Research on the Coupling Effect of Rural Infrastructure and Economic Development in Sichuan Province

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Abstract: *To investigate the interactive relationship between rural infrastructure and economic development, this study focuses on Sichuan Province using a coupling coordination model to analyze their development trends from 2014 to 2023. The findings reveal that rural infrastructure and economic development in Sichuan have consistently maintained a high-level coupling stage, though coordination exhibited distinct phases: low coordination during 2014-2017, followed by gradual improvement from 2018 to 2023. The paper further identifies core issues during the low-coordination phase and proposes targeted optimization recommendations, providing actionable insights to enhance the deep integration of rural infrastructure and economic development in Sichuan, thereby supporting rural revitalization efforts.*

Key words: *rural infrastructure, rural economic development, coupling coordination, entropy power method*

1. INTRODUCTION

The report of the 20th National Congress of the Communist Party of China emphasized "continuing to prioritize rural areas in public infrastructure development." The Central Document No.1 for 2025 explicitly proposed the "Rural Infrastructure Gap-Filling" policy, aiming to boost economic growth through accelerated rural infrastructure construction, ultimately achieving rural revitalization and common prosperity.[1] It is evident that rural infrastructure development and economic progress are interdependent and mutually reinforcing. Their unified development orientation plays a crucial role in advancing agricultural and rural modernization.

With increasing investment in rural infrastructure, more villages have gained access to safe drinking water, road construction, night lighting, and clean energy. However, current infrastructure development levels still fail to fully meet economic growth demands and farmers' growing needs for improved living standards. Imbalanced and insufficient investment in rural infrastructure remains widespread, while applying urban infrastructure models to rural areas still faces numerous challenges. Most rural infrastructure projects suffer from subpar quality.[2] This raises critical questions: Can rural infrastructure development and economic growth achieve positive synergy? What gaps need to be addressed? How can long-term planning for rural infrastructure investment be optimized? These questions form the foundation for addressing infrastructure deficiencies and coordinating infrastructure development with rural economic growth. Using Sichuan Province (2014-2023) as a case study, this paper establishes an evaluation index system for rural infrastructure and economic development. Through a coupling coordination model, it analyzes the synergy between infrastructure construction and rural economic progress, revealing inherent contradictions and evolutionary trends in coordinated development. The study identifies key factors affecting coordination, providing scientific evidence to address current imbalances in rural infrastructure investment and improve construction quality. Ultimately, it offers strategic references for optimizing resource allocation and advancing rural modernization efforts.

2. THEORETICAL ANALYSIS

2.1 Investment in Rural Infrastructure and the Current Situation of Rural Economic Development

As the core infrastructure supporting agricultural production, rural industrial revitalization, and livelihood improvement, rural infrastructure development directly impacts the pace and effectiveness of rural economic growth through its investment intensity and construction quality. The synergy between these two factors creates a virtuous cycle of mutual reinforcement and coordinated development. Table 1 below presents the current status of rural infrastructure construction and economic development.

Table 1 Status of rural infrastructure construction and rural economic development

system	present situation	
	effect	difficult position
Rural infrastructure construction	The scale of rural infrastructure in China is expanding rapidly under the policy drive, the coverage and hardware facilities in key areas such as transportation, water conservancy and communication are constantly improving, and the key facilities are constantly being perfected.	Some areas have built infrastructure in advance and duplicated, the economic benefit of investment is not timely; the supply structure of infrastructure can not meet the needs of rural industrial development in various places, the matching degree of common part of infrastructure and local industry needs to be improved, and the supporting role of infrastructure to industrial upgrading and farmers' income increase is not great.
Rural economic development	The agricultural production and supply have been steadily improved, the rural industries have been gradually diversified, the farmers' income has been increasing, the development momentum has been continuously enhanced, and the level of agricultural modernization has been improved to a certain extent.	The regional development is unbalanced, the industrial structure is single, the traditional agriculture is too dependent, the high value-added industry is not enough to support; the capital supply is less, the local government's financial pressure is big; the young and middle-aged labor force is going out to work, the local talent is lacking; the lack of coordination between departments.
The two work together.	The construction of transportation, water conservancy, energy and other infrastructure has solved the shortage of rural economic development to a certain extent, and the development of rural economy also needs the construction of infrastructure. The combination of the two has changed the single agricultural production mode to a certain extent, formed a variety of business forms, and promoted the coordinated development of urban and rural areas.	However, there are still some problems in the coordinated development of infrastructure and industry, such as the imbalance of investment structure, the mismatch of supply and demand, and the poor linkage mechanism. That is, the infrastructure supply is out of step with the industrial demand, and some infrastructure projects are divorced from the reality. The enabling effect of infrastructure on the economy has not been fully released, and the shortage of infrastructure talents in rural areas affects the quality and efficiency of the coordinated development of infrastructure and industry.

As shown in Table 1, China must continuously balance the relationship between rural infrastructure development and economic growth. While the government has consistently increased investment in transportation, water conservancy, and communication infrastructure, regional disparities remain significant. Some areas still lack adequate infrastructure to meet the diverse needs of rural economic development. On the economic front, traditional agriculture still dominates, emerging industries lack momentum, and industrial structures require optimization. The underutilized role of infrastructure in driving economic growth has led to a degree of imbalance between infrastructure development and rural economic progress. Therefore, it is crucial to foster mutual reinforcement and coordination between these two aspects. By optimizing resource allocation and policy coordination, increasing funding for infrastructure through rural economic development will help achieve synergistic progress.

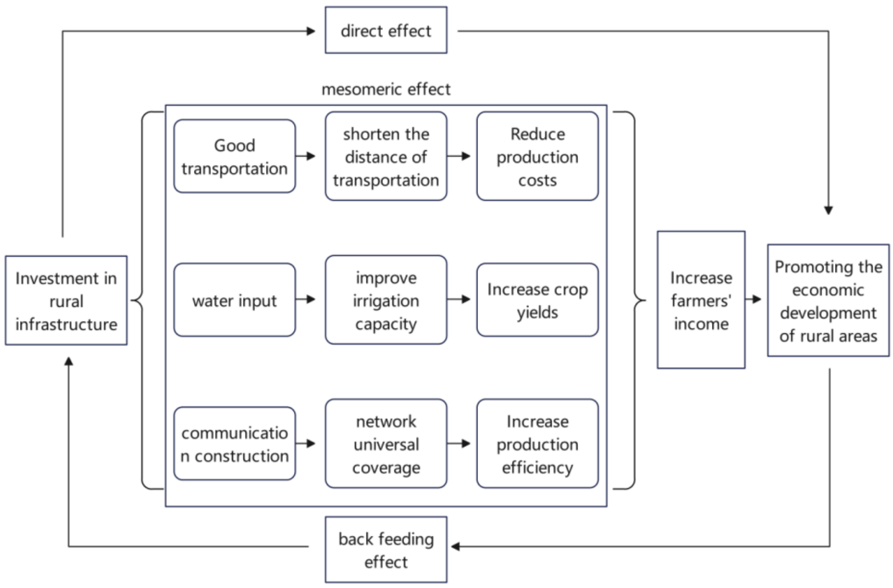
2.2 The relationship between rural infrastructure investment and rural economic development

2.2.1 The investment in rural infrastructure directly affects the rural economic development

Rural infrastructure serves as the material foundation for rural socio-economic development, with its development level playing a guiding, foundational, and safeguarding role. A well-developed transportation network reduces agricultural transaction costs and transaction fees, enhances market accessibility, and promotes resource allocation. Efficient water conservancy facilities improve agricultural resilience against natural disasters, increase farmland irrigation rates and water resource utilization efficiency, ensuring food security and agricultural productivity. Accessible information infrastructure facilitates the application of information technology in rural agriculture, commerce, and management, while fostering new business models like rural e-commerce and tourism, thereby creating more opportunities for farmers to increase their income.

2.2.2 The Rural Economic Development Feeds Back to the Rural Infrastructure Construction

The level of rural economic development determines investment in rural infrastructure. The achievements of rural economic development enrich both fiscal and social capital for infrastructure investment. Adjustments in rural industrial structure, consumption patterns, and demographic changes will generate higher, more extensive, and smarter infrastructure investment demands, which in turn influence the direction and efficiency of rural infrastructure investment. Moderately advanced investment in rural infrastructure serves as a lever for rural economic development, while economic growth provides capital support and momentum for continuous improvement and upgrading of rural infrastructure. Together, they promote the modernization of agriculture and rural areas through a virtuous cycle. Understanding the intrinsic logical relationship between these two aspects is the prerequisite for rational investment, addressing weaknesses, and subsequent empirical analysis of their coordinated coupling.



Source: self-drawn based on theoretical content

Figure 1 Schematic diagram of interaction between rural infrastructure and rural economic development

3. Research Methods and Design

3.1 Research Methods

3.1.1 Data source

Considering the availability of data, this paper takes Sichuan Province as the research sample, and some individual data have not been made public, so the sample period is 2014-2023, and the original data are all from the China Statistical Yearbook and Sichuan Statistical Yearbook.

3.1.2 Standardization processing

Because the different units of each index have different effects, the results can not be calculated. Therefore, considering the influence of different dimensions on the calculation, the paper uses the range standard deviation method to normalize the calculation results. The formula is as follows:

$$\text{Positive indicators: } Zij = \frac{z_{ij} - \min(z_{ij})}{\max(z_{ij}) - \min(z_{ij})} \quad (1)$$

$$\text{Negative indicators: } Zij = \frac{\max(z_{ij}) - z_{ij}}{\max(z_{ij}) - \min(z_{ij})} \quad (2)$$

In equations (1) to (2), Zij denotes the normalized value after processing, while Zij represents the original value of ZijZijthe j-th indicator in the system during the i-th year. The functions max(Zij) and min(Zij) are used to identify the maximum and minimum values among the original indicators of the j-th indicator in the system during the i-th year.

3.1.3 Weight Determination

This paper adopts the entropy method to assign weights to the processed data and determine the weights in the system, as follows:

(1) For the j-th indicator, calculate the proportion of the i-th system under this indicator using the following formula:

$$P_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{n} Z_{ij}} \quad (3)$$

(2) Calculate the entropy value ej for the j-th indicator using the following formula:

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} P_{ij} \ln(P_{ij}) \quad (4)$$

(3) Calculate the difference coefficient Sj for the j-th indicator using the following formula:

$$S_j = 1 - e_j \quad (5)$$

(4)Calculate the weight Wj for the j-th indicator using the formula:

$$W_j = \frac{S_j}{\sum_{j=1}^{m} S_j} \quad (6)$$

(5) The comprehensive evaluation values of rural infrastructure and economic development are calculated using the following formulas:

$$U_1 = \sum_{j=1}^{m} A\, Z_{ij} \quad (7)$$

$$U_2 = \sum_{j=1}^{m} B\, Z_{ij} \quad (8)$$

In equations (7)～(8), j=1,2,3,...,m, which is the number of indicators; U1 and U2 are the comprehensive evaluation values of rural infrastructure and economic development; A and B are the weights of rural infrastructure level and economic development level respectively.

Table 1: Rural Infrastructure Indicator System

target layer	guideline level	indicator layer	Unit (attribute)	weight of indicator level
rural area foundation Installation system	Productive infrastructure	farm machinery production	10,000 kW (+)	0.044
		Agricultural area with effective irrigation	10,000 hectares (+)	0.082
		Total storage capacity of the reservoir	100 million cubic meters (+)	0.060
		Annual electricity consumption in rural areas	100 million kWh (+)	0.138
	Living infrastructure	The rate of access to safe drinking water	%(+)	0.060
		Sanitation coverage rate	%(+)	0.074
rural area economy develop system	Transportation infrastructure	road area per capita	square meter (+)	0.083
		Village road hardening rate	%(+)	0.083
	communication infrastructure	Internet broadband access port	Ten thousand (+)	0.071
		Internet broadband access users	Households (+)	0.105
		The length of the long-distance optical cable line	10,000 km (+)	0.200

Data source: from China Statistical Yearbook and Sichuan Statistical Yearbook

Table 2: Indicators of Rural Economic Development

target layer	guideline level	indicator layer	Unit (attribute)	Weight of indicator level
Nong village Jing the Ji River Send open up Tie Interconnected system	Income levels of rural residents	Per capita disposable income of rural residents	Yuan (+)	0.192
		Operating income of rural residents	Yuan (+)	0.194
		Wage income of rural residents	Yuan (+)	0.087
		Property income of rural residents	Yuan (+)	0.088
		Transfer income of rural residents	Yuan (+)	0.081
		urban-rural income ratio	% (-)	0.246
	scale of rural developm ent	Investment in the primary industry	100 million (+)	0.212
		Agricultural labor productivity	¥/person (+)	0.156
		Total output value of agriculture, forestry, animal husbandry, and fisheries	100 million (+)	0.088
		Number of people employed in rural areas	thousands of people (+)	0.130
		Gross Product of the Primary Industry	100 million (+)	0.095

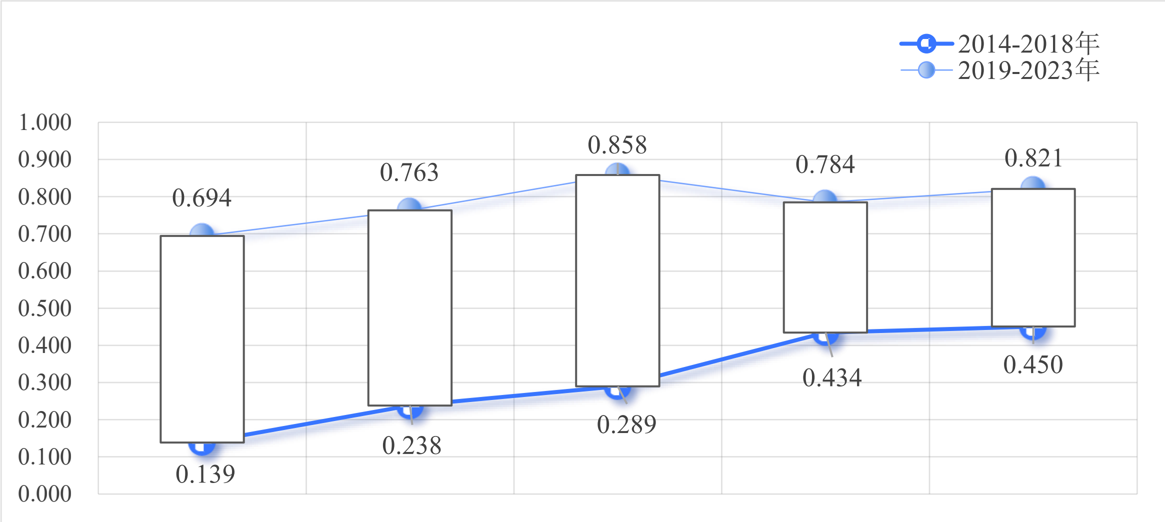
Source: Sichuan Statistical Yearbook

3.2 Analysis of the overall development level

The entropy method is used to obtain the level of rural infrastructure and rural economic development from 2014 to 2023, and the time series change is analyzed.

3.2.1 The level of rural infrastructure construction

The development of rural infrastructure not only improves the living environment for rural residents, but also contributes to their physical health and indirectly enhances the quality of the rural workforce, while positively impacting rural economic growth. Figure 2 below illustrates the current status of rural infrastructure development.



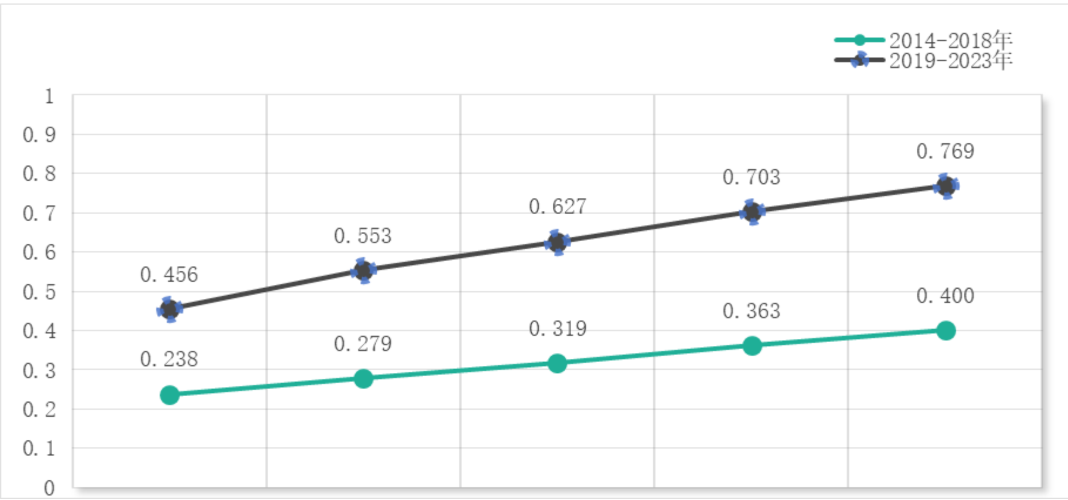
Source: calculated using the entropy-weighted method

Figure 2 Schematic diagram of the level of rural infrastructure construction

Figure 2 reveals that Sichuan Province's rural infrastructure development maintained steady improvement from 2014 to 2023, demonstrating consistent growth over the five-year period. However, the relatively low infrastructure development levels during 2014-2018 indicated underlying challenges in rural infrastructure construction. The accelerated growth momentum from 2018 to 2023, despite a temporary decline in 2022, maintained a high overall standard. This progression reflects continuous expansion of rural internet broadband access, annual increases in information technology adoption, expanded long-distance fiber-optic networks, and enhanced transportation infrastructure. These improvements have not only upgraded rural infrastructure but also optimized agricultural structures, boosted farmers' employment and income, reduced information asymmetry and logistics costs, indirectly improved economic efficiency, and provided crucial data support for subsequent analysis of rural economic development.

3.2.2 The level of rural economic development

The overall operation of rural economy is closely related to the scale of rural residents' per capita disposable income, the efficiency of agricultural labor productivity, the change of rural employment, the investment intensity of the primary industry and the fluctuation of the total output value of agriculture, forestry, animal husbandry and fishery.



Source: calculated using the entropy-weighted method

Figure 3 Schematic diagram of rural economic development level

As shown in Figure 3, China's rural residents have maintained a sustained and significant growth in per capita disposable income, demonstrating marked improvements in living standards and enhanced consumption and investment capabilities. Meanwhile, the stable employment population in rural areas, driven by profound industrial restructuring, provides a steady workforce for economic development. The continuous rise in total output value of agriculture, forestry, animal husbandry, and fishery industries further highlights the rural economy's scale advantages and improved overall economic efficiency. These indicators collectively reveal the dynamic evolution of rural economic development. However, the relatively low overall economic performance during 2014-2018 indicates that Sichuan Province's rural economy still faces pressing challenges. A comparative analysis of rural infrastructure construction over these five years reveals that inadequate infrastructure remains a critical constraint on economic growth.

3.3 Construction of coupling coordination degree model

3.3.1 Calculate coupling degree (C)

Coupling coordination degree model is important to judge the degree of mutual influence and interaction between two systems. This paper constructs the coupling relationship model of rural infrastructure and economic development by referring to the research results of Dai Taoming et al.[3-7].

$$C = \frac{2\sqrt{U_1 U_2}}{U_1 + U_2} \quad (9)$$

In Equation (9), U1 and U2 represent the composite evaluation scores for rural infrastructure and economic development, respectively. The coupling coefficient C indicates their interaction: when C=0, no coupling exists between the two systems; when C=1, they achieve optimal coupling. As C increases, the coupling intensifies, reflecting a complementary and mutually reinforcing relationship between rural infrastructure and economic development. Conversely, lower C values indicate mutual obstruction and detrimental effects.

3.3.2 Calculate the coordination degree (T)

The coupling degree reflects the degree of coupling between systems, while the coordination degree indicates the level of coordinated development between two systems. Based on the research findings of Li Wenyen et al.[8-10], a coordination degree model for rural infrastructure and economic development is constructed:

$$T = a \times U_1 + b \times U_2 \quad (10)$$

3.3.3 Calculate the coupling coordination degree (D)

To accurately reflect the coordination relationship between rural infrastructure and economic development, a coupling coordination degree model is constructed by combining Equation (9) and Equation (10).

$$D = \sqrt{C \times T} \quad (11)$$

By calculating the coupling degree and coordination degree of rural infrastructure and economic development, and by referring to the research results of Guan Yuwei et al.[11-13], the coupling degree and coordination degree are classified into different levels.

Table 3 Classification of coupling degree levels

interval partitioning	coupling degree level
[0,0.20)	low level coupling
[0.20,0.40)	running-in coupling
[0.40,0.70)	antagonistic coupling
[0.70,1.00]	high level coupling

Table 4 Classification of coupling coordination degree

interval partitioning	coupling coordination level	interval partitioning	coupling coordination level
0-0.09	major maladjustment	0.50-0.59	barely coordinated
0.10-0.19	severe dysregulation	0.60-0.69	primary coordination
0.20-0.29	moderate dysregulation	0.70-0.79	intermediate coordination
0.30-0.39	mild dysregulation	0.80-0.89	Good coordination
0.40-0.49	approaching deficit	0.90-1.00	high quality coordination

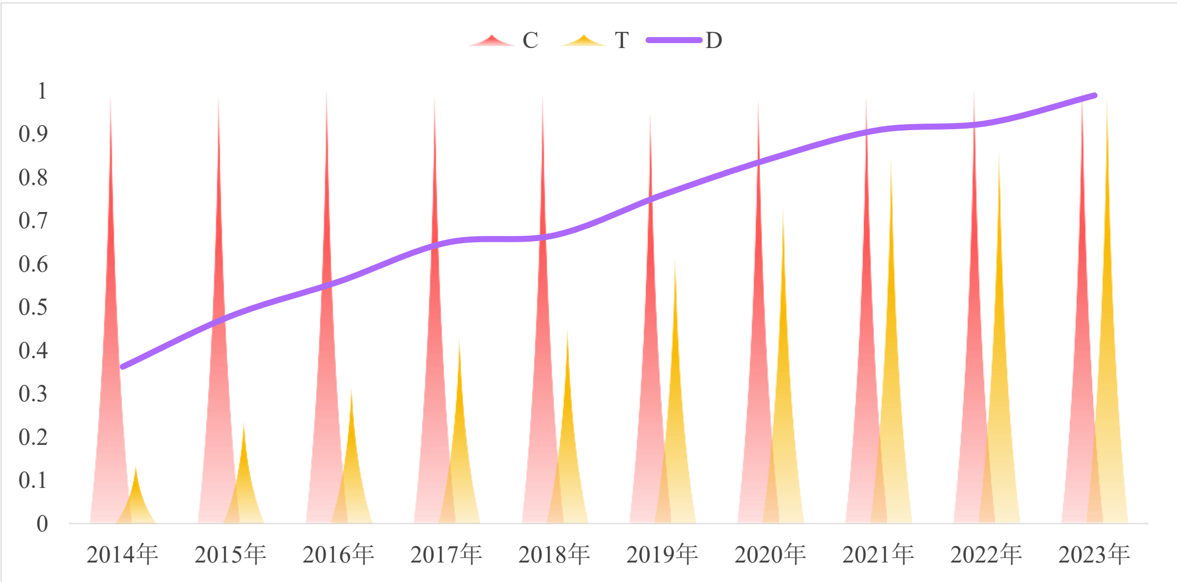
3.4 Coupling and Coordination Analysis of Rural Infrastructure and Economic Development

This paper calculates the coupling degree of rural infrastructure and rural economic development in Sichuan province from 2014 to 2023 by sorting and calculating the data of rural infrastructure and rural economic development in Sichuan province from 2014 to 2023.

Table 5 Coupling measurement results of rural infrastructure and economic development in Sichuan Province from 2014 to 2023

a particular year	degree of coupling	Coupled calculation results	comprehensive coordination index	coupling coordination degree	Coupled coordination calculation results
2014	0.964	high level coupling	0.189	0.426	approaching deficit
2015	0.997	high level coupling	0.258	0.508	barely coordinated
2016	0.999	high level coupling	0.304	0.551	barely coordinated
2017	0.996	high level coupling	0.399	0.630	primary coordination
2018	0.998	high level coupling	0.425	0.652	primary coordination
2019	0.978	high level coupling	0.575	0.750	intermediate coordination
2020	0.987	high level coupling	0.658	0.806	Good coordination
2021	0.988	high level coupling	0.743	0.857	Good coordination
2022	0.998	high level coupling	0.743	0.862	Good coordination
2023	0.999	high level coupling	0.795	0.892	Good coordination

Source: calculated by coupling coordination model



Data source: made according to the coupling coordination degree model

Figure 4 Schematic diagram of coupling coordination analysis results

As shown in Table 5 and Figure 4, rural infrastructure development and economic growth in China's countryside maintained a high-level coupling phase from 2014 to 2018. However, significant coordination challenges emerged, likely stemming from inadequate infrastructure investment, brain drain, misalignment between infrastructure and industrial development, and insufficient targeted policy support. These issues manifested as infrastructure investment lagging behind economic growth, subpar infrastructure in remote rural areas, and inefficient resource allocation. Moreover, the economic development failed to provide sufficient feedback or create mutually reinforcing mechanisms for coordinated growth.

From 2019 to 2023, the coupling degree between rural infrastructure and economic development in Sichuan Province consistently remained within the[0.70,1.00] range, indicating a strong and complementary relationship between the two systems at a high level. The coordination level progressed from basic to intermediate and then to good, reflecting continuous improvements in infrastructure investment efficiency. Accelerated development of transportation and water conservancy infrastructure has driven industrialization. Meanwhile, economic growth has generated fiscal resources to support infrastructure upgrades. Notably, between 2021 and 2023, significant improvements in rural broadband penetration and logistics network coverage boosted e-commerce and specialty agricultural product processing. This virtuous cycle not only optimized regional resource allocation but also facilitated talent return and innovation-driven development, maintaining the coupling coordination at a high value of 0.85. These factors collectively ensure the revitalization and sustainable development of rural areas in Sichuan Province.

4. Problems and Suggestions on Coupling and Coordination of Rural Infrastructure and Economic Development

4.1 Advance investment in rural infrastructure, but the benefit is relatively lagging

In Sichuan Province, the alignment between certain investments and regional economic development needs remains inadequate, resulting in inefficient resource allocation. Particularly in high-altitude mountainous and desert regions, infrastructure resources are scarce, and economic benefits are released slowly. To address this, a dynamic mechanism should be established to match infrastructure investments with industrial development speed based on big data statistics, thereby reducing the lag period. Additionally, a scientific project evaluation system should be implemented to conduct comprehensive feasibility analyses and benefit forecasts for investment projects, ensuring precise alignment with regional economic development needs. For special regions like high-altitude mountainous and desert areas, targeted infrastructure investment strategies should be formulated to avoid blind investments and resource waste, thereby improving the efficiency and economic benefits of infrastructure utilization.

4.2 The mismatch between the universality of rural infrastructure and the characteristics of industries

In some rural areas of Sichuan Province, excessive pursuit of uniformity in infrastructure development—such as roads, water conservancy, and energy facilities—has led to a lack of adaptation to local conditions and failure to align with regional core industries. This has resulted in basic infrastructure that is overly simplistic and ill-suited to local needs. To address this, regional industrial planning and infrastructure development should be better coordinated, with enhanced multi-stakeholder collaboration. Infrastructure should be designed around industrial characteristics, creating modular and scalable facilities. For specialized agricultural zones, priority should be given to developing farmland water conservancy systems and cold chain logistics to ensure efficient production and distribution of agricultural products. Additionally, a feedback mechanism linking industrial development and infrastructure should be established. This would allow for timely adjustments and optimizations in infrastructure layout and functionality based on actual industrial demands, ensuring deep integration and coordinated development between infrastructure and local industries.

4.3 Difficulty in matching production factors

The massive influx of young and middle-aged workers into cities has left rural areas with a significant population surplus, hindering the timely and effective conversion of advanced infrastructure into productive capacity. This further weakens the synergistic effects between infrastructure development and industrial growth. To address this, increased investment in rural education and vocational training is essential to enhance local workforce skills. Simultaneously, preferential policies should be implemented to encourage high-quality talent to flow into rural areas, injecting new vitality into their economic development. Additionally, developing distance education and online training can help bridge the gap in rural educational resources, thereby improving the alignment between resource allocation and production factors.

4.4 Fragmentation of the Policy System

In Sichuan Province, the initial infrastructure for rural poverty alleviation and industrial poverty alleviation efforts are inconsistent, with uneven regional development levels and inadequate rural infrastructure. To address this, it is essential to coordinate departments such as rural water conservancy, agriculture, and transportation in planning rural infrastructure and industrial development, thereby promoting rational resource allocation. A unified policy-making and implementation mechanism should be established to break down departmental barriers, ensure policy coherence and coordinated advancement, and strengthen monitoring of rural infrastructure construction and industrial development. Policies should be continuously adjusted and improved to adapt to new demands and changes in rural economic development, ultimately enhancing the coupling consistency between infrastructure and economic growth.

Conclusion

The continuous improvement of rural infrastructure and addressing its shortcomings are key priorities outlined in the 2025 Central Document No.1. This study employs a coupling coordination model to systematically examine the intrinsic relationship and interaction between rural infrastructure development and economic growth in Sichuan Province, while providing an accurate assessment of their current coordination status. The findings reveal that although the coupling coordination degree between rural infrastructure and economic development in Sichuan has shown a sustained upward trend over time, the coordination level remained relatively low during the 2014-2018 period, indicating potential developmental imbalances during this phase. Major challenges identified include slow conversion of economic benefits, severe brain drain, infrastructure construction lacking industrial characteristics, and a "fragmented" policy system. To address these issues, the paper proposes specific optimization strategies from perspectives of industry, talent, resources, and policy. However, the study also has limitations, such as the absence of micro-level mechanism analysis and the need for further refinement in indicator system research, which could provide better references for rural revitalization development.

While Sichuan Province has achieved a relatively high level of synergy between rural infrastructure development and economic growth, certain issues from previous years remain noteworthy. Currently, the coordination between rural infrastructure construction and economic development still requires improvement. Comprehensive consideration of various factors is essential to formulate rational measures that foster positive interaction between infrastructure and economic progress. This approach will further enhance the coupling and coordination between rural infrastructure development and economic advancement.

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