RESEARCH ON THE MEDIATING EFFECTS OF RURAL ROADS ON AGRICULTURAL DEVELOPMENT

Nan Liu[1], Jianhua Wen[2]
**Corresponding author E-mail: wjhscau@scau.edu.cn*

ARTICLE INFO

Original Article

Received: *24 June 2025*

Accepted: *28 July 2025*

doi:10.59267/ekoPolj2503983L

UDC 625.711.2:338.431

Keywords:

Rural roads; Agricultural development; Intermediary selection process;Multiple mediating effects

JEL:*L83, Z32*

ABSTRACT

Rural roads, regarded as the "entrepreneurial capital" of agricultural modernization, serve as critical infrastructure for connecting urban and rural resources and ensuring the smooth circulation of agricultural products. Their level of development profoundly influences rural economic vitality and farmers' well-being. However, financial constraints in rural areas necessitate the strategic optimization of investment to maximize both the direct benefits and indirect impacts of roads. Based on a composite multiple mediating effect model, this study reveals that rural roads drive agricultural growth through dual pathways of "direct empowerment" and "indirect catalysis." The results indicate that rural roads directly break the "honeycomb" spatial lock of farmland by promoting land consolidation (e.g., returning farmland to cultivation, merging small plots into larger fields), thereby optimizing spatial layout and establishing a core pathway of "road construction → land transfer → output growth." Simultaneously, rural roads significantly enhance agricultural mechanization, accelerating the transition toward large-scale and intensive production, while jointly with land optimization, reshaping the rural employment structure.

Introduction

Rural roads serve as a critical link for agricultural production and market circulation. Beyond their fundamental role in facilitating the transport of agricultural products, they play a pivotal role in high-quality farmland development, agricultural modernization, rural revitalization, and urban-rural integration. From a multidimensional perspective, the impact of rural roads on agricultural development can be categorized into direct and indirect effects, operating through multiple transmission pathways to ultimately

1 Nan Liu, Postgraduate, College of water conservancy and civil engineering, South China Agriculture University, Guangzhou, 510640, China, E-mail: LiuNan9803@outlook.com, ORCID ID (https://orcid.org/0009-0000-0744-2520)

2 Jianhua Wen, PhD, Associate Professor, College of Water Conservancy and Civil Engineering, South China Agriculture University, Guangzhou, 510640, China, E-mail: wjhscau@scau.edu.cn, ORCID ID (https://orcid.org/0000-0002-3818-3012)

support high-quality agricultural growth. This study aims to systematically investigate the causal mechanisms by which rural road development affects agricultural growth.

Rural roads have a significant direct impact on the economic development of agricultural regions (Banerjee and Duflo et al., 2020). They enhance the efficiency of agricultural product transportation(Lu and Li, 2022), enabling faster market access(Aggarwal, 2018; Zhou and Duan et al., 2021), reducing losses, and increasing agricultural output value and farmers' income(Donaldson, 2018; Lu and Zhao et al., 2022). Enhanced transportation conditions also help lower transport and labor costs, promote the optimization of industrial structures, improve production efficiency, and strengthen market competitiveness. Furthermore, rural roads facilitate the flow of agricultural capital, promote modernization, and activate rural labor markets. These dynamics contribute to technological spillover effects, foster the coordinated development of related industries, and create a virtuous cycle that supports sustained regional economic growth.

Rural roads also exert important indirect effects on agricultural modernization and regional economic development. Improved transportation infrastructure enhances the operational efficiency of agricultural machinery(Sotelo, 2019; Teng and Han, 2020) and supports the upgrading of farmland facilities(Bacior and Prus, 2018), thereby boosting productivity and income. It also facilitates land transfer and consolidation, contributing to the optimization of land use and the development of modern agricultural systems. Moreover, improved road networks expand employment opportunities, promote labor mobility, narrow the urban–rural income gap, and attract both capital and talent to rural areas(Zhang and Xu, 2024). These factors accelerate the dissemination of agricultural technology and support economic upgrading. Rural roads also promote the growth of rural tourism and related industries, thereby enhancing rural economic vitality. In parallel, they improve access to public services such as education and healthcare, contributing to poverty reduction. Rural roads serve as key drivers of balanced regional economic development by fostering industrial clustering and strengthening urban–rural linkages(Arbués and Baños et al., 2015).

However, existing research has predominantly focused on higher-grade highways, while rural roads have received comparatively less attention due to their limited service scope, difficulty in quantifying economic benefits, and heavy reliance on government investment. This research gap has left rural roads relatively disadvantaged in resource allocation, preventing the full realization of their potential value. Therefore, scientifically evaluating the role of rural road construction in stimulating regional economic development along their corridors can provide a critical basis for designing more efficient investment strategies and development plans.

Based on the above studies, this research proposes the following working hypotheses: first, rural road construction can significantly enhance agricultural output; second, rural roads exert significant indirect effects on regional economic and social development through the mobilization of capital, technology diffusion, land optimization, and labor mobility; third, rural road development generates a chain-mediated mechanism, producing continuous indirect impacts on agricultural development and regional economic growth.

Using Shaoguan City, Guangdong Province, as a case study, this research employs a composite multiple mediating effects approach to analyze how rural roads improve public service systems, promote rural revitalization, reduce poverty, and foster coordinated urban–rural development. The findings provide both theoretical insights and practical guidance for sustainable agricultural development and regional economic growth.

Literature Review

Rural roads, as critical infrastructure in rural areas, address transportation deficiencies, connect dispersed agricultural populations, and promote the optimization and upgrading of industrial structures, thereby enhancing regional agricultural economic development and serving as a key means to narrow the urban-rural gap(Aggarwal, 2018; Asher and Novosad, 2020; Li and Wang et al., 2020). For developing countries, where most people live in rural areas with low living standards and high trade costs, governments worldwide have prioritized the construction and study of rural roads. In recent years, countries like China, India, Iran, and Ethiopia have made significant progress in rural road development. Notably, in 2023, China invested 484.3 billion yuan in rural road infrastructure, adding 188,000 kilometers of roads, which facilitated employment for 200,000 rural workers and provided robust transportation support for the rural revitalization strategy(Han, 2024).

Numerous studies have explored the impact of rural roads on agricultural economic growth. (Asomani-Boateng and Fricano et al., 2015)noted that rural road construction increases per capita income for agricultural households, expands agricultural markets, reduces working hours, and lowers transportation costs(Zhang et al, 2018), significantly contributing to poverty alleviation in many developing countries. Kebede (2024), using the Ricardian trade model, demonstrated that rural road development reduces price disparities for agricultural products across regions, lowering trade costs. Donaldson (2018) found that transportation infrastructure in India enhances commodity circulation, significantly increasing the income of agricultural workers. Additionally, (Li and Wang et al., 2020), using a nonlinear time-varying factor model, empirically showed that road infrastructure reduces the urban-rural gap. Hu and Liu (2022) highlighted that transportation infrastructure facilitates human resource mobility, serving as a key driver of China's rapid economic growth over recent decades, expanding inter-regional trade, and promoting economic integration.

Recent empirical evidence further highlights the role of rural roads in poverty alleviation and social welfare. Yang (2025) found that rural road construction significantly alleviates poverty and facilitates farmers' transition to non-agricultural sectors, thereby increasing their access to broader social welfare benefits. Similarly, Wiegand and Koomen et al. (2023) applied a random effects model in Papua New Guinea and demonstrated that rural road upgrades improve household welfare, housing quality, and school enrollment while encouraging a shift from subsistence to market-oriented farming. In Nigeria, Jimoh and Araromi (2024) emphasized that investment in additional rural road branch lines strengthens the link between farmland and markets, facilitating more efficient transportation of agricultural products.

Further, Maphela and Adanlawo (2025), through a comprehensive literature review, highlighted that inadequate rural transport infrastructure constrains residents, exacerbating poverty, hunger, and food insecurity. Rikhotso et al. (2025) argued that enhancing the quality and connectivity of rural roads is essential for promoting rural economic growth, expanding development opportunities, and improving access to public services. Adamopoulos (2025) empirically demonstrated in Ethiopia that rural road expansion shapes the spatial distribution of agricultural production and inputs, lowers transportation costs, and increases overall productivity.

Du et al. (2023) analyzed data from 285 cities between 2017 and 2022 in China, showing that rural infrastructure development not only directly promotes economic growth but also indirectly supports it by improving rural living environments, thus underscoring the necessity of rural roads for balanced regional development. Kaiser et al. (2022) further highlighted the contribution of rural roads to welfare in low- and middle-income countries, advocating for stronger integration with education to maximize the poverty alleviation effects of transportation infrastructure. Zeng and Wang (2025) confirmed that transport infrastructure positively influences the gross output of both agricultural and industrial sectors, reinforcing its central role in fostering rural economic development.

However, some studies suggest that rural road construction has a stronger positive impact in poorer areas, enabling resource accumulation (e.g., financial and educational resources), but has less effect on wealthier groups. Chatterjee and Turnovsky (2012) indicated that infrastructure investment may, in the long term, widen regional income disparities, affect labor efficiency, and have a moderate positive causal effect on per capita GDP for industries near transportation networks, though per capita GDP growth shows no clear correlation with road development. Zhou et al. (2021) analyzed panel data from 31 Chinese provinces spanning 2002–2018 and found that while rural road construction significantly enhances agricultural sustainability, it has a negative and delayed impact on environmental sustainability.

Despite extensive research on the relationship between rural roads and agricultural economic growth, the clarity of their causal relationship remains limited. Moreover, the combined effects of confounding factors and the insufficient consideration of variable interactions often undermine the reliability of research conclusions. Therefore, further in-depth studies are necessary to comprehensively reveal the mechanisms by which rural roads impact agricultural economies and their potential variable influences.

The mediating effect of rural roads on agricultural development

To thoroughly investigate the mechanisms by which rural roads influence agricultural development and address underlying rural agricultural issues, this study employs mediation effect theory to comprehensively explore and expand the added value of rural road services.

2.1 Mediation Effect

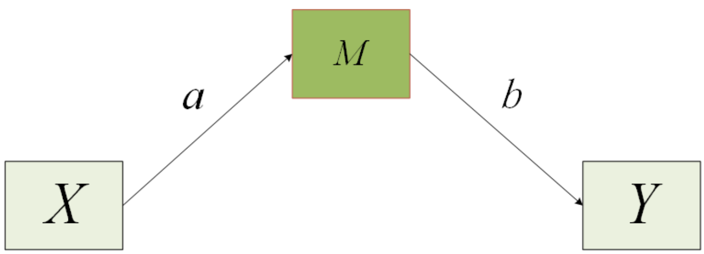
The theoretical evolution of the mediation effect model originates from Woodworth's (1928) Stimulus-Organism-Response (*S-O-R*) framework, which broke away from the unidirectional logic of the traditional Stimulus-Response (*S-R*) paradigm. The S-O-R framework emphasizes that external stimuli (e.g., rural road construction) indirectly influence outcome variables (e.g., agricultural development) through internal transformation processes within the organism (e.g., resource reorganization, technological diffusion). However, the empirical application of this theoretical advancement lagged for decades until the 1980s, when Baron and Kenny (1986) and Judd and Kenny (1981) introduced the Causal Steps Approach. This approach provided a standardized procedure for quantifying simple mediation effect models (single independent variable $X \rightarrow$ mediator $M \rightarrow$ dependent variable Y)(WEN et al., 2022).

Notably, while mediation effect models have been widely applied in psychology and management, their use in studying the relationship between rural infrastructure and agricultural economies remains limited. Existing literature primarily focuses on the direct impact of road construction on agricultural output, often overlooking the mediating mechanisms, such as land transfer and technological diffusion. This research gap may lead to policy designs overly reliant on "hard inputs" (e.g., inter-regional highways) while neglecting "soft connections" (e.g., the added value of rural road networks and their synergistic effects with rural development factors).

(1) Mediation Effect

The mediation effect is a mechanism analysis method used to explain how an independent variable (X) influences a dependent variable (Y) through a mediator variable (M). Its core principle is that changes in the independent variable X affect the mediator variable M, which then transmits the effect to the dependent variable Y, forming an indirect effect ($X \rightarrow M \rightarrow Y$). This process is illustrated in Figure 1.

Figure 1. Schematic diagram of the mediating effect



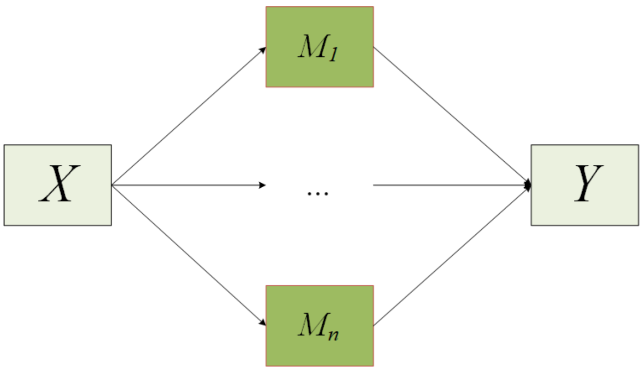
(2) Multiple Mediation Effects

The mediation effect model, due to its simple structure and clear explanatory power, is widely used to effectively reveal the direct influence of an independent variable on a dependent variable, as well as the bridging role of a mediator variable (M). However, in complex scenarios, relying solely on a simple mediation model may be insufficient to fully explain the mechanisms by which the independent variable affects the dependent variable. In such cases, multiple mediating variables need to be introduced to construct a multiple mediation effect model. Based on the mechanisms of the mediating variables, multiple mediation effects are classified into three types: parallel multiple mediation effect, sequential multiple mediation effect, and composite multiple mediation effect.

1) Parallel Multiple Mediation Effect

The parallel multiple mediation effect model incorporates multiple independent mediating variables into the analytical framework to explore the mechanisms through which the independent variable influences the dependent variable via multiple pathways. Its core characteristics are manifested in three key dimensions: The mediating variables do not influence each other and independently receive the effect of the independent variable; Each mediating variable is driven separately by the independent variable, forming distinct pathways, with the effects of these pathways being additive; The influence of each mediating variable is homogeneous, meaning different pathways consistently transmit the effect from the independent variable (X) through the mediators to the dependent variable (Y). This structure is illustrated in Figure 2.

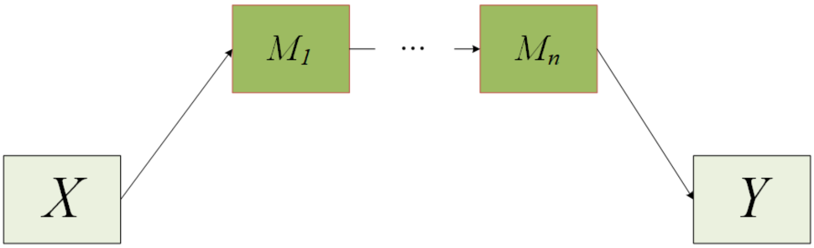
Figure 2. Parallel multiple mediating effects



2) Sequential Multiple Mediation Effect

In the real world, causal relationships are often far more complex. Relying solely on the parallel multiple mediation effect, which assumes that mediating variables independently influence the relationship between the independent variable and the dependent variable, fails to account for interactions and dependencies among mediators. As a result, it is insufficient to fully explain the causal relationships in the data. The sequential multiple mediation effect model overcomes the independence assumption of the parallel model by addressing the interactive nature of real-world causal relationships, constructing a sequential transmission mechanism. The core characteristics of this model are reflected in three key attributes: Mediating variables are interdependent, and the effect from the independent variable to the dependent variable is realized only through their mutual interactions; The indirect effect of the independent variable on the dependent variable is transmitted through multiple mediators in a sequential manner, with the mediation effect calculated as the product of the path coefficients, rather than the simple additive effects seen in parallel mediation; The model exhibits a strong sequential causal relationship, where the effect of earlier mediators on subsequent mediators is necessary for the model to be computed step-by-step. This structure is illustrated in Figure 3.

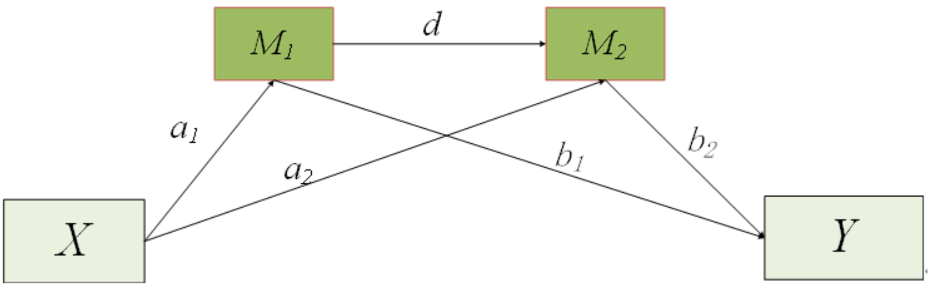
Figure 3. Chained multiple mediating effects



3) Composite Multiple Mediation Effect

The composite multiple mediation effect integrates the dual mechanisms of parallel multiple mediation and sequential multiple mediation, constructing a multidimensional network of transmission relationships. At the level of mediation effect analysis, it can be decomposed into the linear additive effects of parallel mediation and the multiplicative effects of sequential mediation, thereby quantifying the heterogeneous contributions of multiple pathways. This integrated design not only identifies the independent effects of mediating variables but also captures their interdependencies, providing a more accurate analytical tool for elucidating the multi-level causal relationships between rural roads and agricultural development. The structure is illustrated in Figure 4.

Figure 4. Compound multiple mediating effects



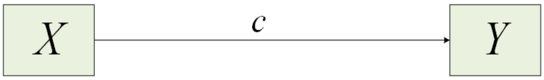
2.2 Mediating Effect Model of Rural Roads on Agricultural Development

When analyzing the mediating effect model, the first step is to determine the total effect of the independent variable on the dependent variable, which serves as the foundational step in model construction. Specifically, regression analysis is required to test whether the independent variable has a significant direct impact on the dependent variable.

The direct impact of the independent variable on the dependent variable yields the total effect (denoted as *c*), with no mediating variables considered at this stage. The corresponding formula is as follows:

Figure 5. Direct impact

$$Y = cX + \varepsilon \qquad (1)$$



The multiple mediating effect refers to the indirect impact of the independent variable on the dependent variable after considering multiple mediating variables. The corresponding formula is as follows:

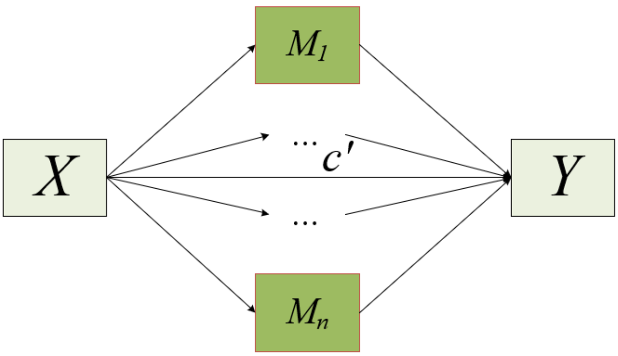
$$Y = c'X + \sum_{j=1}^{n} b_j M_j + \varepsilon, j = 1,\ldots n \qquad (2)$$

(1) Parallel Multiple Mediating Effect Model

The relationship between the independent variable X and multiple mediating variables M_j indicates how changes in X affect M_j, with the coefficient denoted as a_j. The corresponding formula is as follows:

Figure 6. Schematic diagram of parallel multiple mediating effects

$$M_j = a_j X + \varepsilon \;, j = 1,\ldots n \qquad (3)$$



(2) Construction of the Chain Multiple Mediating Effect Model

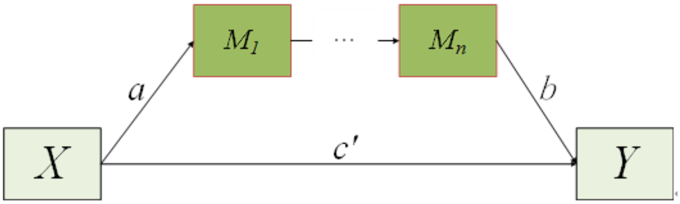
The relationship between the independent variable X and the first mediating variable M_1 indicates how changes in X affect M_1, with the coefficient denoted as a_1. The corresponding formula is as follows:

$$M_1 = a_1 X + \varepsilon \qquad (4)$$

The relationships among multiple mediating variables M_j are represented by coefficients denoted as d_j. The corresponding formula is as follows:

$$M_j = \sum d_j M_{j-1} + \varepsilon, j = 2,\cdots n \qquad (5)$$

Figure 7. Chained multiple mediating effects



(3) Construction of the Composite Multiple Mediating Effect Model

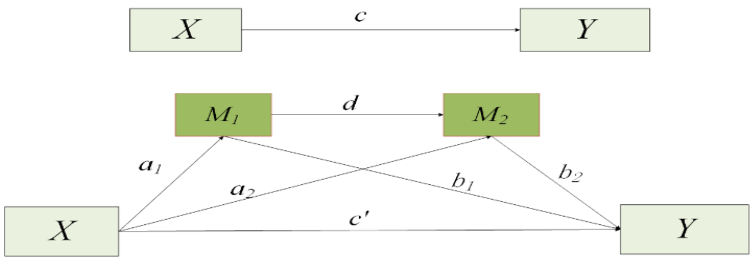
The relationship between the independent variable X and multiple mediating variables M_j illustrates how changes in X affect M_j, with the coefficients denoted as a_j. The corresponding formula is as follows:

$$M_j = a_j X + \varepsilon, j = 1,\cdots n \qquad (6)$$

The relationships among multiple mediating variables M_j are represented by coefficients denoted as d_j. The corresponding formula is as follows:

Figure 8. Compound multiple mediating effects

$$M_j = \sum d_j M_{j-1} + \varepsilon, j = 2,\cdots n \qquad (7)$$



2.3 Selection of Mediation Effect Models for the Impact of Rural Roads on Agricultural Development

When considering multiple variables mediating the relationship between the independent variable and the dependent variable, selecting an appropriate multiple mediation model involves the following operational steps and methods:

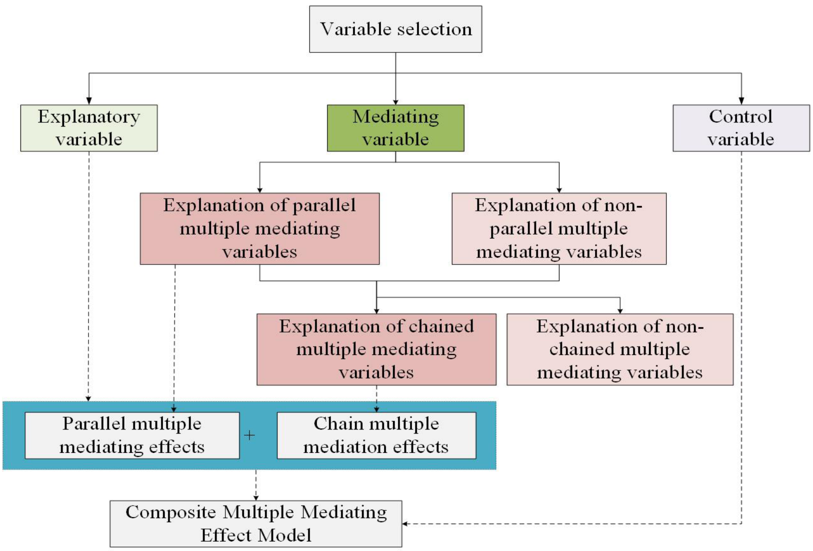
Step 1: Variable Selection and Classification: First, identify the explanatory variable (independent variable), mediating variables, dependent variable, and control variables. This requires a literature review and theoretical analysis to screen for mediating variables that are correlated with both the independent variable and the dependent variable. Ensure that the role of each variable is clearly defined for subsequent analysis.

Step 2: Identification of Parallel Mediating Variables: After determining the mediating variables, assess whether these variables independently influence the dependent variable. If multiple mediators operate independently, are driven by the independent variable, and directly affect the dependent variable, they are classified as parallel multiple mediating variables.

Step 3: Identification of Sequential Mediating Variables: Following the identification of parallel mediators, further examine whether there are causal dependencies among the mediating variables. If the effect of one mediator depends on another and forms a sequential pathway, these are classified as sequential multiple mediating variables.

Step 4: Model Determination: If both parallel and sequential mediating variables coexist, a composite multiple mediation effect model should be applied. Otherwise, based on the type of mediators identified, select either the parallel multiple mediation effect or the sequential multiple mediation effect for analysis.

Figure 9. Flowchart for determining the composite multiple mediating effect model



Testing the Mediation Effect Model of Rural Roads on Agricultural Development

This study employs the Bootstrap sampling method to test the significance and accuracy of the mediation effect model, with the core approach being the coefficient product test method, assuming $H_0 : ab = 0$. This method uses the principle of resampling with replacement to extract multiple samples from the original data, approximating the variability of statistical estimates and their confidence intervals (Xie, 2021; Xiao and Kim et al., 2024). It establishes the relationship between the dependent variable and the independent variable, making it particularly suitable for scenarios with limited sample sizes or unknown data distributions. The specific steps are as follows:

Step 1: Total Effect Test: Test the total effect coefficient c. If the total effect coefficient c is significant, it indicates that the independent variable (*X*) has a significant impact on the dependent variable (*Y*), and the analysis proceeds to the next step for mediation effect analysis. If *c* is not significant, analyze the masking effect to explore which variables may be suppressing the effect.

Step 2: Testing Parallel Multiple Mediation Effects: Conduct a Bootstrap test for parallel mediation effects, with the null hypothesis $H_0 : ab = 0$ for each mediator. If the null hypothesis is rejected, the variable is confirmed as a parallel mediating variable. Otherwise, the mediator does not participate in the parallel mediation effect.

Step 3: Testing Sequential Multiple Mediation Effects: Apply the Bootstrap test for sequential mediation effects, where the coefficient product test examines the product of path coefficients. The null hypothesis is $H_0 : adb = 0$. If the null hypothesis is rejected (i.e., the confidence interval of the sequential indirect effect does not include zero), a significant sequential mediation effect exists. Otherwise, no sequential mediation effect is present.

Step 4: If *ab* or *abd* has the same sign as *c'*, it indicates the existence of a partial mediating effect. The parallel mediating effect value is ab/c, and the chain mediating effect value is *abd/c*. The opposite sign is the masking effect. The parallel masking effect value is |*ab/c'*|, and the chain masking effect value is |*abd/c'* |.

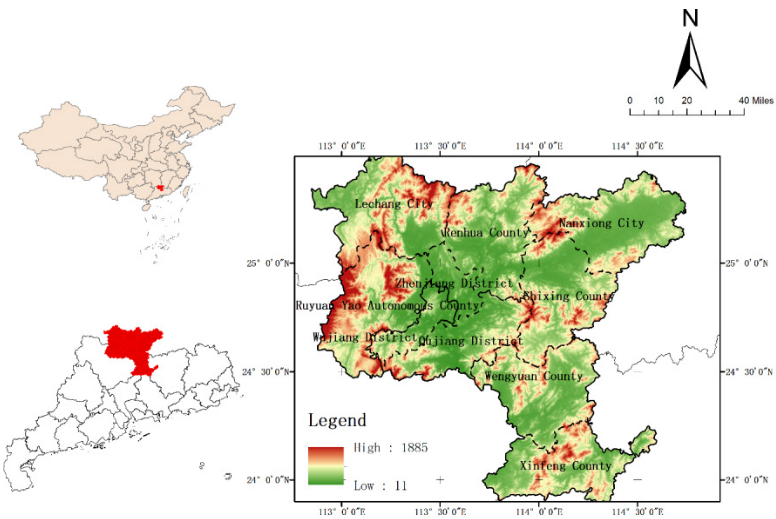
Case Study on the Mediation Effects of Rural Roads on Agricultural Development

Study Area

Shaoguan City is located in northern Guangdong Province, bordering Hunan to the north and Jiangxi to the east. The terrain is higher in the north and lower in the south, with the Nanling Mountains running through the region. Mountainous and hilly areas account for approximately 80% of the total land, earning Shaoguan the nickname "eight parts mountains, one part water, one part farmland." The city covers a total area of 1.8413 million hectares, of which 1.4553 million hectares are forested, making it a key forestry city in Guangdong. Shaoguan enjoys a warm and humid climate, with synchronized rainy and warm seasons, where March to August serves as the primary rainy season, providing favorable natural conditions for agricultural development. Leveraging its abundant agricultural resources, Shaoguan has become a significant agricultural development base in Guangdong, with per capita arable land ranking among the highest in the province. In 2023, the total output value of agriculture, forestry, animal husbandry, and fisheries reached 39.29 billion yuan, forming a distinctive “6+6” agricultural industry system, laying a solid foundation for regional economic development.

In terms of transportation, Shaoguan’s total road mileage reaches 17,200 kilometers, with rural roads accounting for 77.9%. However, a high proportion of these are fourth-grade roads, indicating limited traffic capacity that requires further improvement. The city has a permanent population of 2.8577 million, with 40.3% residing in rural areas and an urbanization rate of 59.7%. The pronounced urban-rural dual structure provides a broad research and practical space for rural revitalization and modern agricultural development.

Figure 10. Topographic map of Shaoguan City



Research Variables and Data

Research Variables

This study selects the total output value of agriculture, forestry, and fisheries (AGDP) as the dependent variable to more accurately assess the impact of rural transportation infrastructure on agricultural development. The core independent variable is rural transportation infrastructure, specifically measured by the total mileage of rural roads in a given year to ensure the reliability of results(Guo et al., 2011). Based on the study’s objectives and the characteristics of the study area (Shaoguan City), agricultural labor (AP), agricultural land area (AL), and agricultural machinery (AM) are selected as mediating variables(Xie, 2021). To reduce errors due to omitted variables and enhance the rigor of the study, control variables are included. The specific definitions of the variables are as follows:

(1) Dependent Variable

Total value of farm output (AGDP): This variable captures the comprehensive output value of agriculture, forestry, animal husbandry, and fisheries. It reflects the overall level of agricultural and rural development. To ensure comparability over time and control for inflation effects, all data are adjusted to constant 2010 prices.

(2) Core Independent Variable

Rural Transportation Infrastructure Level (Road): Measured by the total mileage of rural roads in each district or county, serving as an indicator of transportation infrastructure.

(3) Mediating Variables

Agricultural Practitioners (AP): Represented by the number of individuals engaged in agriculture, forestry, animal husbandry, and fisheries. This reflects the availability of rural labor and its potential contribution to agricultural productivity.

Agricultural Machinery (AM): Measured by the total power of agricultural machinery. This indicator captures the level of technological advancement in agriculture, which plays a critical role in improving productivity and promoting labor substitution and transfer (Rahman and Ali et al., 2021).

Agricultural Land (AL): Defined as the total area of agricultural land, including arable land, garden plots, forest land, grassland, and fishponds. It provides a comprehensive measure of land resources available for agricultural production.

(4) Control Variables

Industrial Structure (IS): Measured by the ratio of primary industry GDP (agriculture) to total regional GDP. This reflects the extent to which the regional economy depends on the agricultural sector (Wei, 2019; Cheng, 2021) .

Urbanization Rate (RU): Calculated as the proportion of the urban registered population to the total population. This variable captures the influence of urbanization on the rural and agricultural economy(Zhang, 2018).

3.2.2 Data Sources and Processing

Since 2011, the Ministry of Transport of China has introduced a series of policies aimed at advancing rural road construction. The *“Twelfth Five-Year Plan” Guidelines for Rural Road Construction* laid the policy foundation. In 2015, the *Opinions on the Construction of “Four Good Rural Roads”* proposed building a safe and green rural road network by 2025. In 2018, the *Measures for the Quality Management of Rural Road Construction* established a lifelong responsibility system for quality. Based on these policies, this study uses data from Shaoguan City spanning 2010 to 2020. To ensure stationarity and eliminate heteroscedasticity, the data were transformed using natural logarithms. Relevant data are presented in Table 1.

Table 1. Descriptive statistics of each variable

Abbreviation	Sample	Units	Mean value	Standard deviation	Minimum value	Maximum value
Road	100	km	7.22	0.53	6.09	7.22
AGDP	100	w	11.97	0.53	11.06	12.97
AL	100	km^2	3.53	0.61	2.28	4.61
AP	100	p	2.33	0.47	1.59	5.08
AM	100	kw	8.61	0.60	7.61	10.16
RU	100	%	2.59	0.83	0.90	2.59
IS	100	%	3.90	0.30	3.44	4.45

Study on the Multiple Mediating Effects of Rural Roads on Agricultural Development

Construction of the Multiple Mediating Effect Model of Rural Roads on Agricultural Development in Shaoguan City

Based on the selection of the mediating effect models described above, the composite multiple mediating effect consists of both parallel and chain multiple mediating effect models. Therefore, in this chapter, the impact of rural roads on agricultural economic development is analyzed using only the parallel and chain multiple mediating effect models. Control variables are introduced to reduce errors caused by omitted variables, thereby forming a complete causal chain and making the analysis results more accurate and reasonable. The corresponding formula is as follows:

The direct effect of rural roads on the total output value of agriculture without considering any mediating factors.

$$AGDP = cRoad + \sum \gamma_i Control_i + \varepsilon \qquad (8)$$

After considering the mediating variables, the multiple mediating effects of rural roads on the total output value of agriculture.

$$AGDP = c'Road + b_1 AL + b_2 AM + b_3 AP + \sum \gamma_i Control_i + \varepsilon \qquad (9)$$

(1) Parallel Multiple Mediating Effects

The impact of rural roads on agricultural land use.

$$AL = a_1 Road + \sum \gamma_i Control_i + \varepsilon \qquad (10)$$

The impact of rural roads on agricultural mechanization.

$$AM = a_2 Road + \sum \gamma_i Control_i + \varepsilon \qquad (11)$$

The impact of rural roads on agricultural labor.

$$AP = a_3 Road + \sum \gamma_i Control_i + \varepsilon \qquad (12)$$

(2) Chain Multiple Mediating Effects

Building on the parallel multiple mediating effects, this section studies the correlations among the mediating variables.

The relationship between agricultural mechanization and agricultural land use.

$$AL = d_1 AM + \sum \gamma_i Control_i + \varepsilon \qquad (13)$$

The effect of agricultural labor on agricultural mechanization.

$$AM = d_2 AP + \sum \gamma_i Control_i + \varepsilon \qquad (14)$$

The effect of agricultural labor on agricultural land use.

$$AL = d_3 AP + \sum \gamma_i Control_i + \varepsilon \qquad (15)$$

3.3.2 Study on the Mediating Effect of Rural Roads on Agricultural Development

This study decomposes the composite mediating effect model into two parts: parallel multiple mediating effects and chain multiple mediating effects. The processes for testing and model determination are constructed for each part to simplify their complexity. The relevant results are as follows:

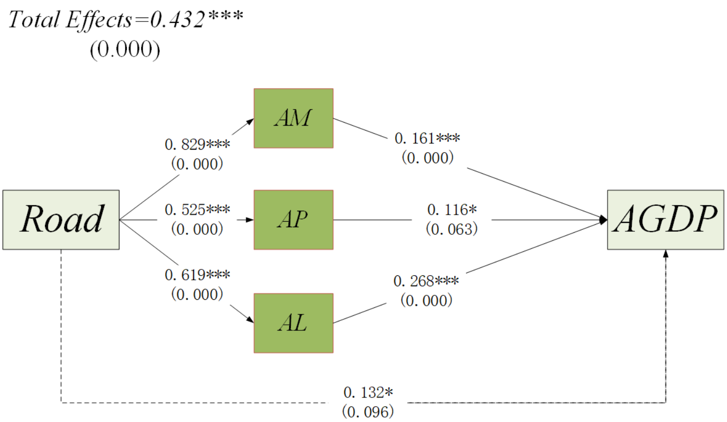
(1) Parallel Mediating Effects of Rural Roads on Agricultural Development

The parallel mediating effect of rural transportation infrastructure on the total output value of agriculture is illustrated in Figure 11. The findings demonstrate that the development of rural roads exerts a significant direct positive effect on agricultural output. Without including any mediating variables, rural road development shows a direct and significant impact on total agricultural output value (c=0.492, p=0.000), indicating that increased rural road mileage directly fosters agricultural growth.

Additionally, rural transportation infrastructure is significantly positively correlated with all mediating variables, particularly with agricultural mechanization (b=0.829, p=0.000), followed by agricultural land area (b=0.619, p=0.000), and finally agricultural employment (b=0.525, p=0.000). These relationships suggest that the expansion of rural roads facilitates improvements in agricultural inputs and production conditions. In the second stage of mediation, all three mediators exert positive effects on agricultural output: Agricultural land area has the strongest effect (b = 0.268, p = 0.000), followed by agricultural mechanization ($b = 0.161$, $p = 0.000$), and agricultural labor ($b = 0.116$, $p = 0.063$), which is marginally significant.

When all mediating variables are included in the model, the direct effect of rural roads on agricultural output remains positive but is reduced in magnitude (c'=0.132, p=0.096), indicating a partial mediating effect. This result confirms that rural road development contributes to agricultural growth not only through direct infrastructural benefits but also indirectly by improving the allocation and efficiency of agricultural production factors—notably through the enhancement of mechanization, more effective land utilization, and labor optimization.

Figure 11. Parallel mediating effects of mediating variables on agriculture, forestry and fishery



Note: Control variables include industrial structure and urbanization rate. Values represent standardized coefficients. The dashed line indicates the direct effect of rural roads on the total output value of agriculture, forestry, and fisheries. *$p < 0.10$, **$p < 0.05$, ***$p < 0.001$.

Table 2. Test of the Parallel mediating Effects of mediating Variables on agriculture, forestry and fishery

Class	c	a	b	$a \times b$	c'	Mediating effect
Road->AM->AGDP	0.492***	0.829***	0.161***	0.133**	0.132*	27.03%
Road->AP->AGDP	0.492***	0.525***	0.116*	0.061	0.132*	0.00%
Road->AL->AGDP	0.492***	0.619***	0.268***	0.166***	0.132*	33.74%

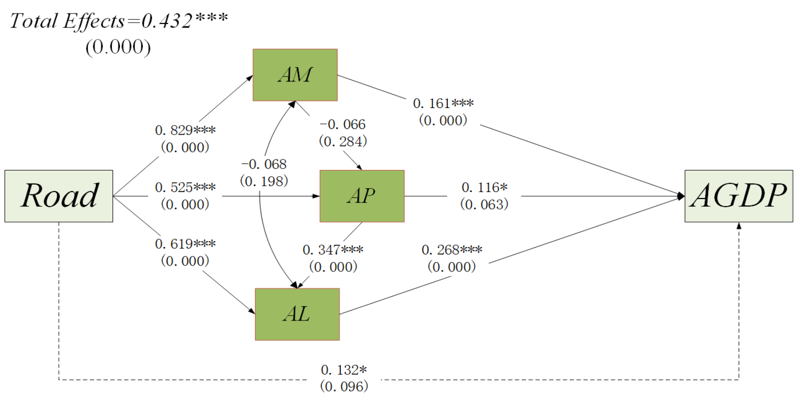
Note: * indicates p < 0.10, ** indicates p < 0.05, and *** indicates p < 0.001.

Using the Bootstrap method, the results presented in Table 2 reveal that the mediating effects of agricultural technological progress and agricultural land area are statistically significant in the relationship between rural roads and agricultural development. Specifically, the indirect effect via agricultural technological progress is *ab*=0.133 (*p*=0.015), accounting for 27.03% of the total effect, while the effect through agricultural land area is ab=0.166 (*p*=0.003), with a mediation proportion of 33.74%. In contrast, the mediating effect of agricultural employment (*ab*=0.061, *p*=0.385) does not reach statistical significance, indicating that this pathway does not constitute a valid mediating mechanism in the parallel mediation model. These results suggest that the positive impact of rural roads on agricultural economic growth is primarily realized through technological advancement and the optimized allocation of land resources, rather than by increasing the number of agricultural workers. This finding reflects a broader trend in the context of agricultural modernization: as mechanization and technology adoption deepen, the direct labor intensity of agricultural production is diminishing, and efficiency gains from land and technology are emerging as the dominant drivers of agricultural development.

(2) Chain Mediating Effects of Rural Roads on Agricultural Development

The potential interactions among mediating variables are shown in Figure 12. Under the influence of rural transportation infrastructure, only a significant positive correlation exists between agricultural employment and agricultural land area (*d*=0.347, *p*=0.000). Agricultural mechanization may have a negative effect on agricultural employment (*d*=-0.066, *p*=0.284) and agricultural land area (*d*=-0.068, *p*=0.198), but these effects did not pass the significance test. This indicates that among the three mediating variables—agricultural technological progress, agricultural employment, and agricultural land area—only agricultural employment and agricultural land area exhibit a potential correlation.

Figure 12. Mediating effects of mediating variables on the chain of agriculture, forestry and fishery



Note: Control variables include industrial structure and urbanization rate. Values are standardized coefficients. The dashed line represents the direct effect of rural roads on the total output value of agriculture, forestry, and fisheries. Values in parentheses indicate significance levels. *$p < 0.10$, **$p < 0.05$, ***$p < 0.001$.

Table 3. Test of the chain mediating Effect of Mediating variables on agriculture, forestry and fishery

S.N.	Class	*abd*	*z*	*p*	Mediating effect
1	Road->AM->AP->AGDP	-0.006	-0.534	0.595	0
2	Road->AM->AL->AGDP	-0.015	-1.163	0.248	0
3	Road->AP->AL->AGDP	0.054	2.271	0.025**	10.98%
4	Road->AP->AM->AL->AGDP	0.002	0.800	0.424	0

Note: *$p < 0.10$, **$p < 0.05$, ***$p < 0.001$.

Simultaneously, the Bootstrap method was used to test the chain multiple mediating effects, as shown in Table 3.3, confirming that only one chain mediating effect exists between rural transportation infrastructure and the total output value of agriculture, forestry, and fisheries. Specifically, the development of rural transportation infrastructure increases agricultural employment, which further expands the development of agricultural land, thereby increasing the total output value of agriculture, forestry, and fisheries. This pathway (*abd*=0.054, *p*=0.025) passed the significance test, with a chain mediating effect value of 10.98%. Since pathways 1, 2, and 4 did not pass the significance test, the hypothesized effects of rural roads influencing agricultural economic development through interactions among mediating variables in these three pathways are not supported. Therefore, rural transportation infrastructure effectively promotes the growth of the total output value of agriculture, forestry, and fisheries only through the chain mediating effect of increasing agricultural employment and expanding agricultural land development.

Discussion

The findings of this study indicate that the enhancement of rural road infrastructure exerts a significant positive effect on agricultural economic development. This effect is primarily mediated through several key pathways, including the advancement of agricultural mechanization, the optimization of land use for farming, and the mobility of agricultural labor. These results not only confirm prior research on the facilitating role of transportation infrastructure in rural and agricultural development(Asher and Novosad, 2020), but also provide new insights into the differentiated mechanisms of multiple mediating effects, thereby enriching the theoretical understanding of how rural roads influence agricultural growth.

Agricultural land is a key parallel mediating pathway through which rural road improvements promote agricultural economic development. Enhanced road infrastructure reduces transaction costs in land transfers, enabling consolidation of fragmented plots through measures such as merging small fields, converting drylands to paddy fields, and reclaiming wastelands. These interventions improve the spatial configuration and overall quality of farmland, thereby increasing agricultural productivity.(Yusheng and Zhaofa et al., 2023; Chen and Peng et al., 2024; Feng and Robinson et al., 2025) Moreover, road improvements interact synergistically with high-standard farmland policies, ensuring more efficient land utilization and further boosting agricultural output. This evidence confirms that rural road enhancement disrupts the "honeycomb-like" spatial constraints of traditional small-scale farming(Liu and Jin et al., 2022), facilitating large-scale, intensive allocation of land resources and substantiating the transmission mechanism of "road improvement → land transfer → agricultural economic growth," consistent with prior research on farmland fragmentation and its driving forces(Liu and Li et al., 2025; Gandidzanwa and Verschoor et al., 2021).

Agricultural mechanization constitutes another key parallel mediating pathway through which rural road improvements foster agricultural economic development. Enhanced transportation infrastructure facilitates the accessibility of large-scale agricultural machinery to farmland, effectively reducing operational costs and time input while significantly increasing the scale and intensity of agricultural production. As a result, farmers can complete more tasks in a shorter period, leading to a marked improvement in labor productivity. This efficiency gain not only optimizes the allocation of production factors but also creates favorable conditions for the adoption of advanced agricultural technologies and modern management practices, driving a gradual transition from traditional extensive farming to high-efficiency, intensive, and modernized agriculture(Ma and Sun, 2024). Additionally, improved roads accelerate the circulation of agricultural machinery and related services, enhancing the coverage of equipment sales, maintenance, and support systems in rural areas, thereby further lowering the costs associated with mechanization(Lu and Yang et al., 2025; Xu and Ma et al., 2025). This virtuous cycle promotes the widespread adoption and deepening of mechanization, which, by increasing land productivity and reducing production risks, provides sustained impetus for agricultural economic growth (Wang and Zhang et al., 2024; Geng and Yan et al., 2025).

Although the agricultural employment does not serve as a direct parallel mediating variable, it indirectly promotes agricultural economic development through a chain mediating pathway. Compared with agricultural mechanization and land optimization, its effect is relatively weaker, likely reflecting the increasing reliance of modern agriculture on technological innovation and efficient resource allocation. The chain mediation analysis reveals a significant linkage between agricultural labor and land use, indicating a nonlinear mechanism through which labor influences agricultural development(Zhang and Chen et al., 2025). Consistent with previous studies, improvements in rural road infrastructure, particularly in areas with poor transportation conditions. It not only enhance land use efficiency but also attract labor back to rural areas, mitigating labor outflow and providing critical support for agricultural growth. Furthermore, the formation of this chain mediating effect is closely associated with industrial restructuring and the optimization of regional development patterns(Pei and Zhao et al., 2024). Road enhancements facilitate the orderly transfer of industries and deeper functional specialization while promoting more equitable provision of public services, thereby alleviating the excessive concentration of urban-rural resources and fostering a multi-centered, balanced development model(Yan and Hu et al., 2025).

Conclusion

Main finding

Based on agricultural data from Shaoguan City from 2010 to 2020, this study constructed a composite multiple effect model, which was decomposed into direct effects, parallel multiple mediating effects, and chain multiple mediating effects.

Corresponding selection processes were established to reduce the complexity of the study. The research findings are as follows:

(1) Rural road infrastructure affects agricultural development through multiple dimensions. Its influence is not limited to a direct positive effect on productivity, but also operates via complex mediating pathways that integrate several interrelated mechanisms.

(2) Improvements in rural roads facilitate agricultural mechanization and optimize land use, which together directly enhance agricultural economic performance. These pathways enable more efficient production processes, higher output, and better allocation of agricultural resources.

(3) Rural roads also indirectly promote economic growth through a sequential interaction between agricultural labor and land use. By improving accessibility and connectivity, roads influence labor distribution and retention, which in turn enhances land productivity and overall agricultural output.

Policy implications

The research results show that rural roads not only have a significant direct impact on agricultural development, but also the economic benefits related to transportation infrastructure are considerable. In the new stage of development, efforts must continue to be made to build rural roads and promote local economic growth related to roads. Through the "transportation +" model, the resources along the transportation routes can be effectively utilized to promote agricultural modernization and economic development. The following suggestions are hereby put forward:

(1) The establishment of the "Transport Plus Land Optimization" model will facilitate the integration of rural road construction with land circulation, land reclamation, and irrigation improvement. This model will promote the intensive development of cultivated land in the region, enhancing land utilization efficiency.

(2) Link the construction and renovation of rural roads with policies on agricultural machinery subsidies and the building of service systems. Strengthen infrastructure support for large-scale mechanized operations and accelerate the transition to modern agricultural production methods.

(3) In rural areas with insufficient transportation networks and large-scale labor mobility, priority should be given to improving connectivity with urban centers. Strengthening the rural road network will enhance the connection between agricultural production areas and markets, improve access to social services, and ultimately help increase rural incomes, reduce poverty, and promote broader economic and social development in rural areas.

Limitations and further research

The influence path of rural roads on agricultural development may have nonlinear characteristics. Therefore, future research can further introduce multiple variables and combine nonlinear modeling techniques (such as structural equation models, machine learning methods, etc.) to systematically analyze the multi-level and nonlinear influence mechanism of rural roads on agricultural development, so as to improve the accuracy and applicability of the research.

Acknowledgements

The project is funded by the Guangdong Provincial Philosophy and Social Science Fund, China (No.GD22XYS06), and Guangdong Basic and Applied Basic Research Foundation, China (Grant No.2025A1515011664).

Conflict of interests

The authors declare no conflict of interest.

References

1. Adamopoulos, T. (2025). Spatial Integration and Agricultural Productivity: Quantifying the Impact of New Roads. *American Economic Journal: Macroeconomics,* 17 (1): 343-78.
2. Aggarwal, S. (2018). Do rural roads create pathways out of poverty? Evidence from India. *Journal of Development Economics,* 133: 375-395.
3. Arbués, P. and J. F. Baños, et al. (2015). The spatial productivity of transportation infrastructure. *Transportation Research Part A: Policy and Practice,* 75: 166-177.
4. Asher, S. and P. Novosad (2020). Rural Roads and Local Economic Development. *American Economic Review*, 110 (3): 797-823.
5. Asomani-Boateng, R. and R. J. Fricano, et al. (2015). Assessing the socio-economic impacts of rural road improvements in Ghana: A case study of Transport Sector Program Support (II). *Case Studies on Transport Policy,* 3 (4): 355-366.
6. Bacior, S. and B. Prus (2018). Infrastructure development and its influence on agricultural land and regional sustainable development. *Ecological Informatics*, 44: 82-93.

7. Banerjee, A. and E. Duflo, et al. (2020). On the road: Access to transportation infrastructure and economic growth in China. *Journal of Development Economics,* 145: 102442.
8. Chatterjee, S. and S. J. Turnovsky (2012). Infrastructure and inequality. *European Economic Review,* 56 (8): 1730-1745.
9. Chen, L. and J. Peng, et al. (2024). Will Agricultural Infrastructure Construction Promote Land Transfer? Analysis of China's High-Standard Farmland Construction Policy. *Sustainability*,16.
10. Donaldson, D. (2018). Railroads of the Raj: Estimating the Impact of Transportation Infrastructure. *American Economic Review*, 108 (4-5): 899-934.
11. Du, X. and F. Jiao (2023). How the rural infrastructure construction drives rural economic development through rural living environment governance—case study of 285 cities in China. *Frontiers in Environmental Science Volume*, 11 - 2023.
12. Feng, Z. and G. M. Robinson, et al. (2025). Rural Revitalization in China: Reversing Rural Decline and Eliminating Poverty. *Geography Compass*, 19 (7): e70039.
13. Gandidzanwa, C. and A. J. Verschoor, et al. (2021). Evaluating Factors Affecting Performance of Land Reform Beneficiaries in South Africa. *Sustainability,* 13.
14. Geng, Y. and Y. Yan, et al. (2025). Achieving sustainable development goals: coupling coordination between agricultural industrialization and rural infrastructure with the case of China. *Humanities and Social Sciences Communications,* 12 (1): 1181.
15. Jimoh, U. U. and C. Araromi (2024). The Perceived Effect of Rural Transportation on Agricultural Produce in Igbara-Oke, Nigeria. *Journal of Inclusive Cities and Built Environment,* 3 (7): 71-80.
16. Kaiser, N. and C. K. Barstow (2022). Rural Transportation Infrastructure in Low- and Middle-Income Countries: A Review of Impacts, Implications, and Interventions. *Sustainability*, 14.
17. Kebede, H. A. (2024). Gains from market integration: Welfare effects of new rural roads in Ethiopia. *Journal of Development Economics,* 168: 103252.
18. Li, W. and X. Wang, et al. (2020). Does High-Speed Railway Influence Convergence of Urban-Rural Income Gap in China? *Sustainability*, 12.
19. Liu, J. and X. Jin, et al. (2022). Evolution of cultivated land fragmentation and its driving mechanism in rural development: A case study of Jiangsu Province. *Journal of Rural Studies,* 91: 58-72.
20. Liu, J. and Y. Li, et al. (2025). Transformative Aspects of Agricultural Modernization and Its Land Use Requirements: Insights from Chinese Case Studies. *Land*, 14.
21. Lu, H. and P. Zhao, et al. (2022). Transport infrastructure and urban-rural income disparity: A municipal-level analysis in China. *Journal of Transport Geography* , 99: 103292.

22. Lu, J. and H. Li (2022). Can high-speed rail improve enterprise capacity utilization? A perspective of supply side and demand side. *Transport Policy,* 115: 152-163.
23. Ma, Z. and H. Sun (2024). Harnessing the Power of Mechanization: A Multivalued Treatment Effect Analysis on Productivity for Chinese Smallholders. *Land,* 13.
24. Maphela, B. and E. F. Adanlawo (2025). Road infrastructure in South Africa: What is missing? Road infrastrucure. *International Journal of Business Ecosystem & Strategy,* (2687-2293) 7 (2): 470-478.
25. Pei, S. and S. Zhao, et al. (2024). Impacts of Rural–Urban Labour Transfer and Land Transfer on Land Efficiency in China: A Analysis of Mediating Effects. *Land,* 13.
26. Rahman, M. M. and M. R. Ali, et al. (2021). Farm mechanization in Bangladesh: A review of the status, roles, policy, and potentials. *Journal of Agriculture and Food Research,* 6: 100225.
27. Rikhotso, V. and T. Gumbo, et al. (2025). Assessing the Effects of Road Infrastructure on Rural Mobility and Development: A Bibliometric Review. *Proceedings of REAL CORP 2025.*
28. Sotelo, S. (2019). Domestic Trade Frictions and Agriculture. *Journal of Political Economy,* 128.
29. Teng, Zhaoyue. and Li. Han (2020). Transportation Costs and Agricultural Mechanization, *Economic Review*. [In English]
30. Wang, L. and Y. Zhang, et al. (2024). Agricultural Production Efficiency and Differentiation of City Clusters along the Middle Reaches of Yangtze River under Environmental Constraints. *Sustainability*, 16.
31. Wiegand, M. and E. Koomen, et al. (2023). The Impact of Road Development on Household Welfare in Rural Papua New Guinea. *The Journal of Development Studies,* 59 (6): 933-953.
32. Xiao, D. and I. Kim, et al. (2024). Does built environment have impact on traffic congestion? —A bootstrap mediation analysis on a case study of Melbourne. *Transportation Research Part A: Policy and Practice,* 190: 104297.
33. Xu, G. and Y. Ma, et al. (2025). "Why Chinese farmers are reluctant to transfer their land in the context of non-agricultural employment: insights from agricultural mechanization." Humanities and Social Sciences Communications 12 (1): 428.
34. Yan, S. and M. Hu, et al. (2025). Exploring the nexus between spatial configuration of urban agglomerations and land use efficiency: A bidimensional analysis considering transport network connectivity. *Cities,* 167: 106353.
35. Yang, D. (2025). Rural Roads and Poverty Alleviation: Evidence from China. *Research on World Agricultural Economy,* 6 (2): 485-498.
36. Yusheng, C. and S. Zhaofa, et al. (2023). Impact of high-standard farmland construction on farmers' income growth—quasi-natural experiments from China. *Frontiers in Sustainable Food Systems Volume,* 7 - 2023.

37. Zeng, G. and H. Wang (2025). Deterioration and improvement: The U-shaped impact of industrialization on agricultural carbon productivity in China. *Science Progress,* 108 (1): 00368504241302960.
38. Zhang, Y. and D. Xu (2024). Transportation upgrades and structural transformation in the labor market: Evidence from a road improvement project in benin. *Transport Economics and Management,* 2: 143-153.
39. Zhang, Y. and Y. Chen, et al. (2025). Digital financial innovation, productivity and modernization of industry chain and supply chain. *Economic Analysis and Policy,* 87: 1198-1211.
40. Zhou, Z. and J. Duan, et al. (2021). Can Rural Road Construction Promote the Sustainable Development of Regional Agriculture in China? *Sustainability*, 13.
41. Chen Yao. (2021). The impact of transportationinfrastructure on rural povertyreduction, *Lanzhou University*. [In English]
42. Guo Yanzhi and Liu Xu. (2011). Research on the influencing factors of farmers' income based on Granger causality test and typical correlation. *Journal of Agrotechnical Economics,* (10): 92-97. [In English]
43. Han Xin. (2024). From 2014 to 2023, over 2.5 million kilometers of rural roads were newly built or renovated in China. *People's Daily*. [In English]
44. Hu Angang and Liu Shenglong.(2022). Transportation Infrastructure and Regional Economic Integration In China. *Economic Research Journal*, (08): 76. [In English]
45. Wei Jing. (2019). Transportation Infrastructure, Industrial Agglomeration and Economic Growth—— Research on Spatial Spillover Effect and Threshold Effect of NewEconomic Geography, *Southwestern University of Finance and Economics*. [In English]
46. WEN Zhonglin and FANG Jie, et al. (2022). Methodological research on mediation effects in China's mainland. *Advances in Psychological Science*, 30 (08): 1692-1702. [In English]
47. Xie Dongmei. (2021). Study on the influence of Agricultural Mechanization Developmenton China's grain production, *Southwestern University of Finance and Economics*. [In English]
48. Zhang Hua. (2018). A Study on the Equalization of Urban and Rural Basic PublicServices in the Process of Urbanization in China, *Liaoning University*. [In English]
49. Zhang Xun and Wang Xu, et al. (2018). A Unified Framework of Road Infrastructure's Growth Effect. *Economic Research Journal,* 53 (01): 50-64. [In English]