specification. The Hausman test is applied to choose between fixed effects (FE) and random effects (RE) models, with the test statistic defined as:

Hausman Test: $H = (\hat{\beta}_{FE} - \hat{\beta}_{RE})'[Var(\hat{\beta}_{FE}) - Var(\hat{\beta}_{RE})]^{-1}(\hat{\beta}_{FE} - \hat{\beta}_{RE}) \sim \chi^2(k)$, to select between random and fixed effects

Where $\hat{\beta}_{FE}$ and $\hat{\beta}_{RE}$ are the are the fixed and random effects estimators, and k is the number of parameters.

The random effects model assumes orthogonality, homoskedasticity and no cross-sectional correlation. Further diagnostics will be reported with p-values in Chapter 4 to ensure model reliability.

3.4.3 Granger causality test

To assess the directionality between TIS and provincial GDP growth, the study employs panel-based causality tests following Dumitrescu and Hurlin (2012). The bidirectional causality framework is specified as:

Bidirectional Causality Tests:

$$GDP_{it} = \Sigma\alpha_j \times GDP_{it-j} + \Sigma\beta_j \times TIS_{it-j} + X_{it} + \varepsilon_{it} \quad (7)$$

$$TIS_{it} = \Sigma\gamma_j \times TIS_{it-j} + \Sigma\delta_j \times GDP_{it-j} + X_{it} + \nu_{it}$$

Hypothesis Testing:

$$H_0: TIS\ does\ not\ Granger - cause\ GDP \rightarrow \beta_j = 0\ for\ all\ j$$

$$H_0: GDP\ does\ not\ Granger - cause\ TIS \rightarrow \delta_j = 0\ for\ all\ j$$

Lag Selection: The Akaike Information Criterion (AIC) determines the optimal lag length, with a maximum of 3 lags given the sample size (2008–2023). Robustness checks will explore alternative lag specifications to ensure consistency.

Expected Outcomes: These tests will determine whether TIS drives GDP growth (supporting infrastructure-led growth) or if GDP influences TIS (indicating reverse causality). Interpretations and findings will be detailed in Chapter 4, linking results to the study's objectives and theoretical framework.

3.5 Endogeneity concerns

The study addresses three primary sources of endogeneity that could bias the estimated relationship between TIS and provincial economic growth (Wooldridge, 2020). First, reverse causality presents a significant concern as economically successful provinces may receive higher infrastructure allocations through political economy channels, where national government prioritises investment in regions demonstrating growth potential or political importance (Calderón & Servén, 2010). Second, omitted variable bias could arise from unobserved provincial characteristics that simultaneously influence both infrastructure spending decisions and economic growth outcomes, such as institutional quality, local political dynamics, or unmeasured geographic advantages.

Third, measurement error introduces potential bias as infrastructure expenditure may not perfectly capture the actual infrastructure services that drive economic growth, given variations in project efficiency, construction quality, and infrastructure utilisation across provinces (Aschauer, 1989; Fedderke & Bogetic, 2009).

To address these endogeneity concerns, the study employs a comprehensive methodological approach which is the random effects, the estimation controls for unobserved heterogeneity while allowing for efficient parameter estimation when provincial-specific effects are uncorrelated with explanatory variables (Baltagi, 2021). The lagged infrastructure spending variables reduce simultaneity bias by introducing temporal separation between the explanatory variable and contemporaneous growth outcomes and the dynamic ARDL specification partially addresses endogeneity through its treatment of feedback effects and adjustment processes (Pesaran, Shin & Smith, 2001).

While perfect causal identification would require instrumental variables that are unavailable for South African provincial infrastructure data, the combination of random effects estimation and dynamic specification provides a reasonable framework for analysing infrastructure-growth relationships, with results interpreted as robust associational evidence with strong theoretical support for causal interpretation (Perkins, Fedderke & Luiz, 2005).

3.6 Conclusion

This chapter has outlined the methodological framework for investigating the infrastructure–growth nexus across South African provinces. By employing a Panel ARDL estimator, the study accounts for dynamic adjustment, provincial heterogeneity, and long-run equilibrium relationships. Using real GDP growth at constant prices ensures that results reflect actual economic output changes, providing policymakers with reliable evidence on the effectiveness of public transport infrastructure investments. For instance, the findings can guide prioritization of mass transit in urban hubs like Gauteng or rural connectivity in resource-based provinces like Limpopo, potentially informing provincial budget allocations and national infrastructure strategies. The next chapter presents the results of this empirical strategy, including diagnostic tests, estimation outcomes, and robustness checks.

Chapter 4: Results and Discussion

This chapter presents the empirical findings from the panel ARDL analysis examining the relationship between public transport infrastructure spending (TIS) and economic growth across South African provinces from 2008 to 2023. The results address the research questions outlined in Chapter 1 and are grounded in the theoretical frameworks (Chapter 2) and methodology (Chapter 3).

4.1. Descriptive statistics and variable overview

The descriptive statistics presented in Table 3 provide foundational insights into the key variables examining the relationship between public transport infrastructure investment and economic growth across South African provinces. The analysis focuses on six critical variables that capture both economic performance and public sector investment patterns.

Table 3: Descriptive Statistics of key variables

Variables	Mean	Std. Dev	Min	Max	Observations
GDP (Y)	0.0114	0.0242	-0.069	0.069	N=144
Log of Transport Infrastructure (lgtis)	7.298	1.099	2.890	9.061	N=144
Inflation (inf)	5.610	1.566	3.232	9.910	N=144
Unemployment (unemp)	27.298	5.966	15.9	45.0	N=144
Log of Social Spending Investment (lgssi)	9.818	0.690	7.956	11.045	N=144
Log of Capital Expenditure (lgce)	8.629	1.101	6.940	11.180	N=144
Log of Interaction term (lgInter)	72.104	14.000	22.995	100.077	N=144

Note: Variables: GDP (Y) = Provincial real GDP growth rate (annual % change); lgtis = Natural log of public transport spending (million constant 2015 Rands); inf) = National CPI inflation rate (%); unemp = Provincial unemployment rate (%); lgssi = Natural log of social infrastructure expenditure (million constant 2015 Rands); lgce = Natural log of total capital spending (million constant 2015 Rands); lgInter = Interaction between lgssi & lgtis Std. Dev. = Standard deviation

Source: Compiled by the author

Key observation from the descriptive analysis shows that the GDP growth rate demonstrates considerable volatility with an average of 1.14 percent and a standard deviation of 2.42 percent, ranging from -6.9 percent to +6.9 percent. This substantial variability reflects the diverse economic trajectories across South Africa's nine provinces during a period marked by significant structural challenges, including the 2008 to 2009 global financial crisis, domestic political uncertainty, load-shedding crises, and COVID-19's economic disruption.

Public LGTIS measured in logarithmic terms, shows an average of 7.298 with moderate dispersion (standard deviation 1.099). The wide range from 2.89 to 9.06 indicates significant variation in infrastructure investment levels across provinces, likely reflecting differences in fiscal capacity, urban development needs, and policy priorities. Provinces like Gauteng and the Western Cape, with major metropolitan areas, typically maintain higher infrastructure spending levels compared to rural provinces.

The notably high unemployment rates, averaging 27.3 percent and ranging from 15.9 percent to 45 percent, highlight South Africa's persistent socio-economic challenges. This context is particularly relevant for public transport infrastructure analysis, as improved public transportation can enhance labour mobility, reduce job search costs, and connect workers to employment opportunities across urban and peri-urban areas. The wide variation across provinces also reflects differential economic structures and development levels.

The inflation rate averaged 5.61 percent during the study period, with a range from 3.23 percent to 9.91 percent, capturing periods of both price stability and elevated inflation pressure. This variation reflects different monetary policy cycles and external shocks affecting the South African economy.

4.2. Preliminary diagnostic tests

4.2.1 Panel unit root test

Before proceeding with the main analysis, we apply the Levin-Lin-Chu (LLC) and Im-Pesaran-Shin (IPS) panel unit root tests to assess the stationarity of panel data variables before conducting econometric analyses. Establishing the stationarity properties of variables constitutes a fundamental prerequisite for panel time series analysis. Following Baltagi (2021), proper identification of integration orders ensures appropriate model specification and reliable estimation in panel data econometrics. The study employed LLC testing approaches to robustly verify stationarity properties.

Table 4: Levin -Lin Unit Root Test

Variables	Level (p-value)	First difference (p-value)	Order of Integration
Gdp (Y)	0.0000	0.0000	I(0)
lgssi	0.0000	0.0001	I(0)
lginter	0.0000	0.0000	I(0)
inf	0.0000	0.0001	I(0)
unemp	0.6163	0.0000	I(1)
lgtis	0.0000	0.0000	I(0)
lgce	0.0000	0.0000	I(0)

Note: Test for stationarity in panel data (Levin-Lin-Chu method). p-values <0.05

Source: Compiled by the author

The LLC test results reveal a mixed order of integration across variables. Unemployment (UNEMP) demonstrates non stationarity at levels I(0), rejecting the null hypothesis of non-stationarity with p-values significantly below 0.05. Conversely, social spending (LGSSI), inflation (INF), unemployment (UNEMP), transport infrastructure spending (LGTIS), and capital expenditure (LGCE) exhibit unit root behaviour at levels, requiring first differencing to achieve stationarity I(1).

4.2.2 Panel cointegration test

Table 5: Pedroni Panel Cointegration Test

Test Statistics	Panel Statistics	Group Statistics
v-statistic	-0.0823	-
rho-statistic	-7.003***	-5.046***
PP-statistic (t-stat)	-11.81***	-14.28***
ADF-statistic	-2.933***	-2.044**

Notes: ***, **, * Statistical significance at 1% (), 5% (), and 10% () levels.

Source: Compiled by the author

The Pedroni cointegration tests provide strong evidence of a long-run equilibrium relationship between TIS and provincial GDP in South Africa. Six of the seven test statistics reject the null hypothesis of no cointegration at conventional significance levels, with particularly strong evidence from the panel and group t-statistics (-11.81 and -14.28 respectively).

The consistency between within-dimension (panel) statistics, which assume homogeneous cointegration parameters across provinces, and between-dimension (group) statistics, which allow for parameter heterogeneity, strengthens confidence in the cointegration finding. This result provides strong theoretical justification for the subsequent panel estimation approach and supports the hypothesis that infrastructure spending generates lasting effects on provincial economic performance.

The cointegration finding implies that while short-term deviations may occur due to economic shocks, policy changes, or implementation delays, transport infrastructure spending and economic output maintain a consistent long-term relationship. This suggests that infrastructure investments create enduring economic benefits rather than merely temporary stimulus effects, aligning with endogenous growth theory's emphasis on infrastructure as a driver of sustained development.

4.2.3 Hausman test

To formally test which model is more appropriate, the Hausman test was conducted. This test evaluates the null hypothesis that the preferred model is Random Effect (RE) and that there is no systematic difference in coefficients between the Fixed Effect (FE) and RE estimators. The results of the Hausman test are presented as follows Chi-squared (χ^2) statistic = 8.10 and degrees of freedom = 5 with p-value = 0.1508

Given that the p-value exceeds the conventional 5% significance level, we fail to reject the null hypothesis. This implies that the assumption of no correlation between the individual effects and the regressors holds. Therefore, the RE model is the more efficient and appropriate specification for the data.

Although minor warnings related to the variance matrix and scale differences across variables were noted, these are common in panel datasets and do not undermine the reliability of the test results. Consequently, all further interpretation of regression outcomes is based on the RE model.

The random effects specification is theoretically justified in this context for several reasons which includes the sample coverage. The study includes all nine South African provinces, representing the entire population rather than a random sample, making random effects appropriate for inference about this specific set of provinces. In terms of time-invariant factors where many provincial characteristics that affect economic growth (geographic location, natural resource endowments and historical development patterns) are time-invariant and may be uncorrelated with infrastructure spending decisions, supporting the random effects assumption (Wooldridge, 2010; Baltagi, 2021).

This approach was necessitated by multicollinearity issues encountered with fixed effects estimation, where the inclusion of provincial dummy variables created perfect collinearity problems that prevented proper model estimation. The random effects specification assumes that provincial-specific effects are distributed independently of the explanatory variables, allowing the model to capture both within-province and between-province variation in the infrastructure-growth relationship.

Standard errors are clustered at the provincial level to account for serial correlation within provinces and potential heteroskedasticity across provinces, providing robust statistical inference that remains valid even when residuals exhibit within-province correlation patterns (Bertrand et al., 2004; Cameron & Miller, 2015).

The choice of random effects over fixed effects is driven by practical estimation constraints rather than theoretical preferences. While fixed effects estimation would theoretically provide stronger controls for unobserved provincial heterogeneity, the severe multicollinearity problems rendered this approach unfeasible for the current dataset. The random effects approach represents a reasonable compromise that maintains statistical validity while allowing for meaningful parameter estimation, with the caveat that results should be interpreted with awareness of the stricter exogeneity assumptions required for consistency.

Random effects estimation and dynamic specification provide strong associational evidence with plausible causal interpretation, but perfect causal identification would require experimental or quasi-experimental variation.

While this study employs random effects estimation and dynamic ARDL specification to control for unobserved heterogeneity and reduce endogeneity concerns, the findings should be interpreted as strong associational evidence with plausible causal interpretation rather than definitive causal effects (Wooldridge, 2020). Perfect causal identification would require experimental or quasi-experimental variation in transport infrastructure allocation, such as randomized infrastructure assignments or natural experiments with exogenous policy changes, which are unavailable in the South African provincial context.

The random effects approach relies on the critical assumption that provincial-specific effects are uncorrelated with the explanatory variables, which may not hold if unobserved provincial characteristics simultaneously influence both infrastructure allocation decisions and economic growth outcomes (Baltagi, 2021). The potential for reverse causality remains, where provinces experiencing economic growth may subsequently receive higher infrastructure allocations through political economy channels, and omitted variable bias could still influence results despite the comprehensive control strategy employed.

The choice of random effects estimation, while necessitated by multicollinearity constraints, introduces additional methodological considerations that must be acknowledged. Unlike fixed effects estimation, which would eliminate all time-invariant provincial characteristics regardless of their correlation with explanatory variables, random effects estimation requires the assumption that these characteristics are uncorrelated with infrastructure spending and other regressors (Wooldridge, 2020). This assumption may be particularly challenging in the South African context, where historical, geographic, and institutional factors that vary across provinces may simultaneously influence both infrastructure allocation decisions and economic growth trajectories (Perkins, Fedderke & Luiz, 2005).

Random effects estimates are more relevant for policymakers interested in the average effect of infrastructure spending across all provinces. Random effects estimation utilizes both within and between province variation, providing more efficient estimates when the orthogonality assumption holds.

4.3. Main empirical results

This section presents the empirical findings in four parts: first, the main regression results examining infrastructure-growth relationships (4.3.1); second, provincial heterogeneity analysis revealing differential impacts across provinces (4.3.2); third, robustness checks including causality testing (4.3.3).

4.3.1 Main regression results

The random effects ARDL model is appropriate for estimating the short and long-run effects of spending on GDP growth across South African provinces while accounting for unobserved heterogeneity between provinces (Hsiao, 2014). The random effects specification is preferred over fixed effects as it avoids multicollinearity issues that arise when province-specific intercepts are perfectly correlated with explanatory variables, and the Hausman test confirms that the random effects estimator is consistent and efficient for this dataset (Cameron & Trivedi, 2005).

The ARDL specification allows for the estimation of both immediate and lagged effects, capturing the dynamic nature of infrastructure impacts on economic growth, while the random effects framework assumes that unobserved provincial characteristics are uncorrelated with the explanatory variables, making it suitable for examining cross-provincial variations in the spending-growth relationship (Kamps, 2006; Calderón & Servén, 2010).

Table 6: Random Effects Panel Regression Results

Variables	**Coefficient**	**Robust std. Error**	**z-statistics**	**p-value**
Lgtis	0.0182933	0.0069654	2.63	0.009
L1.lgtis	0.0101344	0.0017015	5.96	0.000
Inf	0.0109625	0.0012738	8.61	0.000
Unemp	-0.001466	0.0003916	-3.74	0.000
lgssi	0.0097451	0.0058077	1.68	0.093
lgce	0.0010149	0.0010045	1.01	0.312
lgInter	-0.0025212	0.0008642	-2.92	0.004
_cons	-0.141365	0.0568944	-2.48	0.013

Note: Lgtis = Current log transport infrastructure spending; L1.lgtis = One-period lag of lgtis. Other variables as in Table 3. Coefficients represent percentage point changes in GDP growth. Robust std. errors clustered by province. p-values: 0.000 = p

Source: Compiled by the author

The regression results reveal that TIS generates both immediate and lagged positive effects on provincial GDP. The current-period transport infrastructure coefficient (0.0182933, p=0.009) is statistically significant, while the lagged infrastructure coefficient (0.0101344, p<0.001) is highly significant. The combined infrastructure effect over two years equals 0.0284 percentage points (0.0182933 + 0.0101344), yielding an infrastructure elasticity of approximately 0.028 percent.

4.3.2 Provincial heterogeneity analysis

In the regression model, the Western Cape is treated as the reference (base) province. This methodological choice is supported by several substantive and statistical considerations that enhance the interpretability and robustness of the provincial heterogeneity analysis.

Western Cape contributes approximately 16 percent to national GDP, making it the second-largest provincial economy after Gauteng. This substantial economic scale provides a meaningful baseline for comparative analysis, as deviations from this reference represent economically significant variations rather than comparisons to a marginal economy.

Good Governance Africa recognises the Western Cape's municipalities as best in the country, indicating superior institutional capacity for infrastructure planning, implementation, and maintenance. This governance quality provides a stable institutional baseline against which other provinces' infrastructure-growth relationships can be assessed. The province's institutional stability reduces the likelihood that reference category effects are driven by governance failures rather than genuine economic relationships.

Unlike provinces heavily dependent on single sectors (such as mining or agriculture), the Western Cape demonstrates significant economic diversification across manufacturing, services, agriculture, and tourism. This diversification provides a more stable foundation for measuring infrastructure impacts across different economic activities and reduces the risk of sectoral shocks affecting the reference baseline.

The province exhibits sufficient variation in infrastructure spending over the study period without extreme outliers, making it suitable as a reference category that avoids estimation bias from atypical observations. Additionally, the Western Cape's intermediate position between highly urbanized Gauteng and predominantly rural provinces provides a balanced reference point for interpreting provincial variations.

This methodological choice allows for meaningful interpretation of provincial coefficients as deviations from a well-established, economically significant, and institutionally stable baseline. The coefficients presented in Table 6 therefore represent additional effects relative to the Western Cape baseline, indicating how each province's infrastructure-growth relationship differs from the reference performance under optimal governance and business confidence conditions.

These are comparative measures, not absolute performance scores. For example, a positive coefficient for Eastern Cape indicates that transport infrastructure spending there is associated with a greater marginal impact on GDP growth than in the Western Cape, all else being equal. Conversely, a negative coefficient for Free State implies a weaker effect relative to the Western Cape. This comparative framework helps identify provincial variations in the infrastructure-growth relationship and informs more geographically targeted policy recommendations.

Table 7: Provincial-Specific Random Effects

Provinces	Provinces Names	Coefficient	Robust std. Error	z-statistics	p-value
Province 1	Western Cape	-	-	-	-
Province 2	Eastern Cape	0.0174**	0.0055	3.23	0.001
Province 3	Northern Cape	0.0037	0.0043	0.87	0.386
Province 4	Free State	-0.0096*	0.0051	-1.90	0.058
Province 5	KwaZulu Natal	0.0105*	0.0055	1.90	0.057
Province 6	North West	-0.0062	0.0054	-1.15	0.249
Province 7	Gauteng	0.0173***	0.0046	3.74	0.000
Province 8	Mpumalanga	0.0085*	0.0037	2.28	0.023
Province 9	Limpopo	-0.0015	0.0015	-1.00	0.315

Note: Robust std. errors clustered by province. ***, **, * denote significance at 1%, 5%, and 10% levels (p<0.01; p<0.05; p<0.10)

Source: Compiled by the author

Given Western Cape's strong governance quality, high business confidence, and economic diversification baseline, the provincial variations reveal important policy insights about infrastructure effectiveness under different institutional and economic conditions.

The provincial coefficients represent additional effects relative to the Western Cape baseline. Eastern Cape (0.0174, p=0.001) and Gauteng (0.0173, p<0.001) show the strongest statistically significant positive effects. Mpumalanga (0.0085, p=0.023) and KwaZulu-Natal (0.0105, p=0.057) demonstrate moderate positive effects. Free State (-0.0096, p=0.058) shows marginally significant negative effects, while North West (-0.0062, p=0.249) and Limpopo (-0.0015, p=0.315) exhibit negative but statistically insignificant coefficients. Northern Cape (0.0037, p=0.386) shows small, statistically insignificant positive effects.

4.3.3 Granger causality analysis

To specifically address the third research objective, which is to determine the direction of causality between TIS and economic growth, the bidirectional Granger causality tests were conducted within a panel data framework. This analysis is crucial for understanding whether infrastructure spending drives growth, growth drives infrastructure spending, or whether both relationships exist simultaneously.

The null hypotheses tested were:

H_0: GDP does not Granger-cause LGTIS

H_0: LGTIS does not Granger-cause GDP

Lag specifications of 1, 2, and 3 periods were used to test these hypotheses to account for potentially delayed effects on the infrastructure-growth relationship. According to Calderón and Servén (2008), this multi-lag approach recognizes that infrastructure expenditures may have an impact on economic results throughout a range of periods.

Table 8: Granger causality test

Null hypothesis	**Test statistics**	**p-value**	**Lag**	**5% Significance**
Does GDP Granger-cause LGTIS?	0.17	0.6769	Level	Fail to reject H_0
	0.81	0.3698	Level 1&2	Fail to reject H_0
	2.64	0.0789	Level 1, 2 & 3	Fail to reject H_0*
Does LGTIS Granger-cause GDP	5.82	0.0015	Level	Reject H_0
	1.41	0.2488	Level 1&2	Fail to reject H_0
	5.82	0.0015	Level 1, 2 & 3	Reject H_0

Note: At p-values <0.05 reject null hypothesis (no causality) at 5% level. Lags: Level = Lag 1; Level 1&2 = Lags 1-2; Level 1,2&3 = Lags 1-3.

Source: Compiled by the author

The Granger causality results reveal a predominantly unidirectional relationship between transport infrastructure investment and economic growth across South African provinces. Specifically. The results show that GDP growth does not Granger-cause transport infrastructure spending across all lag specifications (p-values: 0.6769, 0.3698, 0.0789). Conversely, transport infrastructure spending Granger-causes GDP growth at 1-lag (p=0.0015) and 3-lag (p=0.0015) specifications, but not at the 2-lag specification (p=0.2488).

4.3.4 Robustness checks

Initial attempts to estimate fixed effects models encountered severe multicollinearity problems, with condition numbers exceeding conventional thresholds. This issue arose because transport infrastructure investments follow multi-year cycles, creating a high correlation between current and lagged spending levels, and provinces with historically high spending levels tend to maintain elevated investment patterns. The resulting near-perfect correlation between current and lagged infrastructure variables, combined with province-specific time trends, created linear dependencies that prevented reliable coefficient estimation. The Variance Inflation Factors (VIFs) for key variables ranged from 2.1 to 8.7, with infrastructure variables showing the highest multicollinearity. The correlation matrix revealed coefficients exceeding 0.85 between current and lagged infrastructure spending in the fixed effects specification.

The random effects specification successfully addresses these multicollinearity concerns while maintaining econometric rigor. The correlation matrix revealed coefficients exceeding 0.85 between current and lagged infrastructure spending in fixed effects specifications, but these correlations remain manageable in the random effects framework.

4.4 Interpretation of main findings

This study provides comprehensive empirical evidence that public spending on transport infrastructure contributes meaningfully to provincial economic growth in South Africa. The findings reveal a nuanced relationship characterized by immediate economic impacts, long-term equilibrium dynamics, and significant provincial heterogeneity. These results emerge from one of the most economically challenging periods in South Africa's democratic history, encompassing the global financial crisis, persistent load-shedding, political uncertainty, and COVID-19, making the consistency of the infrastructure-growth relationship particularly noteworthy.

The robustness of these findings aligns with recent global evidence on transport infrastructure in economic development. Transport infrastructure drives economic growth and social inclusion in developing countries, supporting theoretical frameworks that position infrastructure investment as a fundamental driver of sustainable development (Zhang et al., 2018; Dimitriou et al., 2021). The persistence of positive infrastructure effects despite South Africa's challenging economic environment demonstrates the resilience of the infrastructure-growth nexus, consistent with findings from other emerging economies facing similar structural constraints (Maparu & Mazumder, 2017; Banerjee et al., 2020).

4.4.1 Infrastructure-growth relationship analysis

The panel ARDL results provide comprehensive evidence of transport infrastructure's economic effects across South African provinces. The current-period transport infrastructure coefficient (0.0183, p=0.009) demonstrates immediate positive effects on provincial GDP growth. This immediate impact likely reflects construction-phase employment, procurement activities, and early accessibility improvements, consistent with production function theory's predictions about infrastructure as a productive input. These immediate effects align with recent South African evidence from Phiri (2021) and Mokoena et al. (2023), who found short-run fiscal multipliers of 1.2-1.8 for infrastructure spending.

The highly significant lagged infrastructure coefficient (0.0101, $p<0.001$) captures longer-term productivity benefits as completed infrastructure projects enhance economic efficiency, reduce transportation costs, and attract additional private investment. This temporal pattern supports endogenous growth theory's emphasis on infrastructure's role in generating persistent productivity spillovers beyond direct construction effects, while also aligning with Roux and Naudé's (2022) documentation of long-run multipliers of 2.1-3.4 developing over 3-7 years in the South African context.

The combined infrastructure effect over two years (0.0183 + 0.0101 = 0.0284 percentage points) yields an infrastructure elasticity of approximately 0.028 percent. This indicates that a 1 percent increase in transport infrastructure spending associates with a 0.028 percent increase in provincial GDP growth over two years. This elasticity falls within established international benchmarks but toward the lower end of the distribution. Calderón and Servén (2010) found infrastructure elasticities ranging from 0.07 to 0.10 for developing countries, while meta-analyses report typical ranges of 0.02-0.08 for developing economies (Romp & De Haan, 2007; Bom & Ligthart, 2014).

The relatively modest magnitude aligns closely with other sectoral infrastructure studies and recent African evidence. Ali et al. (2025) reported comparable infrastructure-growth elasticities in Nigeria using ARDL methodology, while Kalejaiye et al. (2023) found similar transport infrastructure effects across ECOWAS countries. This convergence across Sub-Saharan African contexts using similar methodologies provides strong external validation of the elasticity estimates. Furthermore, Fedderke and Bogetic (2009), using earlier South African data, reported similar modest effects, suggesting consistency in the South African infrastructure-growth relationship over time.

Several methodological and contextual factors explain this positioning within the international literature. First, sectoral infrastructure studies typically yield lower elasticities than aggregate infrastructure measures due to complementarity effects between infrastructure types (Égert et al., 2009; Straub, 2011). Second, infrastructure effectiveness depends critically on institutional quality and complementary factors (Esfahani & Ramírez, 2003; Rodrik et al., 2004), factors that may vary significantly across South African provinces. Third, spatial spillover effects, which may account for 20-30 percent of total infrastructure benefits (Cohen & Morrison Paul, 2004), are not captured in this provincial-level analysis.

Despite the modest magnitude, the effect remains economically significant when considered at scale. For provinces spending R2-5 billion annually on transport infrastructure, a 0.028 elasticity translates to GDP impacts of R56-140 million per year, with cumulative effects building over time through the demonstrated cointegration relationship (Zhang et al., 2018; Dimitriou et al., 2021).

4.4.1.1 Long-run equilibrium relationship

The strong cointegration evidence confirms the existence of a stable, long-run equilibrium relationship between transport infrastructure spending and provincial GDP. These findings align strongly with foundational theoretical work on infrastructure and growth. Aschauer (1989) established the theoretical framework for understanding public expenditure productivity, particularly infrastructure's role in enhancing private sector productivity. Our results provide contemporary South African evidence for Aschauer's core proposition that public infrastructure investment generates significant economic returns through productivity enhancement channels.

Romer (1990) and Lucas (1988) developed endogenous growth theory emphasizing the role of public goods, including infrastructure, in generating sustained economic growth. Our cointegration findings and evidence of long-term infrastructure-growth relationships directly support these theoretical predictions, demonstrating that transport infrastructure creates the type of persistent productivity gains that endogenous growth theory predicts.

Krugman (1991) provided theoretical foundations for understanding spatial economic development and agglomeration effects. Our provincial heterogeneity findings, particularly the strong performance of Gauteng and the challenges in rural provinces, align with Krugman's predictions about how infrastructure investments interact with existing economic concentrations to generate differential returns.

Recent empirical studies have reinforced this theoretical foundation, with Melo et al. (2013) demonstrating that transport infrastructure generates persistent productivity gains through reduced transaction costs and enhanced connectivity. Their meta-analysis of transport infrastructure productivity found elasticity ranges of 0.02-0.08 percent for developing countries, and our elasticity of 0.028 percent falls within their confidence intervals, providing strong empirical validation of our results within the broader international literature.

The cointegration result suggests that infrastructure investments create lasting economic benefits rather than merely temporary stimulus effects. This relationship's stability over the 2008-2023 period, which included the global financial crisis, domestic political volatility, energy crises, and COVID-19, demonstrates remarkable robustness in the infrastructure-growth nexus across South African provinces. This resilience echoes findings from Crescenzi & Rodriguez-Pose (2012), who documented stable infrastructure-growth relationships across European regions despite varying economic cycles and external shocks (World bank, 2021).

The long-run relationship implies that while short-term deviations may occur owing to implementation delays, economic shocks, or policy changes, TIS and economic output maintain a consistent equilibrium path. This provides strong theoretical justification for sustained infrastructure investment programs and supports arguments for infrastructure as a foundation for long-term economic strategy, consistent with recent policy frameworks emphasizing infrastructure's role in structural transformation (Calderón & Servén, 2014; World Bank, 2021).

4.4.1.2 Dynamic effect of infrastructure spending

The regression results reveal that TIS operates through dynamic channels, with both immediate and lagged effects contributing to economic growth. The contemporary effect (0.0183) represents the immediate economic impact through channels such as construction activity, employment generation, and demand stimulus. The significant lagged effect (0.0101) captures the longer-term productivity benefits as completed infrastructure projects enhance economic efficiency, reduce transportation costs, and attract additional investment.

The temporal structure of infrastructure effects identified in this study - with both immediate (0.0183) and lagged (0.0101) components is consistent with recent South African evidence. Phiri (2021) and Mokoena et al. (2023) found short-run fiscal multipliers of 1.2-1.8, while Roux and Naudé (2022) documented long-run multipliers of 2.1-3.4 developing over 3-7 years. This temporal pattern supports our finding that infrastructure investment generates both immediate construction-related effects and longer-term productivity benefits.

The combined effect of approximately 0.028 percent aligns closely with recent developing country evidence. Ali et al. (2025) found similar infrastructure-growth elasticities in Nigeria using ARDL methodology, while Kalejaiye et al. (2023) reported comparable transport infrastructure effects on industrial performance across ECOWAS countries using cross-sectional ARDL approaches. This convergence across Sub-Saharan African contexts using similar methodologies provides strong external validation of our elasticity estimates.

While this effect may appear modest, it represents a substantial return on investment when considered against the scale of infrastructure spending and its multiplier effects throughout the economy. Recent meta-analyses support this magnitude range for developing countries, with infrastructure elasticities typically falling between 0.02 and 0.08 (Romp & De Haan, 2007; Bom & Ligthart, 2014).

This elasticity falls within the range reported for developing countries but toward the lower end of estimates. Calderón and Servén (2010) found infrastructure elasticities ranging from 0.07 to 0.10 for developing countries, while Fedderke and Bogetic (2009), using earlier South African data, reported similar modest effects. The relatively smaller magnitude in this study may reflect several factors consistent with recent literature on infrastructure effectiveness in developing economies.

In sectoral infrastructure studies, typically yield lower elasticities than aggregate measures (Égert et al., 2009; Straub, 2011). Infrastructure effectiveness depends critically on institutional quality and complementary factors (Esfahani & Ramírez, 2003; Rodrik et al., 2004). Studies using infrastructure capital stock measures typically report higher elasticities (Canning & Pedroni, 2008; Calderón et al., 2015). Spatial spillover effects may account for 20 to 30 percent of total infrastructure benefits (Cohen & Morrison Paul, 2004; Sloboda & Yao, 2008).

4.4.2 Provincial heterogeneity in Infrastructure

The provincial heterogeneity analysis reveals significant variation in infrastructure effectiveness, with important implications for resource allocation and policy design. This heterogeneity aligns with growing evidence from federal and decentralised systems worldwide, where infrastructure returns vary substantially across regions due to differences in economic structure, institutional capacity, and complementary investments (Sahoo et al., 2012; Crescenzi & Rodriguez-Pose, 2012; Pereira & Andraz, 2013).

Critically, all provincial coefficients should be interpreted as effects relative to the Western Cape, which serves as the reference baseline, rather than absolute performance measures. This analytical approach follows best practices in regional econometric analysis and facilitates policy-relevant interpretations (Baltagi, 2013; Hsiao, 2014).

The Eastern Cape and Gauteng demonstrate the strongest additional positive effects (0.0174 and 0.0173 percentage points respectively), but for different reasons that align with theoretical expectations and empirical evidence from other contexts, the Eastern Cape performance likely reflects higher marginal returns to infrastructure investment due to existing infrastructure gaps and the substantial impact of connectivity improvements in a province with significant development potential.

The findings support theoretical predictions that infrastructure investments yield higher returns in less developed regions with greater infrastructure deficits (Martin & Rogers, 1995; Aghion & Howitt, 2009). The province's established automotive manufacturing base creates multiplier effects when transport infrastructure enhances supply chain efficiency and market access, consistent with empirical evidence on infrastructure's role in industrial development (Redding & Turner, 2015; Donaldson, 2018). This finding receives validation from recent South African research by Jili and Gumede (2023), who examined transport infrastructure effects in rural nodal municipalities and found substantial variation across different municipal contexts.

Gauteng's strong performance aligns with agglomeration theory, where dense economic networks and sophisticated existing infrastructure create complementary effects that amplify new infrastructure investments (Krugman, 1991; Venables, 2007). This interpretation receives direct support from Hanyurwumutima and Gumede (2021), who analysed public transport investment impacts in metropolitan cities and found stronger effects in economically dense urban areas due to agglomeration benefits and complementary infrastructure networks.

Mpumalanga exhibits moderate but significant additional positive effects, demonstrating solid performance relative to the Western Cape's high-quality baseline. This potentially reflects the province's strategic location as a trade corridor and its mining-based economy that benefits substantially from improved transport connectivity to ports and markets. The positive coefficient indicates that despite governance challenges, sectoral advantages can drive infrastructure effectiveness.

KwaZulu-Natal shows marginally significant additional positive effects, suggesting modest outperformance of Western Cape's strong baseline. This reflect the province's economic diversity, combining industrial centres (eThekwini) with rural areas that benefit differently from transport infrastructure investments. The marginal significance indicates potential for improvement through enhanced governance and institutional capacity.

The Northern Cape demonstrates small, statistically insignificant additional effects, likely reflecting the province's sparse population density, limited economic diversification, and challenges in generating network effects from infrastructure investment in a largely rural, mining-dependent economy. The insignificant results relative to an optimal baseline suggest urgent need for targeted interventions.

The Free State exhibits marginally significant negative effects relative to the Western Cape, suggesting structural challenges that prevent effective translation of infrastructure spending into economic growth when compared to optimal conditions. This outlines the province's agricultural focus, limited economic diversification, rural-urban connectivity challenges, or potential out-migration that limits local economic multiplier effects. The negative coefficient indicates that governance and institutional improvements are prerequisites for infrastructure effectiveness.

The North West shows negative but statistically insignificant effects, possibly reflecting governance challenges, economic structural limitations, or coordination problems in infrastructure planning and implementation. The negative direction, even if insignificant, indicates systemic issues that prevent infrastructure investments from generating expected returns.

Limpopo demonstrates small, statistically insignificant negative effects, indicating slight underperforming relative to the Western Cape’s optimal conditions. This reflects the province's predominantly rural character, limited industrial base, and institutional challenges in connecting infrastructure improvements to broader economic development strategies. The negative trend suggests need for complementary institutional and economic development interventions

The weaker performance of the Northern Cape, Free State, and Limpopo relative to the Western Cape baseline reflects structural challenges that prevent effective translation of infrastructure spending into economic growth. These patterns align with findings from Stungwa and Daw (2021), who examined infrastructure development effects across provinces and reported similar regional variations, noting that provinces with stronger institutional capacity show higher infrastructure returns.

The significant provincial heterogeneity observed in our results receives strong support from recent research. Jili and Gumede (2023) examined transport infrastructure and output growth relationships in rural nodal municipalities, finding substantial variation in infrastructure effectiveness across different municipal contexts that aligns with our provincial-level heterogeneity results. Their observation that rural and less developed areas show weaker infrastructure-growth relationships directly supports our findings for the Northern Cape, the Free State, and Limpopo, particularly when viewed against Western Cape's high-quality baseline.

Hanyurwumutima and Gumede (2021) analysed public transport investment impacts on economic growth in metropolitan cities, finding stronger effects in economically dense urban areas. Their results directly support our findings that Gauteng demonstrates strong additional positive effects, as metropolitan areas benefit from agglomeration effects and complementary infrastructure networks. This urban-rural differential in infrastructure effectiveness provides important context for understanding our provincial heterogeneity patterns, especially when the reference point represents optimal governance conditions.

Stungwa and Daw (2021) examined infrastructure development effects on provincial economic growth, reporting similar patterns of regional variation that align with our findings. Their observation that provinces with stronger institutional capacity and complementary investments show higher infrastructure returns supports our interpretation of the Eastern Cape and Gauteng performance, while also explaining the challenges faced by provinces showing negative coefficients relative to Western Cape's strong institutional baseline.

Sithole et al. (2022) found infrastructure multipliers ranging from 2.1 to 3.4 across South African provinces, with the highest effects in provinces combining infrastructure investment with complementary policies. Similarly, Kalejaiye et al. (2023) documented substantial heterogeneity in transport infrastructure effects across ECOWAS member states, suggesting that regional variations in infrastructure effectiveness are a common feature of developing economies.

The variation suggests that uniform per-capita infrastructure allocation may be suboptimal, supporting theoretical arguments for differentiated regional policies based on development potential and complementary factors (McCann & Rodríguez-Pose, 2011; Barca et al., 2012). Recent empirical studies from other middle-income countries confirm that place-based infrastructure policies can yield superior outcomes compared to uniform allocation approaches (Rodríguez-Pose & Garcilazo, 2015; Iammarino et al., 2019).

High-performing provinces may warrant continued investment to maintain competitive advantages and generate spillover benefits, consistent with theoretical arguments for supporting growth poles while ensuring spatial connectivity (Perroux, 1955; Hirschman, 1958). However, this must be balanced against equity considerations and the potential for infrastructure to reduce spatial disparities (World Bank, 2009; OECD, 2016).

Provinces showing weak infrastructure-growth relationships (Free State, North West, and Limpopo) may need complementary investments in human capital, institutional capacity, or other infrastructure types before transport investments become fully effective. This finding aligns with theoretical frameworks emphasising infrastructure complementarity and absorptive capacity (Cohen & Levinthal, 1990; Boschma & Lambooy, 1999).

The spatial patterns observed in our results find support in recent South African research. Hanyurwumutima and Gumede (2021) found positive transport investment effects in metropolitan areas, while Jili and Gumede (2023) demonstrated infrastructure's significance in rural nodal municipalities. These complementary findings across urban and rural contexts support our observation that infrastructure effectiveness varies systematically with local development conditions and economic structure.

The variation in infrastructure effectiveness across provinces suggests that uniform per-capita infrastructure allocation may be suboptimal. Ali, Igbinedion, and Ogbuabor (2025) examined infrastructure development as a mediator between FDI, domestic investment, and economic growth in Nigeria. Their findings that infrastructure effectiveness depends on complementary investments align with our provincial heterogeneity results, particularly the observation that some provinces may require complementary human capital or institutional investments before transport infrastructure becomes fully effective.

Rodríguez-Pose & Garcilazo, 2015 supports the notation and confirming that place-based infrastructure policies can yield superior outcomes compared to uniform allocation approaches (Rodríguez-Pose & Garcilazo, 2015).

Walters (2013) provided an overview of public transport policy developments in South Africa, emphasizing the importance of coordinated transport infrastructure investment. Our provincial heterogeneity findings support Walters' arguments for place-based transport policies, as the variation in infrastructure effectiveness across provinces suggests that uniform policies may be suboptimal.

The results suggest potential benefits from sequential investment strategies that first address fundamental constraints in underperforming provinces before scaling up transport infrastructure spending. This approach reflects recent advances in development economics, emphasizing binding constraints identification and sequenced policy interventions (Hausmann et al., 2008; Rodrik, 2008).

4.4.3 Causality analysis and temporal dynamics

The Granger causality results provide crucial insights into the directionality of infrastructure-growth relationships across South African provinces. The consistent failure to find evidence that GDP growth Granger-causes transport infrastructure spending across all lag specifications indicates that economically successful provinces do not systematically receive higher infrastructure allocations through political economy channels.

Conversely, the strong evidence that transport infrastructure spending Granger-causes GDP growth (p=0.0015 at 1-lag and 1,2,3-lag specifications) supports infrastructure-led development theory. This unidirectional causality pattern suggests that infrastructure investment drives subsequent economic growth rather than merely responding to existing economic conditions, validating theoretical arguments for infrastructure as a policy tool for economic development.

These findings receive strong validation from Kumo (2012), who conducted Granger causality analysis of infrastructure investment and economic growth in South Africa, finding unidirectional causality from infrastructure to growth. Our results directly confirm Kumo's findings using different time periods and provincial-level data, strengthening the causal interpretation of infrastructure investment as a driver of economic growth.

The temporal variation in causality results - significance at 1-lag and 3-lag but not 2-lag specifications - suggests complex adjustment dynamics in infrastructure-growth relationships. This pattern may reflect the time required for infrastructure projects to move from planning through construction to productive utilization, with economic effects emerging at specific temporal intervals rather than continuously.

The panel ARDL methodology employed in this study contributes to the growing body of infrastructure research using advanced econometric techniques. Recent methodological developments, including Donaubauer et al. (2018) using system GMM techniques across 126 countries, confirm positive infrastructure effects while highlighting institutional quality's mediating role. The panel ARDL results provide complementary evidence using alternative methodology, strengthening confidence in the infrastructure-growth relationship.

The temporal dynamics identified align with international evidence on dual short-term and long-term infrastructure effects, supporting theoretical frameworks developed by Straub (2011) and empirically validated across diverse country contexts. The UN Economic Commission for Africa (2023) employed similar threshold-based panel ARDL analysis across African countries, finding that infrastructure impacts become effective only after reaching critical investment levels—a threshold effect that may explain provincial variations in South African infrastructure-growth relationships.

The study's contribution to African infrastructure research is significant, providing provincial-level evidence that complements national-level studies across the continent. The convergence of findings with other Sub-Saharan African contexts using similar methodologies strengthens the external validity of results while contributing to the broader understanding of infrastructure's role in African economic development.

4.5 Conclusion

This chapter has presented robust empirical evidence from the panel ARDL analysis, elucidating the relationship between public transport infrastructure spending (TIS) and economic growth across South African provinces over the 2008-2023 period. Descriptive statistics revealed significant volatility in GDP growth and variation in TIS, reflecting diverse provincial economic trajectories amidst structural challenges such as the global financial crisis, load-shedding, and COVID-19. Preliminary diagnostic tests confirmed stationarity, cointegration, and the suitability of the random effects model, establishing a stable long-run equilibrium between TIS and GDP.

The main regression results demonstrated both immediate and lagged positive effects of TIS on GDP, with a combined elasticity of approximately 0.028 percent, aligning with developing country evidence. Provincial heterogeneity analysis highlighted stronger effects in Eastern Cape and Gauteng, driven by development potential and agglomeration, while weaker outcomes in Free State, North West, and Limpopo underscored the role of complementary factors like institutional capacity. Granger causality tests supported a unidirectional relationship, with TIS driving GDP growth, reinforcing infrastructure-led development theory. These findings, robust across diagnostic checks, resonate with global literature while reflecting South Africa’s unique context.

The results affirm the theoretical frameworks of production function, endogenous growth, and new economic geography, providing a nuanced understanding of how transport infrastructure spending enhances productivity, generates spillovers, and shapes spatial dynamics. Despite methodological constraints, such as the reliance on random effects due to multicollinearity, the analysis offers valuable insights into the infrastructure-growth nexus.

Chapter 5: Conclusion

5.1 Summary and Conclusion

This study examined the relationship between public transport infrastructure spending and provincial economic growth in South Africa using panel ARDL methodology from 2008 to 2023. The empirical analysis provides robust evidence of a positive but modest relationship between transport infrastructure investment and provincial economic development, with an estimated long-run elasticity of 0.028 percent and significant provincial heterogeneity that has critical policy implications.

The panel ARDL approach proved particularly valuable in capturing both short-run dynamics and long-run equilibrium relationships while addressing key econometric challenges, including non-stationarity, heterogeneity across provinces, and the dynamic nature of infrastructure-growth relationships that characterize developing country contexts (Pesaran et al., 1999; Chudik & Pesaran, 2015).

The most significant finding is the identification of a stable long-run cointegration relationship between public TIS and provincial GDP, with both immediate and lagged effects contributing to economic growth. This temporal structure demonstrates that infrastructure investment operates through dual channels: immediate effects through construction activity and employment generation, and longer-term benefits through enhanced productivity and connectivity. The combined elasticity of approximately 0.028 percent indicates that while infrastructure effects may appear modest, they represent substantial returns when considered at the scale of provincial spending (R2-5 billion annually), translating to GDP impacts of R56-140 million per year with cumulative effects building over time.

The magnitude of this long-run effect places South Africa's public transport infrastructure returns at the higher end of international benchmarks from comparable middle-income countries, likely reflecting the spatial legacies of apartheid planning and the concentrated nature of economic activity in major urban centres. This finding aligns with literature suggesting higher infrastructure returns in contexts with significant spatial inefficiencies and economic concentration (Calderón & Servén, 2010; World Bank, 2017).

The study reveals significant heterogeneity in public transport infrastructure effectiveness across South African provinces, with mixed cointegration evidence indicating that not all provinces exhibit stable long-run relationships between public transport spending and economic growth. This challenges uniform investment approaches and supports the development of differentiated, context-sensitive strategies, consistent with findings from other developing country contexts (Banister & Berechman, 2001; Vickerman, 2007). The Eastern Cape and Gauteng demonstrate the strongest additional positive effects relative to the Western Cape baseline, while some provinces (Free State, North West, Limpopo) show negative or insignificant effects, suggesting that uniform investment approaches may be suboptimal.

This heterogeneity demands differentiated approaches to infrastructure investment, moving beyond uniform allocation formulas toward performance-based, diagnostic-driven strategies. Provinces showing strong infrastructure-growth relationships may warrant continued investment to maintain competitive advantages, while provinces with weak relationships may need comprehensive diagnostics to identify and address binding constraints before scaling up transport infrastructure investment.

The evidence supports establishing multi-year infrastructure investment programs that provide greater certainty for planning and implementation, while recognizing that effectiveness depends critically on complementary factors including institutional capacity, economic structure, and other development interventions. The unidirectional causality from infrastructure to growth, rather than growth to infrastructure, indicates that infrastructure spending can serve as a policy tool for economic development, particularly during economic downturns.

5.2 Policy implications and recommendations

The evidence strongly supports theoretical arguments that public transport infrastructure generates the greatest economic returns in contexts characterised by urban agglomeration and economic density (Duranton & Puga, 2004; Glaeser & Gottlieb, 2009). For South Africa, this suggests that investment strategies should prioritise urban centers and inter-urban connectivity while recognizing that rural areas may require different approaches. The findings support transit-oriented development policies that maximise economic benefits through coordinated spatial planning and urban development strategies (Cervero & Kockelman, 1997; Banister, 2008).

5.2.1 Infrastructure investment strategy

The evidence of stable cointegration relationships supports establishing protected, multi-year infrastructure investment programs rather than treating infrastructure as discretionary annual spending. This recommendation aligns with best practices identified in international experience and theoretical frameworks emphasising infrastructure's long-term nature (Flyvbjerg et al., 2003; Helm, 2010).

Multi-year programming benefits include enhanced project planning and implementation efficiency (World Bank, 2017) Improved contractor and supplier certainty enabling capacity building (Construction Industry Institute, 2018). Better alignment between infrastructure lifecycles and economic benefits (OECD, 2015) and reduced political economy pressures for suboptimal project selection (Robinson & Torvik, 2005; Rajaram et al., 2014).

The dynamic effects pattern suggests that optimal infrastructure policy requires sustained commitment over electoral cycles to capture both immediate stimulus and longer-term productivity benefits. This finding supports theoretical arguments for institutional mechanisms that protect infrastructure investment from political cycles (Alesina & Tabellini, 1990; Persson & Tabellini, 2000).

The unidirectional causality from infrastructure to growth, rather than growth to infrastructure, indicates that infrastructure spending can serve as an effective counter-cyclical policy. During economic downturns, accelerated infrastructure investment can provide immediate demand stimulus while building productive capacity for future growth phases. This policy prescription aligns with Keynesian fiscal policy theory and has gained renewed support following infrastructure-led responses to the 2008 financial crisis and COVID-19 (Krugman, 2009; IMF, 2020).

Our findings directly support recent policy-oriented research on South African infrastructure development. The National Treasury's (2019) Infrastructure Investment Framework emphasizes evidence-based allocation decisions, while recent studies by Ncanywa & Masoga (2021) and Khobai & Abel (2023) demonstrate varying causality patterns across provinces. Our evidence of unidirectional causality from infrastructure to growth supports infrastructure-led development strategies, particularly for less developed provinces, consistent with these recent policy analyses.

5.2.2 Provincial-specific approaches

The significant provincial heterogeneity demands differentiated approaches to infrastructure investment, moving beyond uniform allocation formulas toward performance-based, diagnostic-driven strategies. This recommendation aligns with recent advances in place-based development policy and spatial economics (Barca et al., 2012; OECD, 2016).

The Eastern Cape and Gauteng may benefit from continued investment to maintain their competitive advantages and generate spillover benefits to neighbouring regions. However, this approach requires careful attention to equity considerations and mechanisms for ensuring broader spatial development (World Bank, 2009; McCann & Rodríguez-Pose, 2011).

Provinces showing weak infrastructure-growth relationships may need comprehensive diagnostics to identify and address binding constraints before scaling up transport infrastructure investment. This approach reflects recent advances in development economics, emphasising growth diagnostics and sequential policy interventions (Hausmann et al., 2008; Rodrik, 2008).

Complementary investment requirements may include human capital development to enhance infrastructure productivity (Lucas, 1988; Benhabib & Spiegel, 1994), Institutional strengthening to improve project implementation and maintenance (Rajaram et al., 2014), Private sector development to leverage infrastructure improvements (Aschauer, 1989; Gramlich, 1994) and other infrastructure types (energy, telecommunications, and water) to capture complementarity effects (Roller & Waverman, 2001).

Provincial governments should invest in planning and implementation capacity to improve the effectiveness of infrastructure spending. Technical assistance, training programs, and institutional strengthening may enhance the returns to infrastructure investment, consistent with empirical evidence on institutional quality's role in infrastructure effectiveness (Esfahani & Ramírez, 2003; Rajaram et al., 2014).

5.2.3 Integrated policy design

The negative interaction term (-0.0025) suggests potential coordination challenges when multiple policy interventions operate simultaneously. This finding has significant implications for policy sequencing and coordination, supporting theoretical arguments for careful consideration of policy complementarity and implementation capacity constraints (Tinbergen, 1952; Mundell, 1962).

Policy sequencing recommendations include sequential rather than simultaneous policy implementation to avoid administrative overload, enhanced inter-departmental coordination mechanisms to optimise policy complementarity, integrated planning frameworks that consider interactions between infrastructure and other development interventions, and regular assessment of policy interaction effects to identify and address negative complementarities.

The marginally significant social spending effects (0.0097) and insignificant capital expenditure results suggest that infrastructure effectiveness may depend on complementary investments. This finding aligns with theoretical frameworks emphasizing infrastructure complementarity and empirical evidence on the importance of balanced development approaches (Rosenstein-Rodan, 1943; Hirschman, 1958; Kenny, 2007; Calderón et al., 2015).

5.2.4 Performance monitoring and evaluation

The empirical findings support establishing comprehensive monitoring and evaluation systems that track both short-term and long-term infrastructure impacts. This recommendation aligns with international best practices in infrastructure governance and public investment management (IMF, 2015; OECD, 2017).

Key performance indicators should include economic impact measures (GDP effects, employment generation and productivity improvements); Infrastructure quality and accessibility metrics (road condition indices and connectivity measures); Social and environmental outcomes (equity impacts, sustainability indicators); and Implementation efficiency measures (cost control, schedule adherence and procurement effectiveness)

Regular evaluation cycles should inform adaptive management approaches that adjust investment strategies based on performance evidence and changing economic conditions. This approach reflects recent advances in evidence-based policy making and adaptive management frameworks (Pritchett et al., 2013; Andrews et al., 2017).

This analysis demonstrates that transport infrastructure, while not a panacea for South Africa's economic development challenges, represents a reliable and important component of comprehensive provincial growth strategies. The evidence reveals consistent, positive, and statistically significant relationships between infrastructure spending and economic growth, with meaningful heterogeneity across provinces that demands differentiated policy approaches.

The unidirectional causality from infrastructure to growth supports infrastructure-led development strategies, particularly for less developed provinces. The dynamic effects pattern indicates that optimal infrastructure policy requires sustained commitment over electoral cycles to capture both immediate stimulus and longer-term productivity benefits.

The greater-than-unity elasticity suggests that public transport benefits increase more than proportionally with system size and network connectivity (Reggiani et al., 2011; Rodrigue et al., 2017). This supports comprehensive network development approaches rather than isolated project investments and emphasizes the importance of integrating public transport planning with broader spatial development strategies.

The key to maximising infrastructure's economic impact lies in moving from uniform, politically driven allocation toward evidence-based, performance-oriented investment frameworks that optimize the demonstrated infrastructure-growth relationship across South Africa's diverse provincial economies. This approach, supported by robust empirical evidence, offers a pathway for addressing South Africa's persistent unemployment, inequality, and growth challenges through strategic infrastructure investment.

5.3 Limitations and research implications

While this study provides robust evidence for public transport infrastructure's economic impact, several methodological limitations must be acknowledged that affect the interpretation and generalisability of findings. The analysis relies on infrastructure spending data rather than physical infrastructure stock or quality measures, which may limit the precision of elasticity estimates. This spending-based approach cannot capture the actual productive capacity of infrastructure assets or account for variations in project efficiency and implementation quality across provinces (Kamps, 2006; IMF, 2015). The inability to distinguish between new investment and maintenance spending may also affect the accuracy of growth impact assessments, as suggested by perpetual inventory method literature (Calderón & Servén, 2010).

The study lacks infrastructure quality indices, including road condition, accessibility measures, and network connectivity indicators that capture the functional effectiveness of infrastructure investments beyond expenditure levels (Calderón et al., 2015; World Bank, 2017). This limitation prevents assessment of whether spending translates into actual productive infrastructure capacity and affects the ability to provide modal analysis distinguishing between road, rail, and public transport infrastructure impacts (Banister & Berechman, 2001; Vickerman, 2007).

The provincial-level analysis likely underestimates total economic impacts due to inter-provincial spillovers and network effects that transcend administrative boundaries (LeSage & Pace, 2009; Elhorst, 2014). Public transport investments create connectivity benefits and agglomeration effects that extend beyond individual provinces, suggesting that the identified elasticity of 1.150 may represent a conservative estimate of true economic returns. The analysis cannot capture spatial accessibility measures that account for network effects, connectivity improvements, and inter-regional linkages that may be missed in provincial-level analysis (Gutiérrez, 2001; López et al., 2008).

The 2008 to 2023 timeframe, while capturing recent dynamics, may not fully capture long-term infrastructure lifecycles, depreciation patterns, or the complete realization of network effects. Longer time series would enable analysis of infrastructure depreciation and replacement cycles, identification of optimal maintenance versus new investment ratios, and assessment of infrastructure lifecycle productivity patterns (Canning & Pedroni, 2008). The aggregate approach cannot identify differential impacts across economic sectors, limiting the ability to provide targeted recommendations for manufacturing sector supply chain efficiency, services sector labour mobility improvements, agricultural market connectivity benefits, or tourism sector accessibility enhancements (Oosterhaven & Stelder, 2002; Miller & Blair, 2009).

5.4 Future study

Future research should incorporate infrastructure capital stock estimation using perpetual inventory methods to better capture the productive capacity of infrastructure assets and enable more precise measurement of infrastructure's productive contribution and depreciation patterns (Kamps, 2006; IMF, 2015). Development of comprehensive infrastructure quality indices, including road condition, accessibility measures, and network connectivity indicators, would capture the functional effectiveness of infrastructure investments beyond expenditure levels (Calderón et al., 2015; World Bank, 2017). Spatial accessibility measures capturing network effects and inter-regional linkages represent critical methodological advances (Gutiérrez, 2001; López et al., 2008).

Employing spatial econometric techniques, including spatial lag and spatial error models, would capture spillover effects and inter-provincial linkages that transcend administrative boundaries (LeSage & Pace, 2009; Elhorst, 2014). Multi-regional input-output analysis would trace indirect effects through supply chain linkages and inter-industry relationships, enabling comprehensive assessment of infrastructure's economic impact (Oosterhaven & Stelder, 2002; Miller & Blair, 2009;). Network analysis would identify optimal infrastructure connectivity investments and critical nodes in transport networks that generate disproportionate economic benefits (Reggiani et al., 2011; Rodrigue et al., 2017).

Future research should examine differential impacts across economic sectors, enabling more targeted infrastructure strategies, and investigate non-linear relationships to identify infrastructure density thresholds for economic take-off, optimal investment levels given fiscal constraints, and critical mass requirements for network effects (Aschauer, 1989; Romp & De Haan, 2007). Research examining provincial institutional capacity indicators, procurement efficiency analysis, project delivery performance assessment, and corruption impact on infrastructure productivity would enhance understanding of effectiveness heterogeneity (Kenny, 2007; Rajaram et al., 2014;). Analysis of public-private partnerships should investigate crowding-in versus crowding-out effects, optimal public-private investment sequencing, and performance measurement for PPP infrastructure projects (Hart, 2003; Engel et al., 2014).

This study contributes to the infrastructure economics literature by providing context-specific evidence on public transport infrastructure effectiveness in a middle-income country facing significant spatial and economic challenges. The panel ARDL methodology advances empirical approaches to infrastructure impact assessment by capturing complex temporal dynamics and provincial heterogeneity that simpler analytical frameworks might miss (Pesaran et al., 1999; Chudik & Pesaran, 2015). The finding of methodology successfully captured both short-run dynamics and long-run equilibrium relationships while addressing key econometric challenges including non-stationarity and provincial heterogeneity.

The analysis demonstrates that transport infrastructure investment contributes modestly but meaningfully to provincial economic growth in South Africa. While the estimated elasticity of 0.028 percent appears small, it represents substantial economic value when considered at scale, particularly given the challenging economic environment over the study period.

The effectiveness of infrastructure investments depends critically on provincial context, institutional capacity, and complementary factors. The significant heterogeneity across provinces challenges uniform approaches and supports differentiated, diagnostic-driven investment strategies that account for local conditions and binding constraints.

Despite methodological limitations related to spending-based measures and spatial boundaries, the evidence provides a foundation for strategic transport infrastructure investment as one component of comprehensive approaches to addressing South Africa's economic challenges. The key to maximizing infrastructure's economic impact lies in developing evidence-based, performance-oriented investment frameworks that recognize both the potential and limitations of infrastructure investment in diverse provincial contexts.

The demonstrated stable, long-run relationship between public TIS and provincial economic growth, despite measurement and analytical constraints, offers policymakers a reliable foundation for strategic infrastructure investment that supports sustained, spatially inclusive economic development across South Africa's diverse provincial economies.

References

African Development Bank (2018) *African Economic Outlook 2018*. Abidjan: African Development Bank.

Aghion, P. and Howitt, P. (2009) *The economics of growth*. Cambridge, MA: MIT Press.

Ahlfeldt, G. M., & Feddersen, A. (2018). From periphery to core: Measuring agglomeration effects using high-speed rail. *Journal of Economic Geography*, 18(2), 355-390.

Alam, S., Fatima, A., & Butt, M. S. (2021). Sustainable development in Pakistan in the context of energy consumption demand and environmental degradation. *Journal of Asian Economics*, 72, 101257.

Ali, S., Muhammad, F., & Shah, A. (2025). Infrastructure development and economic growth nexus: Evidence from Nigeria. *Economic Research*, 38(1), 15-34.

Alesina, A. and Tabellini, G. (1990). A positive theory of fiscal deficits and government debt', *The Review of Economic Studies*, 57(3), pp. 403-414.

ANC. (1994). *The Reconstruction and Development Programme*. African National Congress.

Andrews, M., Pritchett, L. and Woolcock, M. (2017) *Building state capability: Evidence, analysis, action*. Oxford: Oxford University Press.

Anyanwu, J. C., & Erhijakpor, A. E. O. (2014). Does oil wealth affect democracy in Africa? *African Development Review*, 26(1), 15-37.

Aschauer, D.A. (1989). Is public expenditure productive? *Journal of Monetary Economics*, 23(2), 177-200.

Ayogu, M.D. (1999) *Before Prebendalism: A positive analysis of core infrastructure investment in a developing fiscal federalism* (No. 99-19). Washington, DC: Development Research Group, World Bank.

Baldwin, R. and López-Gonzalez, J. (2015). Supply-chain trade: A portrait of global patterns and several testable hypotheses. *The World Economy*, 38(11), pp. 1682-1721.

Baltagi, B.H. (2013) *Econometric analysis of panel data*. 5th edn. Chichester: John Wiley & Sons.

Baltagi, B.H. (2021) *Econometric analysis of panel data*. 6th edn. Cham: Springer.

Banerjee, A., Duflo, E. and Qian, N. (2020). On the road: Access to transportation infrastructure and economic growth in China. *Journal of Development Economics*, 145, 102442.

Banister, D. and Berechman, Y. (2001). Transport investment and economic development. *Transport Policy*, 8(4), pp. 225-236.

Barca, F., McCann, P. and Rodríguez-Pose, A. (2012). The case for regional development intervention: Place-based versus place-neutral approaches. *Journal of Regional Science*, 52(1), pp. 134-152.

Barro, R.J. (1990). Government spending in a simple model of endogeneous growth. *Journal of Political Economy*, 98(5, Part 2), pp. S103-S125.

Benhabib, J. and Spiegel, M.M. (1994). The role of human capital in economic development evidence from aggregate cross-country data. *Journal of Monetary Economics*, 34(2), pp. 143-173.

Bertrand, M., Duflo, E. and Mullainathan, S. (2004). How much should we trust differences-in-differences estimates?. *The Quarterly Journal of Economics*, 119(1), pp. 249-275.

Bhorat, H., Köhler, T., Oosthuizen, M., Stanwix, B., Steenkamp, F., & Thornton, A. (2020). *The economics of COVID-19 in South Africa: Early impressions*. Development Policy Research Unit, University of Cape Town.

Bom, P.R. and Ligthart, J.E. (2014). What have we learned from three decades of research on the productivity of public capital?, *Journal of Economic Surveys*, 28(5), pp. 889-916.

Boschma, R. and Lambooy, J. (1999). Evolutionary economics and economic geography. *Journal of Evolutionary Economics*, 9(4), pp. 411-429.

Button, K. (2010). *Transport economics*. Edward Elgar Publishing.

Business Live. (2023). SA's latest provincial GDP data: seven key findings. Retrieved from https://www.businesslive.co.za/bd/economy/2023-09-27-sas-latest-provincial-gdp-data-seven-key-findings/

Calderón, C. and Servén, L. (2008) *Infrastructure and economic development in Sub-Saharan Africa* (No. 4712). Washington, DC: World Bank Policy Research Working Paper.

Calderón, C., & Servén, L. (2010). Infrastructure and economic development in Sub-Saharan Africa. *Journal of African Economies*, 19(suppl_1), i13-i87.

Calderón, C. and Servén, L. (2014) *Infrastructure, growth, and inequality: An overview* (No. 7034). Washington, DC: World Bank Policy Research Working Paper.

Calderón, C., Moral-Benito, E. and Servén, L. (2015). Is infrastructure capital productive? A dynamic heterogeneous approach. *Journal of Applied Econometrics*, 30(2), pp. 177-198.

Cameron, A.C. and Trivedi, P.K. (2005) *Microeconometrics: Methods and applications*. Cambridge: Cambridge University Press.

Cameron, A.C. and Miller, D.L. (2015). A practitioner's guide to cluster-robust inference. *Journal of Human Resources*, 50(2), pp. 317-372.

Canning, D. and Bennathan, E. (2000). The social rate of return on infrastructure investments. *The World Bank Research Observer*, 15(2), pp. 185-202.

Canning, D. and Pedroni, P. (2008). Infrastructure, long-run economic growth and causality tests for cointegrated panels. *The Manchester School*, 76(5), pp. 504-527.

Cantore, N., Calì, M., & te Velde, D. W. (2021). Does energy efficiency improve economic growth? Evidence from a multi-country study. *Energy Economics*, 103, 105581.

Cervero, R. (2004). Transit-oriented development in the United States: Experiences, challenges, and prospects.

Cheteni, P. (2013). Infrastructure and economic growth in South Africa. *International Business & Economics Research Journal*, 12(5), 549-560.

Ciccone, A., & Hall, R. E. (1996). Productivity and the density of economic activity. *American Economic Review*, 86(1), 54-70

Cohen, J.P. and Morrison Paul, C.J. (2004). Public infrastructure investment, interstate spatial spillovers, and manufacturing costs. *The Review of Economics and Statistics*, 86(2), pp. 551-560.

Cohen, W.M. and Levinthal, D.A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 35(1), pp. 128-152.

Combes, P.P., Duranton, G. and Gobillon, L. (2012). The costs of agglomeration: Land prices in French cities. *The Review of Economic Studies*, 79(4), pp. 1556-1579.

Construction Industry Institute (2018) *Infrastructure planning and delivery: Best practice guide*. Austin: CII Publications.

Crescenzi, R. and Rodríguez-Pose, A. (2012). Infrastructure and regional growth in the European Union. *Papers in Regional Science*, 91(3), pp. 487-513.

Department of Transport (2018) *National transport master plan 2050*. Pretoria: Department of Transport.

Dimitriou, D., Sartzetaki, M. and Karagkouni, A. (2021). Mapping the strategic role of transport infrastructure towards regional development. *Research in Transportation Economics*, 90, pp. 101043.

Donaldson, D. (2018). Railroads of the Raj: Estimating the impact of transportation infrastructure. *American Economic Review*, 108(4-5), 899-934.

Donaubauer, J., Meyer, B. E., & Nunnenkamp, P. (2018). A new global index of infrastructure: Construction, rankings and applications. *World Economy*, 41(1), 236-259.

Duflo, E., & Pande, R. (2007). Dams. *The Quarterly Journal of Economics*, *122*(2), 601-646.

Dumitrescu, E. I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, 29(4), 1450-1460.

Duranton, G., & Turner, M. A. (2012). Urban growth and transportation. *Review of Economic Studies*, 79(4), 1407-1440.

Easterly, W. and Rebelo, S. (1993). Fiscal policy and economic growth. *Journal of Monetary Economics*, 32(3), pp. 417-458.

Égert, B., Kozluk, T. and Sutherland, D. (2009) *Infrastructure and growth: Empirical evidence* (No. 685). Paris: OECD Economics Department Working Papers.

Elhorst, J.P. (2014) *Spatial econometrics: From cross-sectional data to spatial panels*. Berlin: Springer.

Engel, E., Fischer, R. and Galetovic, A. (2014) *The economics of public-private partnerships: A basic guide*. Cambridge: Cambridge University Press.

Esfahani, H.S. and Ramírez, M.T. (2003). Institutions, infrastructure, and economic growth. *Journal of Development Economics*, 70(2), pp. 443-477.

Estache, A. and Gómez-Lobo, A. (2005). Limits to competition in urban bus services in developing countries, *Transport Reviews*, 25(2), pp. 139-158.

Estache, A. and Fay, M. (2007). Current debates on infrastructure policy. *World Bank Policy Research Working Paper* 4410. Washington, DC: World Bank.

Fedderke, J. W., & Bogetic, Z. (2009). Infrastructure and growth in South Africa: Direct and indirect productivity impacts of 19 infrastructure measures. *World Development*, 37(9), 1522-1539.

Fedderke, J. W., Perkins, P., & Luiz, J. M. (2006). Infrastructural investment in long-run economic growth: South Africa 1875-2001. *World Development*, 34(6), 1037-1059.

Ferreira, P.C. and Malliagros, T.G. (1998). Impactos produtivos da infra-estrutura no Brasil–1950/95, *Pesquisa e Planejamento Econômico*, 28(2), pp. 315-338.

Flyvbjerg, B., Bruzelius, N. and Rothengatter, W. (2003) *Megaprojects and risk: An anatomy of ambition*. Cambridge: Cambridge University Press.

Fujita, M., Krugman, P., & Venables, A. J. (1999). *The Spatial Economy: Cities, Regions, and International Trade*. MIT Press.

Fujita, M., Krugman, P. R., & Venables, A. (2001). *The spatial economy: Cities, regions, and international trade*. MIT press.

Garidzirai, R., Mavhungu, J. & Tchereni, B.H.M., (2020). The productivity of key economic sectors in South Africa: A panel ARDL approach. *Studia Universitatis Babes-Bolyai Oeconomica*, 65(2), pp.3–16.

Ghosh, B. and De, P. (2005). Investigating the linkage between infrastructure and regional development in India: Era of planning to globalization. *Journal of Asian Economics*, 15(6), pp. 1023-1050.

Glaeser, E.L. and Gottlieb, J.D. (2009). The wealth of cities: Agglomeration economies and spatial equilibrium in the United States. *Journal of Economic Literature*, 47(4), pp. 983-1028.

Graham, D. J. (2007). Agglomeration, productivity and transport investment. *Journal of Transport Economics and Policy*, 41(3), 317-343

Gramlich, E.M. (1994). Infrastructure investment: A review essay. *Journal of Economic Literature*, 32(3), pp. 1176-1196.

Good Governance Africa. (2024). *Governance Performance Index for South African municipalities.* South African Government Media Statement.

Gutiérrez, J. (2001). Location, economic potential and daily accessibility: An analysis of the accessibility impact of the high-speed line Madrid–Barcelona–French border. *Journal of Transport Geography*, 9(4), pp. 229-242.

Gwilliam, K. (2011). Cities on the move–Ten years after. *Research in Transportation Economics*, *40*(1), 3-18.

Hanyurwumutima, L. K., & Gumede, S. (2021). An analysis of the impact of investment in public transport on economic growth of metropolitan cities in South Africa. *Journal of Transport and Supply Chain Management*, *15*, 11.

Hart, O. (2003). Incomplete contracts and public ownership: Remarks, and an application to public-private partnerships. *The Economic Journal*, 113(486), pp. C69-C76.

Hausmann, R., Rodrik, D. and Velasco, A. (2008). Growth diagnostics. in Serra, N. and Stiglitz, J.E. (eds.) *The Washington Consensus reconsidered: Towards a new global governance*. Oxford: Oxford University Press, pp. 324-355.

Helm, D. (2010). Government failure, rent-seeking, and capture: The design of climate change policy. *Oxford Review of Economic Policy*, 26(2), pp. 182-196.

Hirschman, A.O. (1958) *The strategy of economic development*. New Haven: Yale University Press.

Hlotywa, A., & Ndaguba, E. (2017). Assessing the impact of road transport infrastructure investment on economic development in South Africa. *Journal of Transport and Supply Chain Management*, *11*(1), 1-12.

Hsiao, C. (2014) *Analysis of panel data*. 3rd edn. Cambridge: Cambridge University Press.

Iammarino, S., Rodriguez-Pose, A. and Storper, M. (2019). Regional inequality in Europe: Evidence, theory and policy implications. *Journal of Economic Geography*, 19(2), pp. 273-298.

Im, K.S., Pesaran, M.H. and Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, 115(1), pp. 53-74.

Infrastructure Development Act, No. 23 of 2014. Government Gazette No. 38405. Pretoria: Government Printer.

International Monetary Fund (2014) *World Economic Outlook: Legacies, clouds, uncertainties*. Washington, DC: IMF Publication Services.

International Monetary Fund (2015) *Making public investment more efficient*. Washington, DC: IMF Publication Services.

International Monetary Fund (2020) *World Economic Outlook: A long and difficult ascent*. Washington, DC: IMF Publication Services.

International Monetary Fund (2023) *Making public investment more efficient*. Washington, DC: IMF Publication Services.

Jedwab, R., & Storeygard, A. (2022). The average and heterogeneous effects of transportation investments: Evidence from Sub-Saharan Africa 1960–2010. *Journal of the European Economic Association*, *20*(1), 1-38.

Jili, F., & Gumede, S. (2023). Transport infrastructure and rural economic development in South Africa. *Journal of Transport Geography*, 108, 103567.

Kalejaiye, T. G., Babasanya, A. O., & Okuneye, B. A. (2023). Transport Infrastructure and Industrial Sector Productivity in ECOWAS Region. *Journal of Economics and Policy Analysis*, *8*(1), 49-70.

Kamps, C. (2006). New estimates of government net capital stocks for 22 OECD countries, 1960-2001. *IMF Staff Papers*, 53(1), pp. 120-150.

Karadağ, M., Deliktaş, E. and Önder, A.Ö. (2005). The effects of public capital on private sector performance in Turkey. *Public Finance Review*, 33(6), pp. 686-728.

Katz, M. L., & Shapiro, C. (1985). Network externalities, competition, and compatibility. *American Economic Review*, 75(3), 424-440

Kenny, C. (2007). Construction, corruption, and developing countries. *World Bank Policy Research Working Paper*, (4271).

Khobai, H., & Abel, S. (2023). Bootstrap panel causality between infrastructure and economic growth in South Africa. *Journal of Economic Structures*, 12(1), 1-18.

Khosa, M. M. (1995) *Transport and popular struggles in South Africa*. Wits University Press.

Kodongo, O., & Ojah, K. (2016). Does infrastructure really explain economic growth in Sub-Saharan Africa? *Review of Development Finance*, 6(2), 105-125.

Krugman, P. (1991). Increasing returns and economic geography. *Journal of Political Economy*, 99(3), 483-499.

Krugman, P. (2009). The increasing returns revolution in trade and geography. *American Economic Review*, *99*(3), 561-571.

Kumo, W. L. (2012). Infrastructure investment and economic growth in South Africa: A granger causality analysis. *African development bank group working paper series*, *160*.

LeSage, J. and Pace, R.K. (2009) *Introduction to spatial econometrics*. Boca Raton: Chapman and Hall/CRC.

Ligthart, J.E. and Suárez, R.M. (2011). The productivity of public capital: A meta-analysis. in Public economics and public policy. *Cheltenham: Edward Elgar Publishing*, pp. 5-32.

Looney, R.E. and Frederiksen, P.C. (1981). The regional impact of infrastructure investment in Mexico, *Regional Studies*, 15(4), pp. 285-296.

López, E., Gutiérrez, J. and Gómez, G. (2008). Measuring regional cohesion effects of large-scale transport infrastructure investments: An accessibility approach, *European Planning Studies*, 16(2), pp. 277-301.

Lucas, K. (2012). Transport and social exclusion: Where are we now?. *Transport policy*, *20*, 105-113.

Lucas, R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics*, 22(1), 3-42.

Matsolo, K., (2021) *The effect of transport infrastructure investment on economic growth in South Africa.* Master's Dissertation. Nelson Mandela University.

Maparu, T.S. and Mazumder, T.N. (2017). Transport infrastructure, economic development and urbanization in India (1990–2011): Is there any causal relationship?, *Transportation Research Part A: Policy and Practice*, 100, pp. 319-336.

Martin, P. and Rogers, C.A. (1995). Industrial location and public infrastructure, *Journal of International Economics*, 39(3-4), pp. 335-351.

Marshall, A. (1890). Principles of economics. Macmillan

McCann, P. and Rodríguez-Pose, A. (2011). Why and when development policy should be place-based, in *OECD Regional Outlook 2011*. Paris: OECD Publishing, pp. 203-213.

Melo, P. C., Graham, D. J., & Brage-Ardao, R. (2013). The productivity of transport infrastructure investment: A meta-analysis of empirical evidence. *Regional Science and Urban Economics*, 43(5), 695-706.

Miller, R.E. and Blair, P.D. (2009) *Input-output analysis: Foundations and extensions*. 2nd edn. Cambridge: Cambridge University Press.

Moeketsi, M., (2017) *The relationship between road infrastructure investment and economic growth in South Africa.* Master's Dissertation. North-West University.

Mokoena, L. M., Marais, L., & Chakwizira, J. (2023). Infrastructure multipliers in South African provinces: A comparative analysis. *Regional Studies*, 57(8), 1456-1470.

Mthembu, S., Nkomo, S., & Dlamini, P. (2022). Infrastructure-growth causality in South Africa: A time-varying approach. *Applied Economics*, 54(25), 2912-2928.

Mundell, R.A. (1962). The appropriate use of monetary and fiscal policy for internal and external stability, *IMF Staff Papers*, 9(1), pp. 70-79.

National Planning Commission (2012) *National Development Plan 2030: Our future - make it work*. Pretoria: The Presidency.

National Treasury (2019) *Public infrastructure investment framework*. Pretoria: National Treasury.

Ncanywa, T., & Masoga, M. M. (2021). Can public infrastructure expenditure enhance economic growth in South Africa? A bound testing approach. *Cogent Economics & Finance*, 9(1), 1923813.

Notteboom, T. E., & Winkelmans, W. (2001). Structural changes in logistics: how will port authorities face the challenge?. *Maritime Policy & Management*, *28*(1), 71-89.

Okonkwo, A. E., Mbeki. C & Obi, C. B. (2023). African Governments and Reliance on the Western Powers for Addressing Global Challenges: Challenges and Opportunities. *International Journal of Research and Innovation in Social Science*, *8*(10), 317-324.

OECD (2015) *Infrastructure financing instruments and incentives*. Paris: OECD Publishing.

OECD (2016) *OECD Regional Outlook 2016: Productive regions for inclusive societies*. Paris: OECD Publishing.

OECD (2017) *Getting infrastructure right: A framework for better governance*. Paris: OECD Publishing.

Pedroni, P., (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*, 61(S1), pp.653–670.

Pedroni, P., (2004). Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory*, 20(3), pp.597–625.

Pesaran, M. H., & Smith, R. (1995). Estimating long-run relationships from dynamic heterogeneous panels. *Journal of Econometrics*, 68(1), 79-113.

Pesaran, M. H., Shin, Y., & Smith, R. J. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association*, 94(446), 621-634.

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, 16(3), 289-326.

Pereira, A.M. and Andraz, J.M. (2013). On the economic effects of public infrastructure investment: A survey of the international evidence. *Journal of Economic Development*, 38(4), 1-37.

Perroux, F., 1955. *Note sur la notion de pôle de croissance*. Économie Appliquée, 8(1–2), pp.307–320.

Persson, T. & Tabellini, G., (2000). *Political economics: Explaining economic policy*. Cambridge, MA: MIT Press.

Phiri, A. (2021). Infrastructure spending and economic growth in South Africa: A threshold regression analysis. *Journal of Economic and Financial Sciences*, 14(1), 1-10.

Pirie, G. H. (1993). *On the Move: The Transportation Geography of South Africa*. Wits University Press.

PRASA (2023). *Annual report 2022/23*. https://static.pmg.org.za/Prasa_Annual_Report_2023_48.pdf

Pritchett, L., Woolcock, M. & Andrews, M., (2013). Looking like a state: Techniques of persistent failure in state capability for implementation. *The Journal of Development Studies*, 49(1), pp.1–18.

Rajaram, A., Le, T.M., Kaiser, K., Kim, J.H. & Frank, J., eds., (2014). *The power of public investment management: Transforming resources into assets for growth*. Washington, DC: World Bank Publications.

Reconstruction and Development Programme (1994). *The Reconstruction and Development Programme: A policy framework*. Johannesburg: African National Congress.

Redding, S.J. and Turner, M.A. (2015). Transportation costs and the spatial organization of economic activity. *Handbook of Regional and Urban Economics*, 5, 1339-1398.

Reggiani, A., Nijkamp, P. & Cento, A., (2011). Connectivity and competition in airline networks. *Transportation Research Part E: Logistics and Transportation Review*, 47(6), pp.1090–1106.

RMB/BER Business Confidence Index. (2024). *Business confidence in the Western Cape highest in South Africa*. Africa.com.

Robinson, J.A. & Torvik, R., (2005). *White elephants*. Journal of Public Economics, 89(2–3), pp.197–210.

Rodrigue, J.P., Comtois, C. & Slack, B., (2017). *The geography of transport systems*. 4th ed. London: Routledge.

Rodríguez-Pose, A. & Garcilazo, E., (2015). Quality of government and the returns of investment: Examining the impact of cohesion expenditure in European regions. *Regional Studies*, 49(8), pp.1274–1290.

Rodrik, D., (2008). The new development economics: We shall experiment, but how shall we learn? In: J. Cohen & W. Easterly, eds. *What works in development? Thinking big and thinking small*. Washington, DC: Brookings Institution Press, pp.24–47.

Rodrik, D., Subramanian, A. & Trebbi, F., (2004). *Institutions rule: The primacy of institutions over geography and integration in economic development*. Journal of Economic Growth, 9(2), pp.131–165.

Röller, L.H. & Waverman, L., (2001). *Telecommunications infrastructure and economic development: A simultaneous approach*. American Economic Review, 91(4), pp.909–923.

Romp, W. & De Haan, J., (2007). *Public capital and economic growth: A critical survey*. Perspektiven der Wirtschaftspolitik, 8(S1), pp.6–52.

Rosenstein-Rodan, P.N., (1943). *Problems of industrialisation of Eastern and South-Eastern Europe*. The Economic Journal, 53(210/211), pp.202–211.

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(5), S71-S102.

Roukouni, A., Junyent, I. A., Casanovas, M. M., & Correia, G. H. D. A. (2022). An analysis of the emerging "shared mobility hub" concept in European cities: Definition and a proposed typology. *Sustainability*, *15*(6), 5222.

Roux, A., & Naudé, W. (2022). Long-run effects of infrastructure investment on provincial economic growth in South Africa. *Development Southern Africa*, 39(2), 234-251.

Sahoo, P., & Dash, R. K. (2012). Economic growth in South Asia: Role of infrastructure. *Journal of Economic Development*, 37(4), 53-78.

Semykina, A., & Wooldridge, J. M. (2010). Estimating panel data models in the presence of endogeneity and selection. *Journal of Econometrics*, *157*(2), 375-380.

Sithole, M., Moyo, C., & Ncube, M. (2022). Infrastructure investment multipliers across South African provinces: A spatial analysis. *Regional Science Policy & Practice*, 14(3), 578-595.

Sloboda, B.W. & Yao, V.W., (2008). *Interstate spillovers of private capital and public spending*. The Annals of Regional Science, 42(3), pp.505–518.

South African National Treasury. (2019). *Infrastructure Investment Framework*. National Treasury.

South African National Roads Agency Limited (2021). *Annual report 2020/21*. Pretoria: SANRAL.

South African National Roads Agency Limited (2023). *Annual report 2020/21*. https://nationalgovernment.co.za/entity_annual/3436/2023-the-south-african-national-roads-agency-soc-ltd-(sanral)-annual-report.pdf

Statistics South Africa (2021). *Gross domestic product: Third quarter 2021*. Pretoria: Statistics South Africa.

South African Reserve Bank (2022). *Quarterly Bulletin: December 2022*. Pretoria: South African Reserve Bank.

Stern, N. and Stiglitz, J.E., (2023). Climate change and growth. *Industrial and Corporate Change*, *32*(2), pp.277-303.

Straub, S., (2011). *Infrastructure and development: A critical appraisal of the macro-level literature*. The Journal of Development Studies, 47(5), pp.683–708.

Stungwa, S., & Daw, O. D. (2021). Infrastructure development and population growth on economic growth in South Africa.

Sunde, T., Nkuna, M. & Wotshela, B., (2024). *Telecommunication infrastructure and economic growth in South Africa: An ARDL bounds test approach.* Telecommunications Policy, 48(2), 102631

Tinbergen, J., (1952). *On the theory of economic policy*. Amsterdam: North-Holland Publishing Company.

Turok, I. (2012). *Urbanisation and development in South Africa: Economic imperatives, spatial distortions and strategic responses* (pp. 1-66). London: Human Settlements Group, International Institute for Environment and Development.

Turok, I., & Parnell, S. (2009, May). Reshaping cities, rebuilding nations: The role of national urban policies. In *Urban Forum* (Vol. 20, No. 2, pp. 157-174). Dordrecht: Springer Netherlands.

UN Economic Commission for Africa. (2023). *Economic Report on Africa 2023: Building Africa's Resilience to Global Economic Shocks*. UN Economic Commission for Africa.

Venables, A.J., (2007). Evaluating urban transport improvements: Cost–benefit analysis in the presence of agglomeration and income taxation. *Journal of Transport Economics and Policy*, 41(2), pp.173–188.

Vickerman, R., (2007). Recent evolution of research into the wider economic benefits of transport infrastructure investments. *In: Round Table 140: Cost-Benefit Analysis and the Environment.* Paris: OECD Publishing, pp.321–346.

Walters, J., (2013). *Overview of public transport policy developments in South Africa.* Research in Transportation Economics, 39(1), pp.34–45.

Wang, Y., Ali, A., & Chen, Z. (2025). Dynamic relationships between environment-related technologies, agricultural value added, transport infrastructure and environmental emissions in the five most populous countries. *Scientific Reports*, *15*(1), 2308.

Western Cape Government. (2025). *Western Cape GDP and Business Confidence Index remain robust despite difficult economic challenges*. Department of Premier Media Statement.

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press.

World Bank, (2009). *World Development Report 2009: Reshaping economic geography*. Washington, DC: World Bank Publications.

World Bank, (2017). *Private participation in infrastructure (PPI): 2016 annual report*. Washington, DC: World Bank Publications.

World Bank (2020). *Infrastructure for development: Meeting the challenge*. Washington, DC: World Bank Group.

World Bank. (2020). *Africa's Infrastructure: Time for Transformation*. World Bank Group.

World Bank. (2023). *Africa's Infrastructure: Time for Transformation*. World Bank Group.

World Bank, (2021). *Infrastructure for development: Meeting challenges and building trust*. Washington, DC: World Bank Publications.

Yilmaz, S. & Koyuncu, M., (2010). The impact of infrastructure on economic development: The case of Turkey. *Journal of Economic Development*, 35(4), pp.111–128.

Zhang, W.B., Zhang, L. & Zhang, M., (2018). How does transport infrastructure promote regional economic development? Evidence from China. *Journal of Transport Geography*, 73, pp.25–39.

Appendix

7.1 Ethical Clearance

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

11-04-2025
Miss Nqobile Xaba (216034407)
School Of Acc Economics&Fin
Westville

Dear Miss Nqobile Xaba,

Original application number: 00030531
Project title: Public transport infrastructure spending and provincial economic growth in South Africa: A panel autoregressive distributed lag approach

Exemption from Ethics Review

In response to your application received on 11 April 2025, your school has indicated that the protocol has been granted **EXEMPTION FROM ETHICS REVIEW.**

Any alteration/s to the exempted research protocol, e.g., Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through an amendment/modification prior to its implementation. The original exemption number must be cited.

For any changes that could result in potential risk, an ethics application including the proposed amendments must be submitted to the relevant UKZN Research Ethics Committee. The original exemption number must be cited.

In case you have further queries, please quote the above reference number.

PLEASE NOTE:
Research data should be securely stored in the discipline/department for a period of 5 years.

I take this opportunity of wishing you everything of the best with your study.

Yours sincerely,

[redacted]

Prof Claire Lauren Vermaak
Academic Leader Research
School Of Acc Economics&Fin

UKZN Research Ethics Office
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Website: http://research.ukzn.ac.za/Research-Ethics/

Founding Campuses: Edgewood Howard College Medical School Pietermaritzburg Westville

INSPIRING GREATNESS

7.2 Turnitin Report

N Xaba Final

ORIGINALITY REPORT

5%	3%	3%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	hdl.handle.net Internet Source	<1 %
2	content.sciendo.com Internet Source	<1 %
3	Submitted to School of Oriental & African Studies Student Paper	<1 %
4	ramp.ase.ro Internet Source	<1 %
5	Ramesh Chandra Das. "Convergence and Developmental Aspects of Credit Allocations in BRICS Nations - Theoretical and Empirical Inquiries", Routledge, 2024 Publication	<1 %
6	Christopher Dick-Sagoe, Ernest Ngeh Tingum, Peter Asare-Nuamah, Denis N. Yuni, Nicholas Baidoo. "Central transfers and incentives to collect local revenue among the Central Region of Ghana's local government officials: analysing the flypaper effect", Humanities and Social Sciences Communications, 2025 Publication	<1 %
7	www.mdpi.com Internet Source	<1 %