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How the rural infrastructure construction drives rural economic development through rural living environment governance—case study of 285 cities in China

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With deepening of rural revitalization strategy, rural infrastructure construction plays an important role in local economic development and living environment governance. Based on the mediation model, this paper takes case study of 285 cities in China from 2017 to 2022 as samples, constructs the explanatory variable, the explained variable and the mediator variable by entropy method, empirically analyzes the impact of rural infrastructure construction on rural living environment governance and rural economic development, as well as the mediation role played by rural living environment governance. It is found that there is a significant positive impact between rural infrastructure construction and rural economic development, and rural infrastructure construction can promote economic development through rural living environment governance. Further analysis show that the impact of rural infrastructure construction on rural economic development presents heterogeneity, and the impacts of rural infrastructure construction on local economic development and on local economic development through living environment governance in the eastern and central China is stronger than that in the western China. After controlling a series of variables related to rural infrastructure construction, and performing endogeneity tests and robustness tests such as tail-shrinkage regression and principal component analysis, the regression results are still robust. This paper firstly provides scientific empirical evidence for the hypothesis that rural infrastructure construction promotes local economic development through rural living environment governance, and secondly confirms the necessity of strengthening rural infrastructure construction in China to promote rural revitalization, providing a policy basis for scientific decision-making, and finally finds an important way out to solve the problem of unbalanced economic development in rural areas to some extent.

KEYWORDS

rural infrastructure construction, rural living environment governance, rural economic development, rural revitalization, transportation

1 Introduction

In March 2023, *the Report on the Work of the Government* of The State Council proposed that steady progress was made in rural reform and development. Rural development initiatives have been launched and the rural living environment continues to be improved. Rural infrastructure such as water, electricity and gas supplies, roads, and mail and communications services have been strengthened (Li, 2023). How to strengthen the construction of rural infrastructure and improve the rural living environment has become an important goal of China's economic and social development. By the end of 2021, 87.3% of villages had accessed to public transportation; In 99.1% of the villages, the main roads to the village were paved with cement or asphalt; 96.3% of the village household waste was treated centrally or partially; 77.5% of rural households had access to sanitary toilets; 47.6% of the villages had centralized or partially achieved centralized treatment of domestic sewage. China's vigorous construction of rural infrastructure is a proper move to comprehensively build beautiful, livable and workable villages. Whether the construction of rural infrastructure will become the main force for improving the rural living environment, and whether rural economic development will also be promoted will become two important issues.

From the perspective of the relationship between rural infrastructure construction and rural living environment as well as rural economic development, on one hand, it is believed that the construction of rural infrastructure is conducive to improving the rural living environment and then promoting local economic development, but on the other hand, it is believed that rural infrastructure construction increases the financial burden of the state and localities, and at the same time, various problems such as housing affordability decreasing, low-quality construction (McRae, 2015) and maintenance difficulties caused by imperfection in construction have negative impacts on the rural economy. In terms of the impact of rural infrastructure on the level of agricultural and rural modernization, rural infrastructure plays a certain role in promoting agricultural and rural development, farmers' production and life, and urban-rural integration, and rural infrastructure can generally improve agricultural and rural modernization (Liu and Chen, 2023). After establishing a measurement system for common prosperity, quantifying the impact of rural infrastructure construction on rural economic development, it is believed that increasing the construction of infrastructure related to agricultural production is the main means to promote rural economic development, narrow the gap between urban and rural income, and achieve common prosperity (Wang et al., 2022). Therefore, rural infrastructure construction is conducive to local economic development, and rural infrastructure construction also has a negative impact on economic development, which means there are shortcomings faced in rural infrastructure construction. It has been found that young generation in rural areas has minimum change to buy own housing not only because of increased housing prices (Hromada and Cermakova, 2021), but also because of increased costs and lower accessibility to mortgage financing (Venhoda, 2022). Problems such as aging rural infrastructure, imperfect supporting facilities, and unscientific management have made some rural projects become jerry-built and face-saving projects, and some infrastructure construction projects cannot play their due role in a short time after being put into use, which greatly restricts the sound development of rural economy (Zhang, 2023). Meanwhile, rural infrastructure construction is facing a shortage of funds, and due to the public welfare nature of infrastructure construction, it is difficult to obtain credit support, the state financial support is also limited, and some townships and villages are unable to raise funds for rural infrastructure construction, which directly restricts the rapid development of rural infrastructure and becomes a "bottleneck" restricting rural economic and social development (Zou, 2017).

In view of the existing research on the relationship between rural infrastructure construction and rural economic development, this paper adopts the rural revitalization data of various prefecture-level cities in China from 2017 to 2022, builds a mediation model, discusses the relationship between rural infrastructure construction and rural economic development, and whether there is a mediation effect of rural living environment governance, and finds relevant empirical evidence. It is found that there is a significant positive impact between rural infrastructure construction and rural economic development, and rural infrastructure construction can promote economic development through rural living environment governance. Further analysis show that the impact of infrastructure on economic development presents heterogeneity, the impacts of rural infrastructure construction on local economic development and on local economic development through living environment governance in the eastern and central China is stronger than that in the western China. After controlling a series of variables related to rural infrastructure construction, testing endogeneity, replacing explanatory variables and performing tail-shrinkage regression, principal component analysis and other robustness tests, the regression results are still robust.

The marginal contribution of this study is mainly as follows: First, unlike the previous selection of a single index as the proxy variable for an explanatory variable, the existing data is used to construct three variables, rural economic development, rural infrastructure construction and rural living environment governance by entropy method, which to a certain extent overcome the problem of inaccurate empirical results due to incomplete measurement factors. Secondly, not only the mediation effect model is used to reveal the importance of rural infrastructure construction to improve rural living environment and promote rural economic development, but also the variable dismantling, Sobel-Goodman and Bootstrap mediation tests are used to confirm the mediation effect of living environment governance between strengthening rural infrastructure construction and promoting rural economic development, and the robustness of empirical research results is proved by principal component analysis and other methods. Thirdly, this paper enriches the literature research on rural revitalization, rural infrastructure construction and rural economic development, and seeks indicators that can improve rural living environment and promote rural economic construction from different aspects, which provides a policy basis for scientific decision-making. Finally, this paper examines the heterogeneity of the impact of rural infrastructure construction on rural living environment governance and rural economic development in eastern, central and western China, and also finds an important way to solve the problem of

unbalanced regional economic development in rural areas to some extent.

The structure of this paper is arranged as follows. The second part mainly explains the current situation of China's rural infrastructure and the literature of promoting rural living environment and economic development by building rural infrastructure. On the basis of the second part, the third part discusses the relationship between rural infrastructure construction, rural living environment governance and rural economic development, forms the theoretical basis of the article, and puts forward the research hypothesis. The fourth part explains the research design and model construction of the article. The fifth part analyzes the empirical results from five aspects: baseline regression, regional heterogeneity, endogeneity test, mechanism effect test and robustness test. Finally, the conclusions and suggestions are given.

2 Literature review

In September 2022, the executive meeting of the State Council issued *the Work Plan on Expanding Current Investment in Agricultural and Rural Infrastructure Construction*, pointing out that strengthening agricultural and rural infrastructure construction is a key task to expand effective investment and stabilize the overall economic market (Ministry of Agriculture and Rural Affairs, 2022). Rural transportation infrastructure such as highway and railway can enhance country's economic development (Mitwallyová et al., 2015) and reduce costs (Ječný and Kadeřábková, 2022). Only by accelerating the construction of rural infrastructure can one nation better enrich the material life of rural areas and lay a solid material foundation for the modernization of agriculture and rural areas. In this part, the impact of rural infrastructure construction on rural economic development, the role of rural infrastructure construction on rural living environment governance and the impact of rural living environment governance on rural economic development are sorted out according to existing literature.

2.1 Influence of rural infrastructure construction on rural economic development

Most of the literature shows that rural infrastructure will help strengthen agricultural production, attract FDI, facilitate factor mobility, increase material resources, raise income level (Fernald, 1999), reduce poverty (Caldero´n, 2015), and promote urban-rural integration, so as to achieve the impact on rural economy. Based on rural infrastructure construction in Nigeria, Daud et al. (2018) explores the relationship between rural infrastructure and rural food production, concludes that rural economic development is affected by rural infrastructure construction, and puts forward suggestions on improving rural infrastructure construction to promote rural economic development. Varahrami and Vajari (2019) argue that rural infrastructure construction is conducive to attracting foreign investment. Kurekova and Hejdukova (2021) confirm that regions with insufficient infrastructure face traditionally low labor mobility and suffer from higher and longer unemployment. Thus, it is advisable to invest in infrastructure to increase labor mobility. Zhou et al. (2023), based on the analysis of the influencing factors of rural infrastructure construction, believe that rural infrastructure construction is the material condition and basic guarantee for China's rural development, and strengthening rural infrastructure construction is an important measure to accelerate rural development. Chotia and Rao (2017) emphasize that rural infrastructure construction can directly reduce farmers' transaction costs and improve productivity, thereby increasing farmers' income and reducing poverty. Hromada and Cermakova (2021) prove that investment in rural infrastructure may help solving housing poverty problem, a resonant issue across Europe. Also, Uczak and Kalinowski (2022) find that countries with relevant improvement in infrastructure have witnessed a clear improvement in poverty status. Lu and Lu (2022) reveal that rural infrastructure construction is the core element in rural modernization, which is conducive to breaking the constraints of traditional production and lifestyle, giving play to the unique functions of rural areas, stimulating the endogenous driving force of rural areas, reducing the gap between urban and rural areas, and improving farmers' production enthusiasm and life satisfaction. Huang et al. (2023), after studying the practical significance and realization path of rural revitalization strategy to strengthen rural infrastructure construction, point out that improving rural infrastructure is an important prerequisite for implementing rural revitalization strategy, and rural infrastructure construction is related to the overall development and integrated construction of urban and rural areas, and to the smooth realization of the overall goal of rural revitalization of "prosperous industry, ecological livability, civilized rural style, effective governance, and rich life".

2.2 Role of rural infrastructure construction in the rural living environment governance

It is believed that rural infrastructure construction will optimize the sanitary environment, enhance water supply, boost the level of informatization, etc., so as to improve the rural living environment and form an excellent rural style. On the basis of analyzing the path and mechanism of rural living environment governance, Zhu (2023) points out that local governments should coordinate the supporting of public infrastructure, solve the problem on the environmental sanitation governance that cannot be solved by villages themselves because of have high costs, and better respond to the daily life needs of villagers. Based on exploring the coupling relationship between rural economy and rural living environment, Liang (2023) finds that relevant measures such as promoting rural water and toilet improvement, implementing centralized water supply in qualified rural areas, strengthening environmental supervision, and reducing the number of sanitary household toilets are conducive to strengthening rural infrastructure construction and laying the foundation for improving rural living environment. Sun (2023) reveals that China's rural society is gradually forming a "new infrastructure" model through 5G mobile networks, big data centers, artificial intelligence and other technologies. With the vigorous rise of digital technology, the level of rural infrastructure will be improved, and the digital level of rural living environment improvement will also be improved.

Cantarero-García et al. (2023) argue that intelligent facilities could improve the quality of rural life, the local economy, transportation, traffic management, the environment, and interaction with the government because of information and communication technologies utilization. When analyzing the problems faced by rural infrastructure construction, Shi et al. (2023) conclude that rural infrastructure has been significantly improved in quantity and quality, but the contradiction of imbalance and inadequacy is still prominent, and it is necessary to increase construction efforts to meet the practical needs of "strong agriculture, beautiful rural areas, and rich farmers" After studying the role of rural infrastructure in rural revitalization, Zeng and Cai (2018) emphasize that rural infrastructure construction can lay the foundation for rural revitalization, and it is the leading capital for industrial prosperity, the necessary condition for ecological livability, and the important guarantee for the prosperous life in rural areas.

2.3 Impact of rural living environment governance on rural economic development

From the literature, it is not difficult to find that the sound rural living environment can improve the rural ecological environment, cultivate new growth points of rural economy, and revitalize rural industries, which are of great significance to the implementation of rural revitalization strategy and rural economic development. After studying the governance of rural living environment in the Yangtze River Delta region, Liu and Yuan (2023), find that the role of rural living environment governance in rural revitalization is becoming increasingly significant, and the improvement of living environment can also drive rural industrial revitalization and enhance attractiveness of rural areas. Zhang (2021) takes the transformation of rural living environment as an example and studies rural environmental governance from the perspective of daily life. He believes that the national and individual perceptions of rural living environmental governance have changed, that is, people used to regard living environment governance as a burden for economic development, but now they pay more and more attention to environmental governance and emphasize that rural environmental governance is regarded as a driving force for economic development. Qing (2023) analyzes the existing problems and countermeasures in the governance of rural living environment in Suining City, puts forward the existing problems and countermeasures in the governance of rural living environment in Suining City, and clarifies that the endogenous driving force of rural living environment governance lies in the development of rural economy, and rural living environment governance can significantly improve the level of rural economic development. On the basis of examining the pollution control of rural living environment in Shandong Province, Zhang et al. (2017) conclude that rural living environment is the foundation of rural residents in China and the basis for cultivating new rural economic growth engine. After studying the operational direction of rural human settlement environment governance, Zhang and He (2023) reveal that improving and upgrading rural living environment is an inevitable requirement and major strategic task for the implementation of the rural revitalization strategy at present and in the future, and is the only way for China to start a new journey of building the modern socialist country in an all-round way.

3 Theoretical analysis and research hypothesis

From the micro perspective, rural infrastructure construction mainly enhances the matching degree between producers, sellers and consumers by improving production efficiency, reducing transaction costs (Wu et al., 2019), and solving the problem on information asymmetry, so as to achieve a balance between supply and demand and promote rural economic development (Sasmal and Sasmal, 2016; Chen et al., 2023). The hardening and repair of rural roads can accelerate the transportation of agricultural raw materials and improve production efficiency (Asher and Novosad, 2020), while the use of e-commerce platforms can accelerate the consumption and supply of agricultural products, dredge transaction channels, reduce transaction costs, build digital villages, and optimize and upgrade rural network infrastructure, which can give full play to the driving and leading role of informatization in rural revitalization and reduce the impact of information asymmetry on rural economy.

From the macro level, rural infrastructure construction mainly has an impact on the rural economy by promoting non-agricultural employment (Qin et al., 2022), enhancing urban-rural integration, and ensuring the rural ecological environment. Rural transportation infrastructure can improve agricultural economic performance and reduce transaction costs (Adamopoulos, 2011; Donaldson, 2018; Negi et al., 2018), thereby helping rural areas free up more labor for non-farm employment. Building rural high-quality infrastructure is the basis for ensuring farmers' lives and rural economic development, and is the first choice to improve the quality of life and happiness of rural residents (Winters et al., 2009). Rural transportation infrastructure such as highway and railway can improve country's income and reduce transportation costs, thereby helping rural areas to release more labor to engage in non-agricultural industries, and farmers have more non-agricultural employment opportunities and higher incomes (Luo et al., 2020). Good rural infrastructure can enhance the transformation of rural production and life style, promote the improvement of agricultural quality and efficiency, so as to improve the urbanization rate and promote the urban-rural integration construction. Measures such as popularization of rural drinking water, treatment of rural sewage and improvement of rural greening rate can effectively protect the sustainability of rural ecological environment and promote the high-quality development of rural economy (Guo and Zeng, 2021). Excellent rural ecological environment is the premise of rural livability, and China is changing the trend of regional policy in pollution control and has gradually shifted the focus of pollution control from industry and cities to the balance between industry and agriculture, urban and rural areas, increased the investment and funds in rural pollution prevention and control, improved rural living environment, enhanced ecological environmental protection, and raised the level of high-quality development of rural economy. Therefore, the research hypothesis is put forward.

H1. Rural infrastructure construction is conducive to promoting rural economic development.

Rural infrastructure construction is related to the governance of rural living environment and is an important measure to promote economic development (Hulten et al., 2006). The role of rural infrastructure in improving living environment is mainly reflected in the following three aspects. Firstly, rural infrastructure construction can improve the rural layout and optimize the structure of rural life. The hardening of rural roads significantly improves the communication between rural areas and between rural areas and cities, accelerates the process of urban-rural integration. The popularization of safe drinking water and the use of sewage treatment equipment have solved the outstanding problems of drinking water safety and sewage waste treatment and recycling in rural China at present, which is of vital significance to improve the rural living environment and promote the sustainable development of the rural ecological environment, and the reference of intelligent waste classification system and digital natural gas are of great importance to promote the green development of rural areas and facilitate the harmonious coexistence of man and nature. Secondly, rural infrastructure construction can enhance the application of rural scientific and technological achievements and diversify farmers' participation channels (Negi et al., 2018). The construction and improvement of rural 5G, the Internet and other communication facilities have greatly expanded the communication channels of farmers, improved the efficiency of communication, strengthened the use of modern digital information technology in rural areas, and enhanced the information symmetry between urban and rural residents' exchanges. China's rural society is gradually forming a "new infrastructure" model through 5G mobile networks, big data centers, artificial intelligence and other technologies to achieve the integration of digital equipment and traditional infrastructure. With the vigorous rise of digital technology, the digital level of rural residential environment improvement will also be improved. Thirdly, the construction of rural infrastructure is of great significance for enriching rural cultural life and enhancing the level of comprehensive rural development. The construction of rural cultural stations is conducive to enhancing farmers' awareness of cultural participation, raising the level of farmers' cultural quality, expanding rural residents' expenditure on education, culture and entertainment, improving the quality of rural life, and promoting the construction of new rural areas with civilized customs (Sun, 2023). When studying the path selection for improving the current situation of rural public infrastructure, it is thought that rural sports and leisure culture should be continued, rural education and medical care should be emphasized, and efforts should be made to realize urban-rural integration, increase talent investment in rural areas, and attention should be paid to rural human resource management (Tang and Wang, 2018). Therefore, the research hypothesis is put forward.

H2. Rural infrastructure construction promotes rural economic development through living environment governance.

China is vast in territory. The level of infrastructure development of various economic zones is different, the management of farmers' living environment is different, and the level of economic development is also different. By improving the rural living environment, rural infrastructure construction may have two impacts on rural economic development. Firstly, the higher the basic level of rural infrastructure, the stronger the role of improving the rural living environment and driving economic development are, forming a basic effect. Secondly, in the rural areas with imperfect infrastructure, the greater the investment in rural infrastructure construction in the later period, which can cause the improvement of the rural living environment to a greater extent, the stronger the radiation effect on rural economic development, and the more obvious the role of improving the level of rural economic development are, forming an incremental effect. Comparing with the developed eastern region, the level of economic and social development in the central and western regions is relatively low, the government's financial strength is weak, and the financial resources available in infrastructure construction are extremely limited, resulting in the serious lag of the infrastructure construction level of the central and western regions, especially the infrastructure construction in rural areas, comparing to that of eastern coastal regions (Shi et al., 2023). Less developed regions suffer from deeper magnitude of real estate price cycle and slower overall economic recovery (Hromada et al., 2023) and private investments in less developed regions are thus more risky signaling a poverty vicious cycle. Fiscal decentralization has been found as favorable for meeting differing needs between regions (Nkoro and Otto, 2023). Based on the empirical study of the impact of digital infrastructure construction on rural residents' income, some scholars found that comparing with the western region, the impact of digital infrastructure construction on rural residents' income in the eastern and central regions has a stronger salience, indicating that in regions with sound economic development, human capital and science and technology foundation, the development of digital infrastructure can better integrate with rural industries and broaden the income channels of rural residents (Deng and Wu, 2023). In terms of data of the western development for 20 years, it is believed that after the implementation of the western development strategy, infrastructure construction has achieved remarkable results, the economic growth rate of the western region has accelerated, the income of residents has increased significantly, and the growth rate of total factors ranks first among the four major regions in China (Deng et al., 2020). Meanwhile, due to the accessibility of transportation and other infrastructure along the "Belt and Road," it will bring the western region great opportunities in the industrial transformation and upgrading, opening up to the outside, market connectivity, border trade and port construction (Chen, 2022). Based on these, the following hypothesis is proposed.

H3. The impact of rural infrastructure construction on rural living environment governance and rural economic development presents regional heterogeneity.

4 Research design and model construction

4.1 Variable selection

4.1.1 Explained variable

In this paper, six second-level indicators, namely, farmers' net income per capita, farmers' income growth rate per capita, rural poverty incidence rate, rural residents' Engel coefficient, car

TABLE 1 Construction of indicator system of rural economic development.

First-level indicator	Second-level indicator	Weight (%)	Direction
Farmers' income level	Farmers' net income per capita (yuan)	19.279	+
	Farmers' income growth rate per capita (%)	4.169	+
	Rural poverty incidence rate (%)	19.195	-
Farmers' consumption structure	Rural residents' Engel coefficient (%)	18.669	-
Farmer living condition	Car ownership per 100 households (pcs)	19.424	+
	Rural residents' housing area per capita (square meter)	19.264	+

TABLE 2 Construction of indicator system of infrastructure construction.

First-level indicator	Second-level indicator	Weight (%)	Direction
Communication infrastructure	Cable TV coverage (%)	16.332	+
	Proportion of administrative villages with Internet broadband service (%)	16.302	+
Cultural communication infrastructure	Number of rural cultural stations (pcs)	17.883	+
Water supply and drainage infrastructure	Penetration rate of safe drinking water (%)	16.609	+
Transportation infrastructure	Village road hardening rate (%)	16.552	+
	Road area per capita (square meter)	16.321	+

TABLE 3 Construction of indicator system of rural living environment governance.

First-level indicator	Second-level indicator	Weight (%)	Direction
Agricultural green development	Comprehensive utilization rate of livestock and poultry manure (%)	19.795	+
Rural sewage treatment	Proportion of administrative villages that treat domestic sewage (%)	20.215	+
	Proportion of administrative villages that treat domestic garbage (%)	19.812	+
	Penetration rate of sanitary toilets (%)	20.333	+
Rural ecological protection	Rate of rural greening (%)	19.845	+

ownership per 100 households, and rural residents' housing area per capita, which belong to three first-level indicators, namely, farmers' income level, farmers' consumption structure and farmers' living conditions are selected according to study of Xu and Wang (2022). Considering the readability of the results, after the entropy method is used to calculate the variables, the logarithm is taken to construct rural economic development (Econ), the explained variable. The index weight is shown in Table 1.

4.1.2 Explanatory variable

In this paper, six second-level indicators, including cable TV coverage, proportion of administrative villages with Internet broadband service, number of rural cultural stations, penetration rate of safe drinking water, village road hardening rate and road area per capita, which belong to three first-level indicators, namely, communication infrastructure, water supply and drainage infrastructure and transportation infrastructure are selected. Considering the readability of the results and in order to facilitate regression analysis, the entropy method is used to calculate and it is necessary to divide the constructed variable by 100 to get the rural infrastructure construction (Infra), the explanatory variable. The index weights are shown in Table 2.

4.1.3 Mediator variable

When constructing the mediation variable of rural living environment governance, this paper selects five second-level indicators, including the comprehensive utilization rate of livestock and poultry manure, the proportion of administrative villages that treat domestic sewage, the proportion of administrative villages that treat domestic garbage, the penetration rate of sanitary toilets, and the rate of rural greening, which belongs to three first-level indicators, namely, agricultural green development, rural sewage treatment and rural ecological protection. Considering the readability of the results, and in order to facilitate regression analysis, entropy method is used to calculate and it is necessary to divide the constructed variable by 10 to get rural living environment governance (Gov), the mediator variable. The index weights are shown in Table 3.

TABLE 4 Construction of indicator system of control variables.

Control variables	First-level indicator	Second-level indicator	Weight (%)	Direction
Agricultural production capacity	Agricultural production capacity base	Total power of agricultural machinery per capita (Kilowatt)	33.077	+
		Comprehensive grain production capacity (10000 tons)	33.289	+
	Agricultural production efficiency	Agricultural labor productivity (yuan/person)	33.634	+
Urban-rural economic gap	Urban-rural income gap	Urban-rural income ratio (%)	100	-
Farmers' education	Farmers' education level	Proportion of rural residents' education, culture and entertainment expenditure (%)	32.919	+
		Proportion of full-time teachers in rural compulsory education schools with bachelor's degree or above (%)	32.641	+
		Average years of education of rural residents (year)	34.440	+
Rural leadership	Governance ability	Proportion of village director and secretary "one shoulder task" (%)	33.339	+
		Proportion of administrative villages that have prepared village plans (%)	32.768	+
	Governance measures	Proportion of administrative villages that have carried out village renovation (%)	33.892	+

4.1.4 Control variables

In order to control the influence of other factors on the empirical results, this paper also uses the entropy method to construct four control variables: agricultural production capacity (Agric), urban-rural economic gap (Urb_rura), farmers' education level (LnEdu) and rural leadership (Leader), and the fixed effects of Region and Year are also controlled.

Among them, agricultural production capacity is derived from three second-level indicators, namely, the total power of agricultural machinery per capita, comprehensive grain production capacity and agricultural labor productivity, which belong to two first-level indicators, namely, the agricultural production capacity base, agricultural production efficiency. After the entropy method is used to construct the variable, in order to facilitate regression analysis, the variable is divided by 10000 to obtain the control variable Agric, namely, agricultural production capacity.

Urban-rural income gap, this first-level indicator is derived from urban-rural economic ratio, this second-level indicator, which is the ratio of urban residents' income to rural residents' income. In order to facilitate regression analysis, the control variable Urb_rura is named directly.

Farmers' education is derived from three second-level indicators: the proportion of rural residents' education, culture and entertainment expenditure, the proportion of full-time teachers in rural compulsory education schools with bachelor's degree or above, and the average years of education of rural residents, all of which are from farmers' education level, this first-level indicator. In order to facilitate regression analysis, the logarithm of the variables constructed by entropy method is taken to obtain the control variable LnEdu, farmers' education.

Rural leadership is derived from the ratio of village director and secretary "one shoulder task", the proportion of administrative villages that have prepared village plans and the proportion of administrative villages that have carried out village renovation, which belong to two first-level indicators, namely, governance ability and governance measures. In order to ensure the readability of the results, after constructing by entropy method, rural leadership Leader, this control variable is obtained by dividing 10. The weights of all the above variables constructed through entropy method are showed in Table 4.

4.2 Evaluation method

In this paper, entropy method is used to construct the comprehensive index of explained variable, explanatory variable, mediator variable and control variables. Entropy is a concept in information theory which is a measure of uncertainty. The more information, the less uncertainty, the less entropy is, and the less information, the greater uncertainty, the greater entropy is (Wang et al., 2020). According to the definition of entropy, the entropy value can be used to judge the degree of dispersion of an indicator. The greater the entropy value of the indicator, the smaller the degree of dispersion, and the smaller the weight of the indicator on the comprehensive indicator is. Similarly, the smaller the entropy value of the indicator, the greater the degree of dispersion, and the greater the influence of the indicator on the comprehensive indicator is (Gan et al., 2021). Therefore, information entropy can be used to calculate the weight of each index and build a comprehensive index. The use of multiple indicators to replace a single indicator makes the index evaluation more scientific and reasonable, provides a basis for comprehensive evaluation, and strengthens the correlation analysis of data. There are a large number of indicators in data on rural revitalization. When selecting second-level indicators and constructing first-level indicators and four variables, it is necessary to pay attention to the positive and negative directions of indicators, standardize indicators, calculate the weight of each indicator, and measure the importance of indicators (Sun and Zhu, 2022). The specific steps to use the entropy method are shown below.

Firstly, set data matrix. Construct the evaluation matrix X of the evaluation index j of sample in year i.

$$X = \begin{pmatrix} X_{11} & \cdots & X_{1j} \\ \vdots & \ddots & \vdots \\ X_{i1} & \cdots & X_{ij} \end{pmatrix} \quad (1)$$

In this formula, X_{ij} is the value of the index j in year i.

Secondly, standardize data. When constructing the four variables, the index units contained therein are not the same, and the mathematical magnitude is also quite different. Therefore, it is necessary to standardize the data, eliminate the differences among variables, and ensure the comparability of the data (Li et al., 2023). The positive and negative indicators are standardized respectively.

$$\text{Standardize positive indicators: } Z_{ij} = \frac{X_{ij} - min\, X_{ij}}{max\, X_{ij} - min\, X_{ij}} \quad (2)$$

$$\text{Standardize negative indicators: } Z_{ij} = \frac{max\, X_{ij} - X_{ij}}{max\, X_{ij} - min\, X_{ij}} \quad (3)$$

In this formula, Z_{ij} is the standardized value of the index j in year i, X_{ij} is still the value of the index j in year i, and $max\, X_{ij}$ and $min\, X_{ij}$ is the maximum and minimum value of the index j in year i respectively.

Thirdly, calculate the weights of each index.

$$\text{Calculate the ratio of index } j \text{ in year } i\text{: } P_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{n} Z_{ij}} \quad (4)$$

$$\text{Calculate the entropy of the index } j\text{: } E_j = -K\sum_{i=1}^{n} P_{ij}\, ln\, P_{ij} \quad (5)$$

$$\text{Calculate the difference coefficient of index } j\text{: } F_j = 1 - E_j \quad (6)$$

$$\text{Calculate the weight of index } j\text{: } W_j = \frac{F_j}{\sum_{j=1}^{m} F_j} \quad (7)$$

$$\text{Calculate the composite score of the indicator: } index_j = \sum_{j=1}^{m} (W_j * Z_{ij}) \quad (8)$$

In the above formulas, P_{ij} is the ratio of the index j to the total value of the index in the year i, E_j represents the entropy of the index j, F_j is the difference coefficient of the index j, and W_j is the weight of the index j.

4.3 Model setting

In order to study how rural infrastructure construction indirectly affects economic development through living environment governance, the following model is established to test the mediation effect by referring to the method utilized by Wen and Ye (2014):

$$Econ_{it} = \alpha_0 + \alpha_1 Infra_{it} + \alpha_2 X_{it} + Region_i + Year_t + \varepsilon_{1,it} \quad (9)$$

$$Gov_{it} = \beta_0 + \beta_1 Infra_{it} + \beta_2 X_{it} + Region_i + Year_t + \varepsilon_{2,it} \quad (10)$$

$$Econ_t = \gamma_0 + \gamma_1 Infra_{it} + \gamma_2 Gov_{it} + \gamma_3 X_{it} + Region_i + Year_t + \varepsilon_{3,it} \quad (11)$$

Among them, $Infra_{it}$ is the infrastructure construction of the i rural area in the t period, Gov_{it} is the living environment governance of the i rural area in the t period, and X_{it} is a group of control variables affecting rural economic development. *Region* indicates the region fixed effect, and *Year* indicates the year fixed effect. In this model, model (1) is used to test the total effect of rural infrastructure on economic development, coefficient α_1 measures the size of the total effect, and coefficient β_1 in model (2) reflects the impact of rural infrastructure on living environment governance. If β_1 is significantly positive, Hypothesis 1 is valid. If the regression coefficients β_1 and γ_2 are both significantly positive, then Hypothesis 2 is valid.

TABLE 5 The descriptive statistics of variables.

Variable name	Number	Mean	Std.Dev	Min	Max
Econ	2526	6.33	2.778	1.312	14.66
Infra	2526	0.657	0.29	0.131	1.58
Gov	2526	1.635	0.722	0.32	3.853
Agric	2526	1	0.447	0.189	2.569
Urb_rura	2526	2.003	0.546	1	3.502
LnEdu	2526	2.314	0.545	0.767	3.337
Leader	2526	1.508	0.667	0.284	3.597

Note: Authors' calculations are based on Stata 17.

4.4 Data sources and descriptive statistics

The rural revitalization panel data of 285 Chinese prefecture-level cities in 31 provinces (excluding Hong Kong, Macao and Taiwan) from 2017 to 2022 are selected as empirical research samples. Among them, the indicators related to rural infrastructure, living environment governance and rural economic development are from "the Statistical Yearbook of China provinces" and "the China Rural Statistical Yearbook" for 2017–2022. The descriptive statistics of the variables are shown in Table 5.

5 Analysis of empirical results

5.1 Baseline regression

In this paper, according to model (9), rural economic development is taken as the explained variable to conduct regression for rural infrastructure construction, and the results are (1)–(3). Column (1) in Table 6 is OLS mixed regression without adding control variables and without controlling regions and years. According to the result, rural infrastructure construction has a significant positive impact on rural economic development, and the results also show that the p-value is significant, indicating that the fixed effect or random effect model is more appropriate. After Huasman's test, Prob > chi2 = 0.0000, it is concluded that the fixed effect is more effective. Due to the existence of regional differences and time trends, next, the region and year fixed effects are added to form the result in column (2). In the third step, agricultural production capacity (Agric), urban-rural

TABLE 6 Baseline regression results.

Variables	(1)	(2)	(3)	(4)	(5)
	Econ	Econ	Econ	Gov	Econ
Infra	9.548***	7.984***	4.572***	1.169***	3.494***
	(0.018)	(0.088)	(0.120)	(0.057)	(0.118)
Gov					0.922***
					(0.044)
Control variables					
Agric			0.324***	0.110***	0.223***
			(0.050)	(0.024)	(0.048)
Urb_rura			−0.425***	−0.100***	−0.333***
			(0.062)	(0.030)	(0.054)
LnEdu			0.293***	0.082***	0.217***
			(0.056)	(0.026)	(0.050)
Leader			1.000***	0.244***	0.775***
			(0.044)	(0.021)	(0.037)
Regional fixed effect	No	Yes	Yes	Yes	Yes
Year fixed effect	No	Yes	Yes	Yes	Yes
Constant	0.052***	1.021***	1.628***	0.386***	1.272***
	(0.010)	(0.054)	(0.248)	(0.125)	(0.218)
Observations	2,526	2,526	2,526	2,526	2,526
R-squared	0.995	0.884	0.935	0.780	0.950

Notes: Values in parentheses are robust standard errors; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. "Yes" indicates that the variable is controlled in the model; the same applies to tables below. Authors' calculations are based on Stata 17.

economic gap (Urb_rura), farmers' education level (LnEdu) and rural leadership (Leader), the four control variables are added to form the result in column (3). The result shows that the regression coefficient of rural economic development on rural infrastructure construction is significantly positive regardless of whether the control variable is added, indicating that rural infrastructure construction is conducive to promoting rural economic development, and Hypothesis 1 is true.

Next, according to model (10), with the addition of control variables, control regions and years, rural living environment governance is used as the explained variable to carry out regression for rural infrastructure construction. The result in column (4) shows that the regression coefficient of rural infrastructure construction is significant-ly positive, indicating that rural infrastructure construction is conducive to improving rural living environment. The above results show that rural infrastructure construction can improve the living environment and promote rural economic development.

Finally, according to the model (11), the regression coefficient of rural infrastructure and rural living environment governance is also regressed by adding control variables, controlling regions and years, and the result in column (5) shows that the regression coefficients of rural infrastructure and rural living environment governance are significantly positive, indicating that rural infrastructure improvement promotes economic development through living environment governance, and rural living environment governance has a mediation effect between rural infrastructure construction and rural economic development, which supports Hypothesis 2.

5.2 Regional heterogeneity test

Generally speaking, in areas with better economic development, infrastructure construction has a stronger driving effect on economic development (Huang et al., 2012), and infrastructure can better improve the living environment (Li, 2021), and the improvement of living environment can better serve economic development (Song et al., 2023). In order to study how regional differences affect the role of rural infrastructure on rural economic development, according to the division of the three economic belts by the National Bureau of Statistics, this paper divides the provinces in which the region is located into three groups: the east, the central and the west, generates infrastructure and interaction items for the three regions, and adds all control variables, region and year fixed effect tests to form the results in Table 7.

Column (1)–(3) are the results of the regression of eastern rural economic development to infrastructure construction, living

TABLE 7 Regional heterogeneity test results.

Variables	East			Central			West		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Econ	Gov	Econ	Econ	Gov	Econ	Econ	Gov	Econ
Infra_east	2.414***	0.619***	1.614***						
	(0.138)	(0.056)	(0.120)						
Infra_central				1.409***	0.421***	0.806***			
				(0.167)	(0.068)	(0.126)			
Infra_west							0.306	0.013	0.287*
							(0.216)	(0.088)	(0.152)
Gov			1.291***			1.429***			1.466***
			(0.049)			(0.047)			(0.047)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.032***	0.745***	2.070***	3.306***	0.811***	2.147***	3.357***	0.839***	2.128***
	(0.305)	(0.132)	(0.255)	(0.316)	(0.133)	(0.264)	(0.321)	(0.134)	(0.267)
Observations	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526	2,526
R-squared	0.896	0.749	0.930	0.879	0.736	0.922	0.874	0.730	0.921

Notes: Values in parentheses are robust standard errors; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. Authors' calculations are based on Stata 17.

environment governance to infrastructure, and rural economic development to infrastructure construction and living environment governance. (4)–(6) are the results of the regression of rural economic development to infrastructure construction in central China, living environment governance to infrastructure construction, rural economic development to infrastructure construction and living environment governance, and (7)–(9) correspondingly represent the data of western China.

The results show that rural infrastructure constructions in eastern and central China have significantly positive impacts on rural economic development, living environment governance, and rural infrastructure constructions have significantly positive impacts on rural economic development through rural living environment governance. The regression coefficients of rural infrastructure construction on rural economic development, living environment governance and rural economic development through rural living environment governance are greater in the east than those in the central, while the positive effects of rural infrastructure construction on rural economic development and living environment governance are not significant in the west. Meanwhile, the positive impact of infrastructure construction on rural economic development through living environment governance in western China is significant at the 10% level, which is much lower than those in eastern and central China at the 1% level. The possible reason lies in the earlier, more complete and larger scale infrastructure construction in the eastern and central areas, and the stronger financial capabilities of the government, which can provide more complete support for the construction of rural infrastructure, resulting in more investment and obvious improvement in the governance of rural living environment. There are also more opportunities for economic exchange in rural areas of two regions. The above factors make the regression coefficients significant. The western region covers a large area, and its infrastructure construction is relatively late and imperfect, and the degree of its communication through roads and other infrastructure is weak. The effect of rural living environment governance is not obvious, and the development of rural local economy needs to be further improved. Therefore, the regression coefficient is not significant. But at the same time, it can also provide some reference for the western region because rural infrastructure constructions in eastern and central regions have significantly positive effects on economic development and living environment governance. The governments in western region should increase investment in infrastructure construction in rural areas, constantly improve the local living environment and economic quality. In conclusion, Hypothesis 3 on regional heterogeneity is valid.

5.3 Endogeneity test

After adding control variables and fixing the year and region in the baseline regression, it can also be concluded that rural infrastructure construction has a significant positive effect on rural economic development. However, the regression coefficient decreases, which indicates that the estimation deviation can be reduced through controlling variables. At the same time, by

TABLE 8 Test results of explanatory variable of one phrase lag processing as instrumental variable.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	1st stage	2nd stage	1st stage	2nd stage	1st stage	2nd stage
	Infra	Econ	Infra	Gov	Infra	Econ
L.Infra	0.145***		0.145***		0.079***	
	(0.010)		(0.010)		(0.009)	
Infra		8.862***		2.440***		8.111***
		(0.411)		(0.181)		(0.723)
Gov					0.187***	0.308**
					(0.007)	(0.153)
F test	21441.71		21441.71		25770.36	
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.061	−0.060	0.061	0.018	0.030	−0.062
	(0.053)	(0.311)	(0.053)	(0.137)	(0.046)	(0.286)
Observations	2,105	2,105	2,105	2,105	2,105	2,105
R-squared	0.989	0.996	0.989	0.989	0.992	0.997

Notes: Values in parentheses are robust standard errors; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. Authors' calculations are based on Stata 17.

studying the possible endogeneity, we can draw the following conclusions: First, there may be endogenous problems caused by missing variables; Second, rural infrastructure construction can have a significant positive effect on economic development through living environment, but at the same time, a higher degree of economic development will in turn affect rural infrastructure construction, forming the reverse causality. Based on this, we searched for two instrumental variables and conducted two endogeneity tests by using two-stage least square method.

5.3.1 Explanatory variable of one phrase lag processing as instrumental variable

The first method is delaying the explanatory variable by one phrase to form the instrumental variable L.Infra, and performing the two-stage least square method, referring to the research of Hu and Kou (2023). The regression results are listed in Table 8.

Firstly, the weak instrumental variable test is carried out on the instrumental variable L.Infra. It can be seen that in the first stage of the three regression results, the F value was all greater than 10, indicating that the instrumental variable L.Infra has passed the weak instrumental variable test. At the same time, there is a significant positive relationship between the instrumental variable L.Infra and the explanatory variable Infra. In the second stage test, it can be seen that there is a significant positive relationship between the explanatory variable Infra and the explained variable Econ in column (2), and the regression coefficient of Infra in column (4) is still significantly positive, indicating a significant positive relationship between the explanatory variable Infra and the mediator variable Gov. In column (6), the coefficient of explanatory variable Infra and the coefficient of mediator variable Gov are significantly positive, indicating that rural living environment governance plays a mediation role between rural infrastructure construction and rural economic development, and rural infrastructure construction can improve rural living environment governance, then promote rural economic development when the explanatory variable of one phase lag processing is used as an instrumental variable. All these support Hypothesis 1 and Hypothesis 2.

5.3.2 The number of rural health technicians as instrumental variable

The second method is to select the number of rural health technicians per 1,000 persons as an instrumental variable for rural infrastructure construction. Its logic lies in that the number of rural health technicians can become a basis for the construction and improvement of rural medical infrastructure, so it will have a positive role in promoting the infrastructure construction in rural areas, but at the same time, the number of rural health technicians is mostly due to healthcare considerations, and is external to the rural economy. Therefore, the number of rural health technicians per 1,000 persons can be used as an instrumental variable for rural infrastructure construction, this endogenous variable. The regression results of the two-stage least square method are listed in Table 9.

Firstly, the weak instrumental variable test is carried out on the number of rural health technicians Sanit, this instrumental variable. It can be seen that in the first stage of the three regression results, the F value was all greater than 10, indicating that the instrumental variable Sanit has passed the weak instrumental variable test. At the same time, there is a significant positive relationship between the

TABLE 9 Test results of explanatory variable of rural health technicians as instrumental variable.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	1st stage	2nd stage	1st stage	2nd stage	1st stage	2nd stage
	Infra	Econ	Infra	Gov	Infra	Econ
Sanit	0.111***		0.111***		0.079***	
	(0.003)		(0.003)		(0.003)	
Infra		8.889***		2.293***		8.191***
		(0.193)		(0.082)		(0.292)
Gov					0.129***	0.305***
					(0.007)	(0.071)
F test	31706.12		31706.12		33253.95	
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.007	−0.095	0.007	−0.012	0.006	−0.091
	(0.041)	(0.281)	(0.041)	(0.120)	(0.038)	(0.261)
Observations	2,526	2,526	2,526	2,526	2,526	2,526
R-squared	0.992	0.996	0.992	0.989	0.993	0.997

Notes: Values in parentheses are robust standard errors; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. Authors' calculations are based on Stata 17.

instrumental variable Sanit and the explanatory variable Infra. In the second stage test, it can be seen that there is a significant positive relationship between the explanatory variable Infra and the explained variable Econ in column (2), and the regression coefficient of Infra in column (4) is still significantly positive, indicating a significant positive relationship between the explanatory variable Infra and the mediator variable Gov. In column (6), the coefficient of explanatory variable Infra and the coefficient of mediator variable Gov are significantly positive, indicating that rural living environment governance plays a mediation role between rural infrastructure construction and rural economic development, and rural infrastructure construction can improve rural living environment governance, then promote rural economic development when the number of rural health technicians is used as an instrumental variable. All these prove Hypothesis 1 and Hypothesis 2 are valid again.

5.4 Mechanism effect test

In order to further investigate the impact of rural infrastructure construction on economic development through living environment governance, this part adopts three methods to test the mechanism effect. They are test for different components of explanatory variables, Sobel-Goodman mediation effect test and Bootstrap mediation effect test.

5.4.1 Test for different components of explanatory variable

The first method is taking the regression of living environment governance to rural infrastructure construction in Table 6 as reference, and to selecting six indicators that constitute explanatory variables, namely, cable TV coverage (TV), proportion of administrative villages with Internet broadband service (Web), number of rural cultural stations (Cult), penetration rate of safe drinking water (Water), village road hardening rate (Road) and road area per capita (Roadarea). The mediation role of rural living environment governance is examined, and the regression results are (1)–(6) in Table 10. It can be seen that infrastructure construction can significantly improve rural living environment, in which road area per capita has the greatest impact on living environment governance, followed by number of rural cultural stations and cable TV coverage. The proportion of administrative villages with Internet broadband services, the village road hardening rate and penetration rate of safe drinking water rank third to sixth. The six aspects have a significant impact on living environment governance. Rural living conditions can be improved by increasing road area per capita and the number of cultural centers, improving Cable TV coverage and Internet infrastructure, and strengthening village road hardening and access to safe drinking water.

Therefore, whether it is rural infrastructure construction, the comprehensive variable in the full sample, or the index variable cable TV coverage, proportion of administrative villages with Internet broadband service, number of rural cultural stations, penetration rate of safe drinking water, village road hardening rate and road area per capita, these components of explanatory variable, all can have a significant impact on the improvement of rural living environment, and the mediation of rural living environment governance is significant. It further confirms Hypothesis 2.

TABLE 10 Test results of different components of explanatory variables.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Gov	Gov	Gov	Gov	Gov	Gov
TV	0.154***					
	(0.014)					
Web		0.151***				
		(0.014)				
Cult			0.156***			
			(0.013)			
Water				0.119***		
				(0.015)		
Road					0.135***	
					(0.016)	
Roadarea						0.194***
						(0.012)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.668***	0.732***	0.709***	0.779***	0.690***	0.470***
	(0.133)	(0.129)	(0.134)	(0.134)	(0.134)	(0.127)
Observations	2,526	2,526	2,526	2,526	2,526	2,526
R-squared	0.749	0.748	0.753	0.741	0.744	0.768

Notes: Values in parentheses are robust standard errors; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. Authors' calculations are based on Stata 17.

5.4.2 Sobel-Goodman mediation effect test

Next, the method of Sobel, M.E. (1990) is adopted to analyze the mediation effect of rural living environment governance, and the regression results are shown in Table 11. When the Sobel-Goodman mediation effect test is carried out, in column (1)–(3) the regression coefficients of rural economic development to rural infrastructure construction, rural living environment governance to rural infrastructure construction, and rural economic development to rural infrastructure construction and rural living environment governance are significantly positive. Moreover, the *p*-value of both the Sobel test and the Goodman test is less than 0.05, indicating that rural infrastructure construction affects rural economic development through rural living environment governance, and there is a mediation effect in rural living environment governance, therefore, it is once again confirmed that Hypothesis 2 is true.

5.4.3 Bootstrap mediation effect test

In addition, to further test the mediation effect of rural living environment governance between rural infrastructure construction and rural economic development, Bootstrap method of Bradley Efron (1979) is selected to sample 1000 times. The results in Table12 show that the confidence intervals for both indirect effect and direct effect do not contain 0, indicating that rural infrastructure construction can affect rural economic development through rural living environment governance, and rural living environment governance has a mediation effect, therefore, Hypothesis 2 is still valid.

5.5 Robustness test

Three methods are used to test the robustness of the baseline regression results. They are subinterval robustness test, robustness test for principal component analysis of explanatory variables, robustness test of explanatory variable tail-shrinkage regression. After testing, the results of baseline regression and regional heterogeneity regression are robust.

5.5.1 Subinterval robustness test

The first method is to divide the observation interval of the sample into two sub-intervals from 2017 to 2019 and 2020 to 2022, and regress the rural economic development to infrastructure construction, rural living environment governance to infrastructure construction, rural economic development to infrastructure construction and living environment governance in the two intervals, and obtain the following results in Table 13, which further prove the conclusion that rural infrastructure improvement

TABLE 11 Sobel-Goodman mediation effect test.

Variables	(1)	(2)	(3)
	Econ	Gov	Econ
Infra	5.822***	1.451***	4.194***
	(0.093)	(0.044)	(0.094)
Gov			1.122***
			(0.035)
Constant	0.049	0.033	0.013
	(0.235)	(0.112)	(0.199)
Observations	2,526	2,526	2,526
Adj-R2	0.997	0.991	0.998
Sobel-Z			22.81
p			0.000
Goodman1-Z			22.80
p			0.000
Goodman2-Z			22.81
p			0.000
Effect share			0.280

Notes: Values in parentheses are robust standard errors; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. "Yes" indicates that the variable is controlled in the model; the same applies to tables below. Authors' calculations are based on Stata 17.

TABLE 12 Bootstrap test of mediation effect.

Routes	Coef	S.E.	Z	P>|z|	95%CI
Direct effect	1.628	0.082	19.77	0.000	[1.466, 1.789]
Indirect effect	4.194	0.102	41.24	0.000	[3.995, 4.393]

Note: Authors' calculations are based on Stata 17.

promotes rural economic development through living environment governance is robust.

5.5.2 Robustness test for principal component analysis of explanatory variable

The second method is to use principal component analysis to replace explanatory variables. Specifically, the principal component analysis is conducted on the six second-level indicators of the explanatory variable rural infrastructure construction (i.e., cable TV coverage, proportion of administrative villages with Internet broadband service, number of rural cultural stations, penetration rate of safe drinking water, village road hardening rate and road area per capita), and the three principal components F1, F2 and F3 are obtained. A new explanatory variable of rural infrastructure, Infra_z, is obtained, and the specific weight is reshown in Table 14. Rural economic development to infrastructure construction (after principal component analysis), rural living environment governance to infrastructure construction (after principal component analysis), rural economic development to infrastructure construction (after principal component analysis) and living environment governance are regressed in turn. The data of the eastern, central and western regions are processed by the same method, and Results in Supplementary Material is obtained. It can be seen that all regression coefficients are significantly positive, which further proves the robustness of the research conclusion in this paper.

5.5.3 Robustness test of explanatory variable tail-shrinkage regression

In the third method, 1% tail-shrinkage regression is performed on the explained variable to obtain the new explained variable Econ_w, and the influence of outliers is excluded. Tail-shrinkage processing can effectively eliminate the effect of outliers and increase the precision of regression. The specific regression results are shown in Supplementary Material. It is not difficult to find that after adding control variables, fixing the effect on regions and years, and shrinking the tail, all regression coefficients are still significantly positive, but the coefficients change slightly, which further verify that the H1, H2, and H3 hypotheses are robust.

6 Conclusion and suggestions

This paper selects the rural revitalization data of various prefecture-level cities in China from 2017 to 2022 as research samples, uses the entropy method to build an index measurement system of explained variable, explanatory variable, mediator variable and control variables and utilizes the mediation

TABLE 13 Subinterval robustness test.

Variable	2017–2019			2020–2022		
	(1)	(2)	(3)	(4)	(5)	(6)
	Econ	Gov	Econ	Econ	Gov	Econ
Infra	4.390***	1.109***	3.484***	4.317***	1.046***	3.337***
	(0.180)	(0.097)	(0.165)	(0.186)	(0.102)	(0.187)
Gov			0.817***			0.937***
			(0.059)			(0.074)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Constant	2.118***	0.517**	1.696***	1.971***	0.531***	1.473***
	(0.369)	(0.206)	(0.332)	(0.408)	(0.197)	(0.349)
Observations	1,263	1,263	1,263	1,263	1,263	1,263
R-squared	0.919	0.732	0.935	0.911	0.718	0.931

Notes: Values in parentheses are robust standard errors; ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. Authors' calculations are based on Stata 17.

TABLE 14 Principal component analysis of explanatory variable in full sample.

First-level indicator	Second-level indicator	Component		
		F1	F2	F3
Communication infrastructure	Cable TV coverage (%)	0.168	4.465	2.779
	Proportion of administrative villages with Internet broadband service (%)	0.168	−3.680	2.261
Cultural communication infrastructure	Number of rural cultural stations (Pcs)	0.168	−0.223	0.240
Water supply and drainage infrastructure	Penetration rate of safe drinking water (%)	0.168	0.802	−5.218
Transportation infrastructure	Village road hardening rate (%)	0.168	−1.542	−0.097
	Road area per capita (Square meter)	0.168	0.180	0.036

effect model to study the relationship between rural infrastructure, living environment governance and economic development. After adding agricultural production capacity (Agric), urban-rural economic gap (Urb_rura), farmers' education level (LnEdu) and rural leadership (Leader), the four control variables, regression coefficients of rural economic development to rural infrastructure construction, rural living environment governance and rural infrastructure construction through rural living environment governance are significantly positive. The empirical results show that.

(1) Rural infrastructure construction is conducive to promoting rural economic development.
(2) Living environment governance plays a significant mediation effect between rural infrastructure construction and rural economic development.
(3) The impact of rural infrastructure construction on rural living environment governance and rural economic development presents regional heterogeneity.

The impacts of rural infrastructure construction on local economic development and on local economic development through living environment governance in the eastern and central China is stronger than that in the western China. The conclusion is still robust after the study year is divided into two sub-intervals for robustness test, principal component analysis of explained variable for robustness test, and tail-shrinkage regression of explanatory variables for robustness test.

Based on the above study results, the following suggestions are drawn.

(1) Strengthen the rural infrastructure construction, scientifically formulate rural infrastructure planning, and fully mobilize the driving role of rural infrastructure in rural economic development. First of all, the supply of rural resources should be ensured, especially the supply of water resources should be strengthened, and drinking water and other resource infrastructure should be built. Secondly, the construction of sanitation and environmental infrastructure should be strengthened, the rural health environment should be improved, the protection of rural ecological environment should be promoted,

and sustainable development of rural economy should be enhanced. Thirdly, the construction of scientific, educational, cultural and health facilities in rural areas should be strengthened, the scientific and cultural level of farmers should be improved, and their physique should be enhanced to meet the needs of the local population at a higher level. Finally, the application level of digital technology facilities in rural areas should be improved, the structure of rural facilities should be optimized, and villages and agriculture with science and technology should be revitalized.

(2) Improve the rural living environment, constantly reform the governance of rural living environment through infrastructure construction, and promote local economic development. First of all, the division of rural functional areas should be improved, the structure of rural life should be optimized, the diversification of rural infrastructure construction should be strengthened, and the rural layout should be improved. Secondly, actively layout digital, informatized and networked rural infrastructure construction, enhance the application of rural scientific and technological achievements, realize the diversified participation of farmers, and build digital villages. Thirdly, rural cultural and recreational activities should be enriched, the construction of farmers' spiritual life should be promoted, educational and cultural infrastructure should be built, a good atmosphere for rural spiritual civilization should be created, and the comprehensive strength of rural areas should be enhanced.

(3) Strengthen the construction of infrastructure in rural areas throughout the country, continue to promote the balanced distribution of infrastructure, and narrow the gap between the level of infrastructure construction and regional rural economic development. It is an effective way to solve the problem of unbalanced economic development in rural areas to some extent. The infrastructure construction in the eastern and central region are large in scale and started early, and their positive impacts on the improvement of rural living environment and economic development have been more obvious after improving in a long period. Chinese government should continue to follow up policies, increase the research and development of digital and information-based infrastructure, enhance infrastructure investment in basic functions such as roads and drinking water in western rural areas, strengthen and expand the infrastructure of science, education, culture and health to raise the potential of rural infrastructure to impact economic development in the western region. Meanwhile, it is also imperative to maintain the existing infrastructure in the eastern and central China and supplement the infrastructure shortage in these regions, and promote balanced economic development in rural areas across the country.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1280744/full#supplementary-material

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