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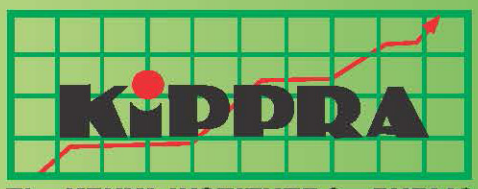

The KENYA INSTITUTE for PUBLIC POLICY RESEARCH and ANALYSIS

Role of Rural Road Infrastructure on Agricultural Productivity in Kenya

Martha Nanekoi Naikumi

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THE KENYA INSTITUTE FOR PUBLIC POLICY RESEARCH AND ANALYSIS (KIPPRA)

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Abstract

This study investigates the implications of rural road infrastructure on agricultural productivity in Kenya, emphasizing the role that effective transportation networks play in facilitating market access for farmers. Given that agriculture constitutes approximately 25 per cent of Kenya's Gross Domestic Product and employs around 70 per cent of the total labour force, either directly or indirectly, enhancing rural road infrastructure is vital for improving productivity and reducing poverty. The current state of rural roads, with only 16 per cent paved and significant disparities across counties, is one of the major factors that hinder agricultural productivity and rural livelihoods. High transportation costs, reduced farming output, and income instability are major challenges, highlighting the need for robust road networks to drive economic growth. The study reveals key findings with significant policy implications. First, a 1.0 per cent improvement in rural road infrastructure is associated with a 2.9 per cent increase in agricultural productivity, while improved road access contributes an additional 1.26 per cent boost. The analysis also reveals a notably strong relationship between capital stock and agricultural productivity—a 10 per cent increase in capital stock is associated with an approximate 3.0 per cent rise in productivity. Moreover, the interaction between aridity and road development shows a positive coefficient of 1.327, suggesting that improvements in road infrastructure could yield greater productivity gains in arid regions. Lastly, climate variability, particularly rainfall, significantly impacts agricultural success, underscoring the need for climate-resilient road infrastructure. Based on these findings, the study recommends prioritizing investments in rural road infrastructure to enhance agricultural productivity. The national and county governments could focus on improving road quality and coverage, especially in areas with high agricultural potential and arid regions, where infrastructure enhancements can yield significant productivity gains. Furthermore, facilitating access to credit and financial services would enhance capital stock. The study also emphasizes implementing measures to manage climate variability, such as promoting drought-resistant crops and improving irrigation systems. Addressing the infrastructure gaps can lead to substantial improvements in agricultural performance and rural livelihoods throughout Kenya.

Abbreviations and Acronyms

BETA	Bottom-Up Economic Transformation Agenda
GCP	Gross County Product
GVA	Gross Value Addition
KeRRA	Kenya Rural Roads Authority
KNBS	Kenya National Bureau of Statistics
KPHC	Kenya Population and Housing Census
KRB	Kenya Roads Board
NDMA	National Drought Management Authority
RICS	Road Inventory and Condition Survey
RRII	Rural Road Infrastructure Index

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1. Introduction

Robust road networks are essential for driving economic growth, especially in the agricultural sector, where they provide farmers with crucial access to input and output markets (Guerrero-Ibanez et al., 2015; Huang et al., 2018). Improved road infrastructure enhances agricultural productivity by reducing transportation costs and enabling farmers to access markets more efficiently. Research by Carew and Mandel (2014) indicates that every US$1 invested in roads yields a US$3 return through reduced transportation costs and increased market access, contributing to higher farm productivity.

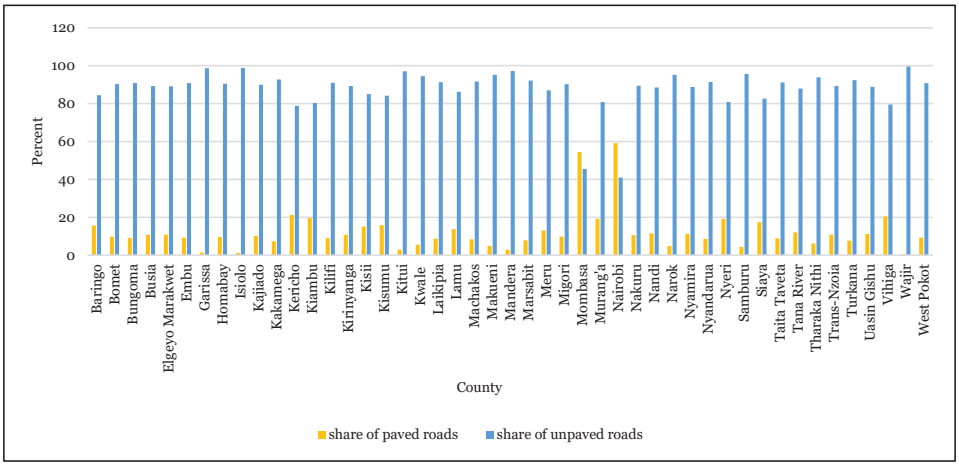
In developing regions like Sub-Saharan Africa, road infrastructure plays a critical role in overcoming the constraints of low road density and high transportation costs, both of which severely limit agricultural growth. A study by Dercon et al. (2008) highlights that improvements in rural road infrastructure significantly reduce transportation costs and enhance market access, which is essential for agricultural productivity. In Kenya, inadequate road conditions during the rainy season result in delayed deliveries, spoilage of perishable goods, and limited market access, all of which negatively affect farmers' income and productivity.

Kenya's agricultural sector, which contributes approximately 25 per cent of Gross Domestic Product (GDP) and employs about 70 per cent of the population either directly or indirectly (Kenya National Bureau of Statistics, 2022), heavily relies on rural road infrastructure. However, only 63,000 km of Kenya's 181,000 km road network are paved (tarmacked) (Kenya Roads Board, 2018). This leaves 55 per cent of the rural population living more than 2 km from an all-weather road, which significantly raises transport costs, constraining farmers' access to markets. Counties such as Samburu and Isiolo, where road networks are poor, face greater challenges in transporting agricultural produce, which directly impacts productivity (Kenya Roads Board, 2018).

Furthermore, disparities in road quality between counties reveal pronounced inequalities in agricultural productivity. For instance, counties with less than 5.0 per cent paved roads, for example, Lamu, Wajir, and Samburu, experience lower agricultural output compared to counties with better infrastructure such as Kiambu and Nyeri, where over 50 per cent of the road network is paved as shown in Figure 1.1 (Kenya Roads Board, 2018). Addressing these infrastructural gaps is crucial, as improved rural roads enhance market access and promote commercialization. Further, Mu and van de Walle (2011) found that improving rural road access increased farm gate prices by 15 to 25 per cent, significantly boosting farmer incomes.

Rural road infrastructure is thus a vital component of agricultural development strategies in Kenya (Kariuki and Mwenda, 2019). Enhancing rural road connectivity by just 10 per cent could lead to a 7.0 per cent increase in crop production (African Development Bank, 2018). This highlights the critical need for targeted investments in rural road rehabilitation to drive agricultural productivity and reduce rural poverty.

Figure 1: Share of paved and unpaved roads across counties in 2018



Source: Kenya Roads Board, Road Inventory and Condition Survey, 2018

Kenya's commitment to regional and global infrastructure goals, such as the African Union's Agenda 2063 and Kenya Vision 2030, emphasizes rural road development as a priority. Although progress has been made in expanding the paved road network, this has largely benefitted urban and inter-urban highways, leaving rural areas underserved. For example, as shown in Figure 1.1, the disparity between counties such as Mombasa and Nairobi, with more paved roads than unpaved, and counties such as Wajir and Samburu, underscores an urban-centric bias in infrastructure development (Kenya National Bureau of Statistics, 2019).

The aim of this paper is to assess the effect of rural road infrastructure on agricultural productivity in Kenya. This focus is central to understanding how improved rural road infrastructure can enhance productivity by reducing transport costs, facilitating market access, and promoting commercialization.

Bridging this rural infrastructure gap is essential not only for agricultural productivity, but also improving rural livelihoods. The findings of this study aim to inform national and county-level infrastructure development plans, ensuring alignment with Kenya Vision 2030's agricultural policy goals. By emphasizing rural road infrastructure as a catalyst for agricultural growth, this research guides policy interventions that prioritize rural areas hindered by poor road access, contributing to the realization of the Bottom-Up Economic Transformation Agenda (BETA).

The remainder of the paper is organized as follows: section two provides the policy context for rural road infrastructure; section three details relevant literature, including theoretical and empirical underpinnings; section four outlines the methodology of the study; section five presents the findings and discussion; and section six concludes the study and provides policy recommendations.

2. Policy, Legal, and Institutional Framework

The policy context in Kenya is critical for increasing agricultural production through the construction and maintenance of rural road infrastructure. This section gives an overview of the current state of rural roads in Kenya and includes a policy evaluation matrix to help with policy analysis.

2.1 Overview of Rural Road Infrastructure in Kenya

Kenya's rural road network is critical for connecting agricultural areas to markets and basic amenities. As of 2020, Kenya had roughly 161,451 km of categorized rural roads, with just about 16 per cent paved (Kenya Roads Board, 2018). This is a tremendous improvement since 2008, when the network covered 91,000 km and was only 8.0 per cent paved. Despite these developments, a significant number of rural roads remain unpaved, posing issues during rainy seasons that impede agricultural productivity.

The Kenya Vision 2030, which emphasizes the importance of robust transportation infrastructure as a foundation for economic growth, and the Roads 2000 Programme, which focuses on labour-based maintenance and rehabilitation of rural roads, are two key policies guiding rural road infrastructure development. The Kenya Roads Act of 2007 established specialized institutions, such as the Kenya Rural Roads Authority (KeRRA), to oversee the management and development of rural roads. Following this, the Kenya Roads Board (KRB), tasked with the classification of roads based on their importance and function, introduced a new road classification system. This system defines classes D, E, F, G, K, L, P, R, S, T, U and W, as county roads (Kenya Roads Act, 2007).

With the advent of devolution in 2010, road administration was decentralized to county governments, marking a significant shift in road management. While this devolution aimed to enhance local decision-making and community responsiveness, it also introduced challenges. Counties often face limitations in technical expertise and financial resources, which hinder the effective construction and maintenance of rural roads (Omondi, 2014). Additionally, the need for coordination between national and county governments complicates projects that span across multiple counties, particularly national highways. Despite these obstacles, as counties gain experience and receive support from the national government, there remains potential for improved rural road management.

Table 2.1 describes the various classes of rural roads that are developed and managed by the county governments as outlined in the Kenya Gazette Supplement No. 4 of 2016.

Table 2.1: Classes and description of county rural roads

Class	Description
Class D	Secondary roads linking locally important centres to each other, to more important centres or to higher class roads
Class E	Also called minor roads or feeder roads, are roads linking to a minor centre, market, or local centre
Class F	Forest roads
Class G	Roads serving schools, hospitals and government institutions
Class K	Roads leading to coffee (Kahawa) growing areas
Class L	Roads accessing settlement schemes
Class P	National parks roads
Class R	Roads accessing rural areas
Class S	Roads accessing sugar growing areas
Class T	Roads accessing tea growing places
Class U	Unclassified rural roads including those leading to areas with mineral deposits
Class W	Roads accessing wheat growing areas

Source: Kenya Roads Act, 2007

Table 2.2 presents a policy, legal and regulatory review matrix with assessment of the legal and regulatory framework for rural roads infrastructure and its linkage to agricultural productivity.

The analysis of the policy and legal review highlights several strengths in Kenya's rural road infrastructure development (Table 2.2). Notably, the Kenya Vision 2030 and the Roads 2000 Programme have established a robust foundation for rural road initiatives, resulting in significant investments and improvements in the road network. The establishment of KeRRA and the devolution of road management to county governments have further enhanced local responsiveness, allowing communities to better express their needs and priorities regarding road infrastructure.

However, there are notable weaknesses that persist within the current framework. Despite the progress made, a substantial portion of rural roads remains unpaved, which severely limits access during adverse weather conditions and negatively impacts agricultural productivity. Additionally, there is a significant gap in funding for road maintenance, which is essential for sustaining the quality of these roads. This issue is compounded by limited technical capacity at the county level, hindering effective management and maintenance efforts. Furthermore, high transportation costs and restricted access to extension services in poorly connected regions continue to create challenges for farmers, particularly in remote areas.

Despite these challenges, there are ample opportunities for improvement in Kenya's rural road infrastructure. Learning from successful international models, such as Rwanda's Rural Feeder Roads Programme and India's Pradhan Mantri Gram Sadak Yojana (PMGSY), can provide valuable insights into community

participation and innovative funding mechanisms. Engaging local communities in the planning and maintenance of rural roads, similar to Tanzania's Village Travel and Transport Programme (VTTP), could enhance ownership and sustainability of road infrastructure. By leveraging these opportunities, Kenya can work towards a more efficient and equitable rural road network that supports agricultural development and improves livelihoods.

Table 2.2: Summary of policy and legal review

Issue	Description	Policies, laws, and regulations	Interventions	Gaps
Rural Road Infrastructure Development	Components: The rural road infrastructure development cycle includes: • Planning and Prioritization – identifying critical road networks that connect agricultural areas to markets, ensuring that local needs are considered	• Kenya Rural Roads Authority (KeRRA) – established in 2007 to oversee the development and maintenance of rural roads • Kenya Roads Act (2007) – governs the management and maintenance of roads. • National Spatial Plan (2015-2045) – provides a framework for the development of transport infrastructure to support agricultural productivity and market access • County Governments Act (2012) – devolves functions including agriculture and rural development to county governments, including the development and maintenance of rural roads	• Planning and prioritization need development of a structured community engagement strategy that allows local stakeholders, including farmers, to participate in the planning process. This ensures that the roads constructed meet the specific needs of agricultural producers. • Integrated Transport and Land Use Planning aligns the National Spatial Plan (2015-2045) with agricultural development plans to ensure that road infrastructure supports agricultural zones and market access efficiently.	• Inadequate integration of policies – the current road policy framework does not have integration, failing to promote cumulative positive externalities. There is insufficient alignment between road infrastructure development and agricultural policies, leading to suboptimal outcomes for rural communities. • Fragmented institutional framework – the management of rural roads is characterized by fragmentation among various institutions, which complicates coordination and accountability. This fragmentation hampers effective implementation of road projects and maintenance strategies.

Issue	Description	Policies, laws, and regulations	Interventions	Gaps
Rural Road Infrastructure Development	• Construction and Rehabilitation – building new roads and upgrading existing ones to improve accessibility and reduce travel time for farmers • Maintenance – regular upkeep of roads to ensure they remain passable, which is essential for continuous agricultural productivity	• Public-Private Partnership Act (2013) – enables private sector participation in the financing, construction, development, operation, or maintenance of infrastructure projects, including rural roads • National Industrialization Policy Framework for Kenya (2012-2030) – promotes the development of agro-processing industries in rural areas, which requires adequate road infrastructure • Roads 2000 Programme – aims to construct and maintain 2,000 km of rural roads annually using labour-based methods and local contractors • Road Maintenance Levy Fund (RMLF) – provides funding for the maintenance of the road network, including rural roads • Road Sector Investment Programme (RISP) – a strategic framework aimed at guiding road sector development and investment in Kenya	• Promotion of labour-based construction methods as part of the Roads 2000 Programme, which can create local employment opportunities while also building roads. This approach can enhance community ownership and maintenance of the infrastructure. • Encourages the use of environmentally friendly materials and construction practices that minimize ecological impact. This can be supported by guidelines from the Kenya Roads Act (2007) and the Public-Private Partnership Act (2013). • Exploring innovative financing options, including public-private partnerships (PPPs), to fund road construction and rehabilitation projects. This can leverage private sector expertise and investment, reducing the financial burden on the government.	• Underfunding of maintenance and rehabilitation – despite the existence of RMLF, inadequate funding and prioritization for maintenance and rehabilitation of rural roads persists. This leads to a deterioration of road conditions, negatively impacting agricultural productivity. • Poor quality of rural roads – a significant portion of the rural road network remains unpaved (more than 80%) and in poor condition, which hinders access to markets and increases transportation costs for agricultural products.

Issue	Description	Policies, laws, and regulations	Interventions	Gaps
Rural Road Infrastructure Development		• Upgrading low-volume roads – this initiative focuses on upgrading roads to bitumen standards, particularly for low-volume rural roads • Routine maintenance of rural roads – this initiative focuses on the routine maintenance of the rural road network to ensure year-round passability, especially during the rainy seasons; and covers clearing drainage systems, patching potholes, and grading unpaved roads to enhance accessibility in rural regions, crucial for agricultural and economic activities	• Implement a comprehensive road maintenance management system that utilizes technology to monitor road conditions in real time. This system can facilitate timely maintenance interventions, reducing long-term repair costs. • Introduction of performance-based contracts for road maintenance that incentivize contractors to maintain high standards and ensure timely repairs. This aligns with the objectives of the Road Maintenance Levy Fund (RMLF).	• Weak implementation of existing policies – there have been unexplained reversals and weak implementation of specific policy strategies, resulting in inconsistent outcomes in road infrastructure projects. This inconsistency undermines the effectiveness of existing frameworks.

Issue	Description	Policies, laws, and regulations	Interventions	Gaps
Agricultural linkages with rural road infrastructure	Rural road infrastructure notably affects agriculture in various ways including: • Market access – improved roads facilitate timely transport of agricultural products to markets, reducing post-harvest losses.	• Transformation and Growth Strategy (ASTGS, 2019-2029) – prioritizes the development of rural infrastructure, including roads, to support agricultural productivity and market access • National Agricultural Research System (NARS) – conducts research on the impact of rural road infrastructure on agricultural productivity and develops strategies to optimize these linkages	• Facilitating partnerships between local governments and input suppliers as outlined in the Agricultural Sector Development Strategy (ASDS) to ensure timely access to quality agricultural inputs for farmers • Implementation of initiatives as per the National Cooperative Policy to strengthen rural cooperatives, enabling them to pool resources for better access to markets and inputs, thus enhancing agricultural productivity	• Insufficient research on infrastructure impact – there is need for further research to understand the relationship between rural road infrastructure and agricultural productivity. Current policies do not adequately address the impacts of road conditions on market access and agricultural efficiency. • Limited community participation – current frameworks do not adequately incorporate community input in the planning and decision-making processes for road infrastructure projects. This lack of engagement can lead to roads that do not meet the actual needs of local farmers.

Issue	Description	Policies, laws, and regulations	Interventions	Gaps
Agricultural linkages with rural road infrastructure	• Input accessibility – enhanced road networks allow farmers to access agricultural inputs such as seeds and fertilizers more easily • Post-harvest management – better road conditions enable farmers to transport their produce to storage facilities quickly, minimizing spoilage	• Agricultural Sector Development Support Programme (ASDSP) – promotes the development of agricultural value chains, which requires efficient rural road networks for the timely transportation of inputs and produce • National Agricultural Policy (2012) – supports the integration of agricultural infrastructure with rural development • Kenya Cereal Enhancement Programme (KCEP) – supports smallholder farmers in accessing inputs and markets through the rehabilitation and maintenance of rural roads	• Leveraging the Roads 2000 Programme to prioritize road construction in agricultural areas, ensuring that rural roads enhance access to markets, inputs and services for farmers • Strengthen agricultural value chains as outlined in the Agricultural Sector Development Support Programme (ASDSP) to include road infrastructure improvements to facilitate better market access for agricultural products • Collaboration with financial institutions as outlined in ASDSP II to provide credit facilities to farmers and cooperatives for investments in agricultural inputs and road maintenance, improving overall productivity and sustainability	• Limited private sector participation –while Kenya has established a legal and regulatory framework for PPPs, there has been slow progress in attracting private investment in rural road infrastructure projects. The primary challenges lie in providing adequate incentives and ensuring a guaranteed rate of return on investment. Many private investors remain hesitant due to the perceived high risks, long project durations, and uncertainties in revenue generation from rural road projects, where economic returns maybe lower compared to urban areas. A clear strategy that offers financial incentives and risk mitigation measures could foster more robust private sector participation.

Issue	Description	Policies, laws, and regulations	Interventions	Gaps
	• Economic growth – overall improvement in rural infrastructure leads to increased agricultural productivity, contributing to local and national economies		• Integrating Climate-Smart Agriculture (CSA) practices into road infrastructure projects to enhance resilience against climate change, ensuring that roads support sustainable agricultural practices and improve market access for climate-resilient crops • Implementation of training programmes for farmers on best practices in utilizing road infrastructure for market access, including logistics, storage, and transportation strategies to minimize post-harvest losses. • Incorporation of technology in agricultural logistics – facilitate the use of technology, such as mobile applications for transport coordination and market information to enhance the efficiency of agricultural logistics linked to rural road infrastructure.	• Inadequate innovation in transport solutions – there is limited innovative and affordable transport technologies suited to rural conditions. This gap limits the potential for improved mobility and access to markets for agricultural producers. • Inadequate focus on climate resilience – policies do not sufficiently address climate resilience in the context of rural road infrastructure. This oversight can exacerbate vulnerabilities for rural communities, particularly in the face of climate change impacts on agriculture.

3. Literature Review

3.1 Theoretical Literature

The existing theoretical evidence highlights that improved road infrastructure lowers transport costs, heightens rural connectivity and fosters economic growth. Rural accessibility and reduced transportation costs from farm to markets promote market participation and help harness the comparative advantage of agricultural producers (Kihiu andand Gachanja, 2022).

3.1.1 Production theory

Production theory underscores the economic process of converting inputs into outputs, emphasizing the dynamic nature of production, shaped by various factors, including the quality of road infrastructure. Birch (2018) emphasizes the importance of technological advancements and innovations in enhancing agricultural productivity, a theme particularly pertinent to Kenya's agricultural landscape.

In Kenya, like other developing countries, the link between production theory and road infrastructure is crucial for understanding the dynamics of agricultural productivity. The three processes outlined in production theory—quantity, form and distribution of the produced goods or services—directly correlate with the role of road networks in facilitating the movement of agricultural products.

Improved road infrastructure plays a vital role in the spatial distribution of agricultural goods. Efficient transportation systems enable farmers to transport their produce from rural areas to urban markets, ensuring a timely and cost-effective flow of goods. This is especially relevant given the geographic diversity of Kenya, with agricultural activities dispersed across different regions.

Birch's (2018) insights into the importance of agricultural technology and innovations in Kenya align with the country's efforts to adopt modern farming practices. The accessibility and quality of road infrastructure become pivotal in realizing the full potential of these innovations. Mechanized agriculture, for example, greatly benefits from well-maintained roads, which facilitates the movement of machinery and inputs.

The adoption of biological, water control and chemical innovations in the agricultural sector, also relies on effective distribution channels. Roads not only enable the transportation of these innovations, but also contribute to the broader goal of reaching remote agricultural areas, ensuring that the benefits are widespread.

Practically, the scalability of these innovations in Kenya, without requiring exorbitant capital inputs, is closely tied to the state of road infrastructure. The adaptability of these technologies to the Kenyan context, especially in tropical and subtropical regions, underscores the need for a well-connected transportation network.

Expanding on this economic viewpoint, Boopen (2006) highlights the significance of infrastructural development as a key determinant of economic growth. Infrastructural development represents the supply-side of economic growth, serving as a direct input to the production process. This aligns with the perspective that an increase in infrastructural stock, particularly in road infrastructure, is poised to boost economic growth by facilitating the movement of goods, services and labour to production sites and markets.

3.1.2 Infrastructure-led development theory

In the same way that a well-maintained irrigation system nourishes crops, fostering growth and yield, rural roads serve as vital lifelines for agricultural production. The theory of infrastructure-led development posits a strong correlation between the quality of infrastructure and economic performance, particularly within the agricultural sector (Mose, 2022). Lokesha and Mahesha (2017) specifically linked improvements in rural transportation networks to increased agricultural productivity and economic growth. This positive impact stems from several key mechanisms.

First, well-developed rural roads enhance market access for farmers (World Bank, 2008). By connecting them to a wider range of buyers and essential agricultural inputs such as fertilizers and high-yielding seeds, these roads encourage farmers to specialize and commercialize their production. This specialization, in turn, can lead to increased efficiency and innovation within the agricultural sector. Second, improved rural roads reduce transportation costs for farmers, allowing them to retain a larger share of their profits and potentially invest those savings back into their farms (Kihiu and Gachanja, 2022). This can incentivize them to expand production and adopt new technologies that further enhance agricultural productivity (World Bank, 2008). This research contributes valuable insights into the critical role these roads play in fostering a thriving agricultural sector via examining how rural road infrastructure aligns with the principles of infrastructure-led development theory.

3.2 Empirical Literature

A plethora of studies highlights the transformative effects of rural road development, particularly in the context of agricultural productivity. Stifel and Minten (2008) emphasize that rural road development enhances access to markets for both inputs and outputs, leading to a reduction in transaction and trade costs. This greater accessibility increases the utilization of inputs by farmers, subsequently boosting agricultural productivity. Jalan and Ravallion (2002) demonstrate a significant positive effect of road density on consumption growth at the farm-household level in rural areas of Southern China, underlining the crucial role of rural roads in enhancing living standards.

The proximity of roads is identified as a major factor in poverty reduction, as demonstrated by Dercon et al. (2008) using household data in Ethiopia. Fan, et al. (2004) further highlight the poverty-alleviating impact of reduced distances to public transportation facilities in Uganda. These findings underscore the integral

role of rural road infrastructure in fostering economic development and poverty reduction.

Aggarwal (2018) compiled district-level panel data in India for over 15 years to assess how the national PMGSY rural road construction initiative since 2000 affected agricultural outcomes. Using a difference-in-difference model, they found that districts witnessing more road construction had substantially higher increases in cultivated land, fertilizer usage, crop output and yield values compared to districts with less rural connectivity improvements. Their production function estimates suggested PMGSY road investments explained 20 per cent rise in agricultural yields across districts over the 15-year period, with gains concentrated in originally low-connectivity districts.

Fan and Chan-Kang (2005) conducted an extensive analysis of the lagged impacts of increased public investments in rural road infrastructure from 1970 to 1997 across provinces in China. They compiled province-level panel data on grain yields and aggregated outputs spanning over 25 years and estimated dynamic agricultural production functions incorporating road infrastructure stock. Their empirical strategy quantified both immediate and cumulative long-run effects finding that a 10 per cent increase in rural road investments had only negligible short-term gains, but raised productivity in grains by 15 per cent over a 10-year lag. This highlighted the need to evaluate long-run returns when analyzing rural public infrastructure spending.

Further, Raballand et al. (2011) adopted spatial econometrics techniques combined with district-level panel data from Uganda from 2001 to 2008. They incorporated road connectivity measures like average travel times to the nearest national paved highway across districts and over time. Their geospatial production models suggested improvements in rural accessibility, for example, 10 to 30 per cent of the changes in yields and net outputs for key cash and food crops in Uganda during 2000s. It provided evidence on how lagged gains from substantial investments in the prior decades accounted for variances in agricultural performance across regions in the 2000s.

Srinivasan and Beynon (2019) provided rare cross-country evidence from an African context analyzing a 10-year district-level panel dataset from Tanzania and Malawi. Adopting a reduced form approach, they isolated the effects of feeder road density expansion between 2002 and 2012 within districts on measures of agricultural commercialization and productivity. Consistent supply response was found as feeder road connectivity improvements causally increased cropping intensity, crop yields and share of marketed surplus for key cereals in both countries over the decade panel.

Inoni and Omotor (2009) assessed the effects of road infrastructure on agricultural output and rural incomes, focused on rural communities in Delta State, Nigeria. Employing household survey data, they found that accessibility determined by rural road quality had a significant and sizeable positive effect on agricultural productivity. Their crop production models estimated a 10 per cent improvement in rural road conditions, which caused a 12 per cent increase in

farm output. The outcomes resemble those of Ogunleye et al. (2018), whose study adopted Lakshmanan's (2007) conceptual framework on wider economic benefits of transport infrastructure to assess impacts of road investments on agricultural development in Nigeria from 1985 to 2014. Using time-series data on road infrastructure and agricultural GDP, they found paved road length per square kilometre had a significant positive correlation with growth in agricultural output. Their production function model estimated a one per cent increase in paved road length increased agricultural GDP by 1.01 per cent.

Kihiu and Gachanja (2022) conducted a comprehensive analysis of the relationship between rural road infrastructure and access to maize retail markets in Kenya. Their study utilized a robust dataset that included transport cost data, market access metrics and agricultural productivity indicators. By employing econometric models, they quantified the effects of road infrastructure on market participation among maize producers. The findings revealed that improvements in rural road infrastructure significantly reduce transportation costs, thereby enhancing access to markets. Specifically, the study found that a 10 per cent improvement in road conditions led to a 12 per cent increase in market participation among farmers over a five-year lag. This underscores the critical role of transportation infrastructure in facilitating agricultural market access, and highlights the need for sustained investment in rural roads to promote economic growth in agricultural sectors.

A similar study by Mbae (2021) delves into the critical nexus between road infrastructure and horticultural production at the county level in Kenya. The author employed panel data analysis covering the years 2015-2019 across all 47 counties in Kenya. The study acknowledges the pivotal role of road connectivity in agricultural productivity, particularly in the horticultural sector, and aims to shed light on the specific dynamics at the county level. Existing literature consistently underscores the positive relationship between rural connectivity and agricultural development. Mbae's focus on horticultural production aligns with the broader understanding that improved road infrastructure facilitates access to markets, reduces transaction costs, and enhances the utilization of inputs by farmers. The study provided a negative relationship between road infrastructure and horticultural productivity, challenging some established empirical findings. This novel insight prompts a reconsideration of the conventional wisdom surrounding the relationship between roads and agricultural productivity. This study builds on this work by utilizing cross-sectional data while exploring agricultural productivity with a special focus on agricultural productivity across rural counties in Kenya.

3.3 Summary of Literature

The existing literature emphasizes the importance of improving road infrastructure in increasing agricultural output and driving economic growth. Numerous studies have found that improved rural connection lowers transportation costs, boosts market access, and encourages farmers to participate more actively in commercial agriculture (Kihiu and Gachanja, 2022; Boopen, 2006). For example, production theory emphasizes the dynamic aspect of production processes by focusing on how

road condition affects the conversion of agricultural inputs into outputs (Birch, 2018). Empirical research supports these theoretical frameworks by indicating that investments in rural road infrastructure boost agricultural production and market participation in a variety of contexts, including Kenya (Aggarwal, 2018; Stifel and Minten, 2008) (detailed in Appendix I). These findings show that rural roads are more than just conduits for traffic; they are critical lifelines that aid in agricultural development.

Despite the wealth of research demonstrating the benefits of rural road development, significant gaps exist in literature. Many studies focus on specific crops or limited consequences, failing to examine the larger implications of road connectivity for agricultural productivity across different areas. For example, while Kihiu and Gachanja (2022) provide useful insights into maize market access, there is no investigation into how these findings apply to other agricultural sub-sectors or crops in Kenya. Furthermore, existing research tends to emphasize immediate effects without sufficiently addressing the long-term advantages of continuous investment in rural infrastructure. This lack of comprehensive study creates a gap in understanding how rural road infrastructure might support broader economic shifts in the agricultural landscape.

This study contributes considerably to the current literature by offering a thorough examination of the multidimensional influence of rural road infrastructure in agricultural productivity across the agricultural output in Kenya. Unlike previous research, which generally focuses on specific crops or localized consequences, this study uses cross-sectional data to examine a larger range of agricultural outputs, allowing for a more comprehensive understanding of how transportation infrastructure influences agricultural practices. The findings provide valuable insights into the interactions between rural road infrastructure and technological adoption, ultimately guiding policy makers on the importance of ongoing investment in rural infrastructure as a catalyst for increasing agricultural productivity and economic resilience in rural areas.

4. Methodology

The section provides theoretical framework, analytical framework clearly outlining the variables used in the empirical model, data sources and descriptive statistics.

4.1 Theoretical Framework

The theoretical framework for this study is grounded on the Solow-Swan production function, which is extensively used in economic literature to examine the factors influencing productivity.

Equation 4.1 shows the Solow-Swan production function:

$Y = AK^{\propto} L^{\beta}$ .....Equation 4.1

Where: Y is the total output, A is the total factor productivity (TFP), K is the capital stock, L is the labour input, $\propto$ and β are output elasticities of capital and labour, respectively.

To capture the specific effect of rural road infrastructure and agricultural land area on agricultural productivity, the study extends the conventional Solow-Swan model. Rural road infrastructure enhances productivity by improving market access, reducing transportation costs and facilitating modern agricultural practices (World Bank, 2009; Edeme et al., 2020; Mose, 2022; Kihiu and Gachanja, 2022). Agricultural land area directly affects production potential (Lobell, Schlenker, and Costa-Roberts, 2011). Consequently, the extended production function is expressed as:

$Y = AK^{\alpha} L^{\beta} R^{\gamma} H^{\delta} T^{\theta}$ ..... Equation 4.2

Where: R is the rural road infrastructure, H is the agricultural land area and T is the technological progress;γ,δ, and θ are the output elasticities of rural road infrastructure, agricultural land area and technological progress, respectively.

The effect of rainfall on agricultural productivity is incorporated in the modified Solow-Swan model by adding it as an exogenous variable that affects total factor productivity (TFP). The TFP is expressed as:

$A = A_0 e^{\rho C}$ ..... Equation 4.3

Where: A0 is the base level of TFP, ρ is the elasticity of TFP with respect to rainfall, and C_i is the mean annual rainfall in millimetres.

To better analyze agricultural productivity, this study expresses the production function in per worker terms. This approach helps to isolate the effects of capital and other variables on productivity, independent of the size of the labour force. However, the Rural road infrastructure index (RRII) is a normalized measure ranging from zero (0) to one (1), effectively capturing the infrastructure quality available to the agricultural workforce. Thus, it is not represented in per worker terms. Equation 4.4 results from dividing both sides of the production function by labour (L):

$\frac{Y}{L} = A_0 e^{\rho C}(\frac{K}{L})^{\propto}(R)^{\gamma}(\frac{H}{L})^{\delta}(\frac{T}{L})^{\theta}$ ..... Equation 4.4

Where:

- Y is the total agricultural output;
- L is the labour force in agriculture;
- AO is a constant representing base TFP;
- C is the mean annual rainfall;
- K,R,H,T are capital stock, land, rural road infrastructure, and technology inputs, respectively; and
- $\propto, \gamma, \delta$, and are the output elasticities.

To linearize this equation, the natural logarithm is applied on both sides as follows:

$ln(\frac{Y}{L}) = \ln(A_0 e^{\rho C}) + \propto ln(\frac{K}{L}) + \gamma ln(R) + \delta ln(\frac{H}{L}) + \theta ln(\frac{T}{L})$ .....Equation 4.5

Following the properties of logarithms, Equation 4.5 can be rewritten as:

$\ln\left(\frac{Y}{L}\right) = lnA_0 + ln\rho C + \propto (lnK - lnL) + \gamma R + \delta(lnH - lnL) + \theta(lnT - lnL)$ ..... Equation 4.6

Rearranging the terms gives:

$ln\left(\frac{Y}{L}\right) = \ln A_0 + c + (\propto + \delta + \theta)lnL + \propto lnK + \gamma lnR + \delta lnH + \theta lnT$ ..... Equation 4.7

The model Equation 4.7 could be simplified as:

$lny = \ln A_0 + c + (\propto + \delta + \theta)lnL + \propto lnk + \gamma lnR + \delta lnh + \theta lnt$ ..... Equation 4.8

Where:

$y = \frac{Y}{L}$, $c = \rho C$, $k = \frac{K}{L}$, $h = \frac{H}{L}$, and $t = \frac{T}{L}$

4.2 Empirical Model

Based on the extended and log-linear transformed Solow-Swan production model Equation 4.8, the empirical model for this study is specified as follows:

$\ln y_i = \beta_0 + \beta_1 c_i + \beta_2 \ln k_i + \beta_3 lnR_i + \beta_4 lnh_i + \beta_5 lnt_i + \beta_6 X_i + \varepsilon_i$ ..... Equation 4.9

Where:

- y is the agricultural productivity calculated as total agricultural GVA for county i over the workforce working in the agriculture sector per county;
- c is the mean annual rainfall in millimetres received by county i;
- k is the capital stock per worker, proxied by the value of agricultural machinery and equipment per worker in county i;

- R is the rural road infrastructure index computed from indicators for rural roads (RAI, rural road density, expenditure on road development and maintenance and rural road quality) for county i;
- h is the size of land in square kilometres (km^2) under agricultural production per worker for county i;
- t is the technology input per worker – proxied by the total number of agricultural holdings per worker in county i;
- X represent all the interaction variables in county i;
- ε_i is the error term;
- β_0 is the constant term; and
- β_1, β_2, β_3, β_4, β_5 and β_6 are the coefficients representing the elasticities of agricultural productivity with respect to rainfall, capital per worker, land per worker, rural road infrastructure, technology input per worker and the interaction terms, respectively.

4.3 Definition of Variables

This sub-section encompasses the descriptions of the different variables used in the study, their units of measurement and data sources.

Agricultural productivity

Agricultural productivity measures the efficiency of using inputs (land, labour, capital, and technology) to produce outputs (crops and livestock). This study focuses on partial productivity, specifically agricultural labour productivity, due to data limitations. It is calculated as the ratio of Agricultural Gross Value Added (AgGVA) to the number of agricultural workers per county. AgGVA reflects the total value of agricultural goods and services, including crops, livestock, fisheries and forestry. The analysis covers 45 rural counties in Kenya, excluding the urban counties of Mombasa and Nairobi (Kenya Population and Household Census, 2019).

Capital stock per worker

Capital stock per worker is a measure of the value of agricultural machinery and equipment available to each agricultural worker. The study uses the value of agricultural machinery and equipment as a proxy for capital stock because it directly reflects the level of mechanization and capital intensity in agricultural production. This measure captures the availability and utilization of capital resources, which are crucial for enhancing productivity and efficiency in agriculture. Further, by assessing the value of machinery and equipment relative to the number of workers, it is possible to gauge how well capital inputs are distributed among the labour force, providing insights into the implications of capital on agricultural productivity.

Rural road infrastructure index (RRII)

Rural road infrastructure index (RRII) is a composite index computed from four indicators, including the Rural Access Index (RAI), rural road density, expenditure on road development and maintenance, and rural road quality. This index reflects the extent and quality of rural road networks, which are crucial for market access and reducing transportation costs. The data is sourced from Kenya Roads Board and Consolidated County Budget Implementation Review Report 2019/2020.

To construct the RRII, the study utilized the World Bank's distance-to-frontier (DTF) approach (World Bank, 2018) on the indicators of rural road infrastructure including RAI, rural road density, rural road quality, and expenditure on road development and maintenance. These indicators were converted into a normalized index value on a scale of zero (0) to one (1). The selection of frontier and worst-case scenario was guided by literature, government commitments and alignment with the Sustainable Development Goals (SDGs). Equation 4.10 shows the DTF formula:

$$Score = \frac{(Worst - y)}{(Worst - frontier)} \quad \text{Equation 4.10}$$

Where:

Worst represents the worst-case scenario, y is the data point and $frontier$ is the benchmark as per government policy or international aspirations.

Table 4.1: Criteria for computing RRII

Indicator	Description	Measurement	Benchmark/ frontier	Scoring criteria
Rural access index (RAI)	Proportion of the rural population living within 2km of an all-weather road	Percentage of rural population with adequate road access	Goal 9 (industry, innovation, and infrastructure) Specifically, Target 9.1 aims to "develop quality, reliable, sustainable and resilient infrastructure" including road infrastructure that supports rural development; thus, RAI benchmark is 100 per cent	Frontier = 100% Worst = 0%
Rural road density	Total length of rural roads per unit area of rural land	Ratio	The World Bank aspires that the density of rural roads increases to 1.2km/ km²	Frontier = 1.2km/km² Worst = 0 km/km²

Indicator	Description	Measurement	Benchmark/ frontier	Scoring criteria
Rural road quality	Condition of rural roads based on surface type, maintenance and usability	Percentage share of rural roads in good and fair condition	SDG 9 emphasizes the need to "build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation," which includes improving road infrastructure; the benchmark used here is high-quality rural roads at 80%	Frontier = 80% Worst = 0%
Expenditure on road development and maintenance	Investment in rural road development and maintenance relative to total county expenditure	Kenya shillings (Ksh)	The benchmark is the county with the highest expenditure on rural road development and maintenance	Frontier = county with highest expenditure Worst = county with least expenditure

Source: Author's computation

Agricultural land area per worker

Agricultural land area per worker represents the total land under agricultural production in square kilometres per county divide by the workforce in agriculture. This variable captures the scale of agricultural operations and is directly related to production capacity.

Climate (rainfall)

Climate (rainfall) is specifically the mean annual rainfall, measured in millimetres and represents the average amount of rainfall received by each county annually. Rainfall is a critical determinant of agricultural productivity, particularly in rain-fed agricultural systems.

Technology input per worker

Technology input per worker represents the techniques applied to enhance the growth of agriculture per worker. The total number of agricultural holdings per county serves as a reasonable proxy for technological progress in Kenyan agriculture, when direct measures are unavailable. This approach is supported by Hu et al. (2019), who found that larger farm sizes or a higher concentration of agricultural activities facilitates the diffusion and adoption of new technologies. Counties with more agricultural holdings may attract increased investment,

support and access to technologies, training and extension services (Salami et al., 2010). This variable is measured as the number of agricultural holdings divided by the total number of workers in agriculture.

Table 4.2 provides the summary of variables, unit of measurement and data source.

Table 4.2: Summary of variables and unit of measurement

Variable	Depiction	Unit of measurement
	Agricultural productivity	Ratio of Gross Value Added for agricultural sector to the number of people working in this sector per county
Independent variables		
	The average annual rainfall amount per county in millimetres	Millimetres (mm)
	Capital stock per worker	Ratio of value of agricultural machinery and equipment available to each agricultural worker
	Rural road infrastructure index (RRII)	An index of the rural road infrastructure indicators constructed at per worker terms
	Size of land under agricultural production per worker in a county	Square kilometres
	This is a technology representative variable proxied by total number of agricultural holdings per worker	Number of agricultural holdings per worker

Source: Author's computation

4.4 Descriptive Statistics

The descriptive statistics presented in Table 4.3 provide an overview of the key variables in the study. The sample consists of 45 observations, representing the counties with rural areas in Kenya. The mean Agricultural Productivity is 192.27, with a standard deviation of 134.043, indicating a wide variation in productivity levels across counties. The minimum value is 36.309, while the maximum is 775.176.

Rainfall has a mean of 117.421 millimetres and a standard deviation of 40.153, suggesting moderate variability in rainfall across the counties. The minimum rainfall is 41.789 millimetres, and the maximum is 181.348 millimetres.

Capital stock per worker has a mean of 474.416 and a standard deviation of 642.562, implying significant differences in capital investment across counties. The minimum value is 36.702, while the maximum is 3,870.914.

The RRII has a mean of 0.53 and a standard deviation of 0.137, indicating that, on average, the counties have moderate levels of rural road infrastructure, with some variation across counties. The minimum RRII is 0.263 and the maximum is 0.93.

Agricultural land area per worker has a mean of 0.005 square kilometres and a standard deviation of 0.004, suggesting substantial differences in land availability per worker across counties. The minimum value is 0.0 and the maximum is 0.018.

The share of total agricultural holdings per worker has a mean of 0.01 and a standard deviation of 0.0, implying that, on average, there are approximately 0.02 agricultural holdings per worker, with some variation across counties. The minimum value is 0.0, and the maximum is 0.5.

Table 4.3: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Agricultural productivity	45	192.27	134.043	36.309	775.176
Rainfall	45	117.421	40.153	41.789	181.348
Capital stock per worker	45	474.416	642.562	36.702	3870.914
Rural road density	45	0.543	0.278	0.125	1
Rural road quality	45	0.743	0.17	0.451	1
Rural access index (RAI)	45	0.643	0.341	0.11	1
Rural road expenditure	45	0.216	0.184	0.00	1
RRII	45	0.536	0.137	.263	0.93
Agricultural land area per worker	45	0.005	0.004	.00023	0.018
Total agricultural holdings per worker	45	0.01	0.00	0.02	0.05

Source: KNBS, KRB, Office of the Controller of Budget (OCOB) and National Drought Management Authority (NDMA)

4.5 Data Sources

The study utilizes secondary data from the Ministry of Agriculture, Livestock and Fisheries (Kilimodata), KNBS, Kenya Roads Board – Roads Inventory and Conditions Survey (RICS) 2018, Kenya Population and Household Census 2019, Census of Agriculture 2019, Office of the Controller of Budget County Report 2019/2020, and the NDMA report 2019. County cross-sectional dataset on rural roads for the period 2018 helps establish the relationship between road infrastructure on agricultural productivity. The agricultural productivity data is based on 2019 since the data for roads was released in December 2018, thus this can only be reflected in the succeeding years.

4.6 Pre-analysis Diagnostic: Correlation Matrix

Table 4.4 presents the correlation matrix with significant interrelationships among key factors influencing agricultural productivity. The RRII is positively correlated with capital stock per worker (0.584***), indicating that better road infrastructure is associated with higher capital investment. Additionally, RRII shows strong correlations with rainfall (0.537***), suggesting that improved infrastructure often coincides with favourable climatic conditions. Other notable correlations include capital stock with both agricultural land area per worker (0.521***) and technology input (0.504***), highlighting that increased capital investment supports larger agricultural areas and better technology utilization.

Table 4.4: Correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)
(1) RRII	1.000				
(2) Capital stock per worker	0.584***	1.000			
(3) Rainfall	0.537***	0.369**	1.000		
(4) Agricultural land area per worker	0.314**	0.521***	0.286*	1.000	
(5) Technology input per worker	0.254*	0.504***	0.306**	0.262*	1.000

Source: Author's computation

5. Findings and Discussion

The findings of this study provide significant insights into the role of rural road infrastructure in enhancing agricultural productivity in Kenya. The results offer a deeper understanding of how various infrastructure indicators affect agricultural output. The study also incorporates interaction terms that provide valuable insights into how these effects vary across different climatic conditions, specifically in arid regions.

5.1 Model Estimations

The findings provide a comprehensive analysis of the impact of rural road infrastructure on agricultural productivity in Kenya, revealing evidence of its significant role in enhancing agricultural output (Table 5.1). The analysis demonstrates strong relationships between various infrastructure indices and agricultural performance, underscoring the interconnectedness of transport infrastructure, market access and overall productivity.

Table 5.1: Model estimations

Variable	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
RRII	2.908***		0.143**		0.44**		0.554*	
RAI		1.264**		0.194		.164		0.001*
RRD		0.132		0.143		0.132		0.136
RRQ		-0.359		0.638		0.601		0.007
Road Development		1.263***		0.502		0.481**		0.122*
CAP			0.341***	0.316***	0.334***	0.316***	0.347***	0.326***
LAND			0.019	-6.477	0.031	0.013	0.032	-0.02
RAINFALL			0.651***	0.819**	0.692***	0.807**	0.688***	1.067**
TECH			-0.008	0.018	0.011	0.008	0.026	-0.032
ARID					0.111	0.036	0.575	0.132

Variable	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
ARID*RRII							-1.172	
ARID*RAI								0.68
ARID*RRD								-0.014
ARID*RRQ								0.627
ARID*ROAD Development								1.327
Constant	3.5***	4.169***	0.196*	0.4	0.26	0.519	0.508**	-0.924
R-Squared	0.385	0.502	0.712	0.742	0.715	0.741	0.719	0.771
*** p<.01, ** p<.05, * p<.1								

Source: *Kenya National Bureau of Statistics, Kenya Roads Board and Office of the Controller of Budget (OCOB)*

(a) Rural roads

The model estimations indicate that RRII has a robust positive coefficient of 2.908, signifying a substantial impact on agricultural productivity. This finding highlights the critical importance of investing in rural roads to facilitate agricultural activities. Improved road infrastructure not only reduces transportation costs, but also enhances market access, allowing farmers to reach consumers more efficiently. For example, a 10 per cent improvement in RRII could result in an estimated increase of approximately 29 per cent in agricultural output, indicating that a 1.0 per cent improvement leads to a 2.9 per cent increase. These results align with existing literature that emphasizes the significant effect of rural roads on agricultural development (Fan et al., 2004; Kihiu and Gachanja, 2022). Policymakers thus need to prioritize investments in rural road infrastructure as a vital strategy for boosting productivity and supporting economic growth in rural areas.

The interaction terms for aridity with RRII reveal mixed results, providing further nuance to the general positive effect of rural road infrastructure on agricultural productivity. Specifically, the negative coefficient for the interaction term ARID*RRII, at -1.172, suggests that while the development of rural road infrastructure boosts agricultural productivity, its effect may be less pronounced in regions with extreme arid conditions. In such areas, factors such as limited water availability, soil degradation and climate

stress could diminish the productivity benefits that roads bring. This interaction indicates that although better rural roads facilitate market access and reduce transportation costs, the agricultural gains in arid regions may be constrained by environmental limitations. Consequently, infrastructure strategies in these areas might need to consider additional investments in water resources and soil conservation to realize the full productivity potential. These findings underscore the importance of a region-specific approach in rural infrastructure planning to ensure that agricultural productivity gains are both achievable and sustainable across diverse climatic conditions.

The RAI shows a significant positive coefficient of 1.264, reinforcing the notion that accessibility is crucial for agricultural productivity. This result underscores the need for comprehensive rural transport strategies that prioritize accessibility for farming communities. Specifically, ensuring that at least 80 per cent of rural households are within 2km of an all-weather road could significantly enhance market access and reduce post-harvest losses. The positive relationship between RAI and productivity highlights how improved access can enhance farmers' market competitiveness. Policies aimed at enhancing road access should be integral to agricultural development initiatives to ensure that farmers can effectively transport their goods to markets.

The interaction term for aridity and the Rural Access Index (ARID*RAI) presents a positive coefficient of 0.68, suggesting that improved road access can enhance agricultural productivity even in arid regions, though the benefits are relatively muted compared to more favourable environments. This finding implies that, despite environmental limitations in arid areas, better accessibility still facilitates important productivity gains by allowing farmers to reach markets, acquire resources and transport goods more efficiently. However, the positive impact of road access in these harsher climates may require complementary investments, such as in climate-resilient infrastructure and water management, to maximize productivity outcomes. This interaction highlights the potential for rural accessibility improvements to contribute positively to agricultural productivity across diverse climates, affirming the value of road access as a key component of rural development strategies even in challenging arid conditions. The coefficient for road development is also significant at 1.263, indicating that investments in constructing and maintaining rural roads directly contribute to increased agricultural output. This finding emphasizes the necessity of ongoing infrastructure projects tailored to the agricultural sector's needs. However, mixed results from other coefficients related to road characteristics—such as Rural Road Density (RRD) with a coefficient of 0.132 and Rural Road Quality (RRQ) showing a negative coefficient of -0.359—suggest that effectiveness may vary based on contextual factors. This variability highlights the importance of adopting a holistic approach that considers both the quantity and quality of rural roads when formulating infrastructure policies.

The interaction between aridity and road development shows a positive coefficient of 1.327, suggesting that improvements in road infrastructure may have an even more pronounced impact on agricultural productivity in arid regions, where

environmental constraints such as limited rainfall and harsh climatic conditions typically hinder output. This finding underscores the strategic role that enhanced road infrastructure can play in overcoming some of the productivity challenges associated with arid climates. In regions where natural resources are scarce, reliable road networks can reduce barriers to accessing markets, inputs and agricultural technologies, thus helping farmers better manage and adapt to environmental limitations. The positive coefficient highlights that investments in road development are especially impactful in areas where climatic conditions might otherwise stifle productivity, making infrastructure improvements an essential part of any strategy aiming to boost agricultural output in these more challenging environments.

(b) Capital stock as a catalyst

Capital stock per worker exhibits a consistently strong positive relationship with agricultural productivity, with coefficients ranging from 0.316 to 0.347 across various models. This suggests that higher levels of capital investment in agriculture—such as machinery, tools and technology—are crucial for enhancing productivity. The results indicate that as farmers invest in better equipment and resources, their output increases significantly. For instance, an increase in capital stock by 10 per cent could lead to an approximate 3.0 per cent increase in productivity, reinforcing broader economic theories that emphasize capital accumulation's importance for productivity growth.

The significance of capital stock underscores the importance of facilitating access to financing and credit for farmers. As agricultural practices become more mechanized and technology-driven, the ability to invest in capital becomes increasingly important for maintaining competitiveness and improving yields.

(c) Influence of rainfall

The rainfall variable shows significant positive coefficients ranging from 0.651 to 1.067, emphasizing the critical role of climatic conditions in agricultural productivity. This finding highlights the importance of rainfall as a determinant of agricultural success; adequate rainfall is essential for crop growth and yield. Given that each millimetre increase in mean annual rainfall can lead to approximately 0.5 per cent increase in productivity, this underscores the need for strategies to manage and mitigate climate variability's effects on agricultural output.

While infrastructure improvements can enhance productivity, they ought to be complemented by effective water management practices and climate adaptation strategies to ensure sustainable agricultural growth.

6. Conclusion and Recommendations

6.1 Conclusion

The findings of this study highlight the critical role of rural road infrastructure in enhancing agricultural productivity in Kenya. The RRII shows a significant positive impact on agricultural output, with a coefficient of 2.908, underscoring the transformative effect of improved rural roads. This robust relationship suggests that investments in rural road infrastructure can lead to substantial gains in agricultural productivity.

The RAI also demonstrates a statistically significant coefficient of 1.264, reinforcing the importance of accessibility in determining agricultural performance. Road development expenditure further contributes to productivity with a coefficient of 1.263. These figures emphasize the interconnectedness of rural road infrastructure, market access and agricultural outcomes.

Policymakers can leverage these findings to make evidence-based decisions, prioritizing rural road development as a key driver of agricultural productivity and rural economic growth. By focusing on improving road infrastructure, particularly in areas with limited access, Kenya can enhance food security, reduce transport costs and foster inclusive development in rural areas.

6.2 Policy Recommendations

(i) Prioritize rural road infrastructure investments in high-potential agricultural areas: The study finds a strong and significant relationship between the rural road infrastructure index and agricultural productivity. The Ministry of Roads and Transport, KeRRA, county governments, and development partners in road and agricultural sectors to consider allocating more resources to improve rural roads in regions with high agricultural potential. Priority ought to be given to building all-weather roads to ensure year-round market access, particularly in regions where transportation costs currently constrain productivity.

(ii) Focus on rural road infrastructure development in arid and semi-arid regions: The interaction between aridity and road development suggests that infrastructure investments in arid regions can have a disproportionately positive impact. Infrastructure development should be tailored to these regions' specific needs, with community-driven approaches to road construction and maintenance.

(iii) Enhance capital investment in agriculture through improved access to credit: The findings indicate that capital stock has a significant positive effect on productivity. The Ministry of Agriculture and Livestock Development could work closely with financial institutions to offer affordable credit and financial products tailored to smallholder farmers, enabling them to invest in modern farming equipment and technology. These investments can align with infrastructure improvements to maximize productivity gains.

(iv) Implement climate adaptation measures alongside rural road infrastructure development: The study shows that climatic factors, particularly rainfall, are critical to agricultural success. The Ministry of Agriculture and Livestock Development and the Ministry of Environment, Climate Change and Forestry could develop and promote irrigation systems and drought-resistant crops to ensure that rural road infrastructure investments remain resilient to climate impacts.

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Appendix

Appendix Table 1: Summary of literature

Author	Year	Objective of study	Country of study	Theoretical framework or conceptual framework	Key findings	Critique
Boopen	2006	Infrastructural development as a determinant of economic growth	Various	Economic growth theory	Increased infrastructural stock, particularly in roads, facilitates movement of goods, services and labour	Does not address the specific impacts on rural or agricultural sectors in depth
Renkow et al.	2004	Effects of inadequate transportation infrastructure on transaction costs	Various	Transaction cost theory	Inadequate transportation infrastructure imposes substantial transaction costs, which can be reduced by improving rural roads	Primarily theoretical; empirical evidence is sparse
Stifel and Minten	2008	Impact of rural road development on market access	Various	Market access theory	Rural road development enhances access to markets, reduces transaction and trade costs, and increases input utilization by farmers	Study may not fully account for other variables affecting market access
Jalan and Ravallion	2002	Effect of road density on consumption growth	Southern China	Household consumption theory	Significant positive effect of road density on consumption growth at the farm-household level	The study is region-specific, and findings may not be generalizable to other regions

Author	Year	Objective of study	Country of study	Theoretical framework or conceptual framework	Key findings	Critique
Dercon et al.	2008	Proximity of roads as a factor in poverty reduction	Ethiopia	Poverty reduction theory	Proximity to roads is a major factor in poverty reduction	The study may not account for all factors influencing poverty reduction
Fan, Zhang and Rao	2004	Impact of public transportation facilities on poverty alleviation	Uganda	Poverty alleviation theory	Reduced distances to public transportation facilities significantly alleviate poverty	The focus is on public transportation broadly, not specifically rural roads
Aggarwal	2018	Impact of rural road construction on agricultural outcomes	India	Agricultural productivity theory	Improved road connectivity significantly boosts agricultural yields	Study may not fully consider the sustainability of agricultural practices post-road construction
Fan and Chan-Kang	2005	Long-term impacts of public investments in rural road infrastructure	China	Long-term productivity theory	Significant long-term productivity gains from increased public investments in rural road infrastructure	The lagged impacts approach may overlook immediate short-term effects.
Raballand et al.	2011	Effects of rural accessibility on agricultural performance	Uganda	Spatial econometrics	Improvements in rural accessibility explain changes in agricultural performance	Spatial econometrics may be complex and difficult to replicate in other studies

Author	Year	Objective of study	Country of study	Theoretical framework or conceptual framework	Key findings	Critique
Srinivasan and Beynon	2019	Impact of feeder road connectivity on agricultural metrics	Tanzania, Malawi	Agricultural intensification theory	Feeder road connectivity improvements increase cropping intensity, crop yields and the share of marketed surplus	Cross-country evidence may not account for unique country-specific variables
Inoni and Omotor	2009	Effects of road infrastructure on agricultural output and rural incomes	Nigeria	Rural development theory	Improved road conditions positively impact agricultural productivity and rural incomes	The study may have limited generalizability due to its focus on a specific state in Nigeria
Ogunleye et al.	2018	Like Inoni and Omotor, the study focusing on road infrastructure and agricultural productivity	Nigeria	Rural development theory	Improved rural road conditions significantly boost agricultural productivity	Findings may be influenced by regional policies and other contextual factors
Mbae	2021	Relationship between road infrastructure and horticultural production	Kenya	Horticultural production theory	Finds a negative relationship between road infrastructure and horticultural production, challenging conventional wisdom	Contradicts many existing studies, raising questions about methodology and context

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