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RESEARCH ARTICLE

Study on the Effect of Rural Low Carbon Logistics Industry Development on Rural Economic Growth

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ABSTRACT Development of the rural low-carbon logistics industry has become the main factor affecting the rapid development of China's rural economy. From the perspective of a low-carbon economy, based on the analysis of the development level of rural low-carbon logistics, this study uses the theory and method of spatial measurement to analyze the interactive effect of rural low-carbon logistics development and rural economic construction in 31 provinces of China from 2002 to 2019 and then analyzes the mechanism of different factors on rural economic development. The results show that China's low-carbon rural logistics development provinces have an obvious geographical agglomeration trend. The main distribution characteristics of rural low-carbon logistics development in China's provinces and regions are ''high-high'' clustering and ''low-low'' clustering. Second, there is a long-term and sustainable interaction between the development of China's low-carbon rural logistics industry and rural economic growth. Third, the income of rural residents in the eastern, central, and western regions has an important positive impact on rural economic growth. In the eastern region, financial industry growth has the largest effect on rural economic growth. In the central region, per capita income and education level of farmers have the greatest impact on rural economic growth. In the western region, the increase in income is the most important factor influencing low-carbon logistics in rural economic growth.

INDEX TERMS Rural, low carbon, logistics industry, rural economic.

I. INTRODUCTION

As a link and bridge connecting rural and urban exchanges, rural logistics plays an important role in promoting the rational flow of urban and rural resource elements, promoting rural revitalization, and promoting rural economic growth. As the country pays more attention to rural construction and vigorously develops the ''three rural economy,'' the economic conditions in rural areas are advancing by leaps and bounds, the consumption level of farmers is increasing, and farmers' requirements for consumer services and types of consumption are increasing, Rural logistics continues to develop. Low-carbon logistics are a new concept derived from the theory of a low-carbon economy. It refers to improving resource utilization, reducing energy consumption, maximizing system benefits, and minimizing carbon dioxide emissions through advanced low-carbon technology and logistics management in logistics activities. Under the current trend of vigorously promoting a low-carbon economy and rural revitalization, how the development of the low-carbon rural logistics industry affects the rapid development of the rural economy has become a key research topic. At present, the vigorous development of low-carbon rural logistics'' has been increasingly publicized and advocated. High energy consumption, high pollution, low efficiency, and non-low-carbon phenomena are also negative characteristics

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of many problems in rural logistics that need to be solved urgently. As an important carrier of agricultural production, rural consumption, and farmers' income increases, rural logistics includes many aspects such as the acquisition and allocation of agricultural production materials, the upward movement of agricultural products, the downward movement of urban industrial products, and the recovery and treatment of rural waste.

The sixth assessment report of the United Nations Intergovernmental Panel on Climate Change (IPCC) showed that global greenhouse gas emissions from agricultural and forestry sources account for 23% of the total anthropogenic greenhouse gas emissions. China is a large, agricultural country. In 2014, greenhouse gas emissions from agricultural activities amounted to 830 million tons of carbon dioxide (CO^2), becoming the third largest source of greenhouse gas emissions after energy and industrial production activities [1].

The Action Plan for Carbon Peak before 2030 clearly proposes implementing carbon peak action for urban and rural construction, accelerating green and low-carbon development of urban and rural construction, implementing green and low-carbon requirements for urban renewal and rural revitalization, and promoting low-carbon transformation of rural construction and energy use [2]. In the early stages of the development of modern rural logistics in China, the sustainable development and environmental problems of rural logistics were ignored, and fuel machinery was used excessively to exchange for the development of the rural economy at the cost of the deterioration of the living environment. With the continuous improvement in people's living standards, the requirements for the ecological environment are also increasing. Rural logistics development must be guided by the concept of a low-carbon economy. Simultaneously, the introduction of a low-carbon economy into the development of rural logistics is the appeal of people's healthy lives and the inevitable requirement of China's rural economic development [3].

Modern rural logistics has become a new profit growth point driving the development of China's rural economy and has made an important contribution to promoting its development of rural economy [4]. Logistics is an economic activity that overcomes the time and space gap, connects the main body of supply and demand, and creates time and space values. Logistics has mobility in space and a strong interrelation between regions. It is urgent to reveal the spatial patterns and dynamic evolution of low-carbon rural logistics using the theory and method of spatial econometrics. Therefore, this study uses the theory and method of Spatial Econometrics to explore the impact of low-carbon rural logistics on the rural economy, which supplements the blank of relevant research on low-carbon logistics and provides useful support for the development of rural logistics and rural economic revitalization.

The study was divided into six parts. The second part is related to work. The third part is the research method and data sources. The fourth part is the research results. The fifth section presents a discussion. The sixth part presents the conclusion and suggestions.

II. RELATIVE WORK

The progress and breakthrough of modern rural logistics is the introduction of the low-carbon concept into relevant research on modern rural logistics. At this stage, research on low-carbon development of rural logistics is gradually increasing. The existing literature mainly focuses on two aspects. One is the research on factors affecting the development of low-carbon rural logistics. Lixiao analyzed the current situation and existing problems of China's rural logistics development from 2002 to 2012, analyzed the impact of China's low-carbon rural logistics development process from economic, infrastructure, and market factors, and proposed countermeasures to promote China's rural logistics development by learning from foreign advanced rural logistics construction experience [5]. Zhao Guanghua and others, by sorting and analyzing the indicator data of the factors affecting the development of rural low-carbon logistics in Zhejiang Province from 2009 to 2015 using the gray correlation analysis method, concluded that the key factors affecting the development of rural logistics in Zhejiang Province are the level of rural logistics infrastructure and rural information level, and the level of rural education development, rural financial development, and government support also have a greater impact. Thus, proposing to strengthen the construction of rural logistics infrastructure to further promote the development of rural logistics in Zhejiang Province, we should improve the construction of rural informatization, strengthen the education of rural labor force, and increase the policy support of the government and financial institutions in rural areas. The second is research on the operation modes of rural logistics [6]. Fuhua et al. analyzed the current situation of rural low-carbon logistics development in Hunan Province through literature statistics and field research and found problems in rural e-commerce and rural logistics in Hunan Province, proposed a coordinated development model of rural e-commerce and rural logistics industry chain integration, and proposed countermeasures and suggestions for the coordinated development of rural e-commerce and rural logistics in Hunan Province [7].

At present, the positive promotion relationship between rural logistics and rural economy has been confirmed [8], and some scholars said that "logistics promotes economy" [9]. Rural logistics influence the development of the rural economy based on the rational use of a perfect logistics system, road infrastructure, resource environment, and its own flexibility [10]. The expansion of logistics supply and demand in various regions is conducive to further development of national and regional economies [11]. Although the level of logistics has an impact on economic development, there are large differences between regions [12]. The more developed the economy, the more effective is the logistics infrastructure. On the contrary, the less developed the economy, the more effective the freight turnover [13]. Padeir studied the impact of logistics on economic growth in regions with weak economies [14]. Lingyi and Ying used the grey system model to explore the relationship between modern logistics and the rural economy and found that there is a strong correlation between the two regions along the "the Belt and Road," but the lagging rural logistics level, unreasonable logistics transportation structure, and backward rural delivery routes all have a negative impact on the development of the rural economy [15]. Chenhuan studied the relationship between logistics infrastructure and regional economic growth based on panel data. From the perspective of the relationship between logistics and economic development [16].

Zhiliang, Xiaoying, and Mingfei believed that the development of logistics is conducive to the development of the regional economy and that regional economic development will also promote the development of regional logistics, which has a two-way promoting effect [17], [18], [19]. Juan studied the relationship between agricultural product logistics and rural economic growth, pointed out the problems with agricultural products in China, and proposed corresponding countermeasures [20]. Jingshui and Lei studied the relationship between the development of the logistics industry and economic growth in Zhejiang Province and found a positive relationship between logistics development and economic growth [21], [22]. Yu believes that the fundamental reason why China's rural logistics are in a bottleneck period is the lack of strong financial support [23]. Xiaozhu and Ming believe that the logistics industry can be vigorously developed by virtue of advanced technology, and that the logistics industry in various regions can also be reformed and developed according to local conditions to optimize the rural logistics chain, improve regional economic strength, and improve the consumption level of rural residents [24], [25]. Minahan et al. explored the interaction between urbanization and rural logistics from the perspective of system dynamics and order parameter identification and proved that the improvement of urbanization level is conducive to the further improvement of rural logistics level [26]. Lingyi and Ying used the grey system model to explore the relationship between modern logistics and the rural economy, and found that there is a strong correlation between the two regions along the "the Belt and Road," but the lagging rural logistics level, unreasonable logistics transportation structure, and backward rural delivery routes all have a negative impact on the development of the rural economy [4]. To study how China's logistics model can realize the transformation of modernization, starting with the model of a low-carbon economy and new rural logistics system, Guanxin et al. proposed countermeasures and suggestions for the development of rural logistics from low-carbon [27]. Weiren and Minyu used empirical research to analyze the relationship between agricultural product logistics and rural residents' incomes. It can be seen that China's agricultural product logistics and rural residents' income have a long-term stable relationship, that is, the increase of agricultural product logistics will promote the growth of rural residents' income [28].

In addition, in terms of the latest low-carbon literature research, low-carbon technology innovation of power grids is crucial for power grid enterprises to improve their competitiveness and resource utilization efficiency [29]. Low-carbon technological innovation with the participation of multiple entities [30]. Comprehensive decision-making for low-carbon tourism strategic evaluation [31]. Low-carbon technology investment in wind power development in the power industry [32]. Effect of carbon regulations on supply chains [33]. Intelligent decision-making of low-carbon supply chains [34].

The above literature has conducted a more detailed study of the relationship between rural logistics and the rural economy. However, the development of the logistics industry in a region must consider other regions, which means that other regions have a certain impact on the logistics decision-making of the region or the logistics decision-making of other regions, which can be called the spatial spillover of the logistics industry between regions. Based on the spatial effect relationship between low-carbon logistics and the rural economy, there are few reports in domestic literature. Based on this, this study uses spatial autocorrelation analysis and a spatial constant coefficient regression model to quantitatively analyze the impact of rural low-carbon logistics and economic development, discusses the relationship between rural low-carbon logistics and economic growth, and the development level of rural low-carbon logistics and rural low-carbon logistics infrastructure investment. This study analyzes the reasons for the relationship between low-carbon logistics and economic growth from the external environment of rural low-cost logistics development, with a view to providing policy recommendations for rural economic development from the perspective of low-carbon logistics development.

The existing research provides an important reference for this paper to deeply understand the impact mechanism of rural logistics on the rural economy, but is limited by the research object and method; it still leaves room for this study to deepen. Compared with the existing literature, this paper attempts to make contributions in the following three aspects: First, in terms of research objects, it focuses more on the impact of rural low-carbon logistics on rural economic development. Most existing studies focus on the analysis of the impact of urban low-carbon logistics or a certain area of urban economic development [35], and lack of direct research on low-carbon logistics in rural areas. This paper focuses on the relationship between economic and social development, studies the impact of low-carbon rural logistics on rural economic development, and provides a new perspective for further understanding and deepening the "rural revitalization strategy." Second, in terms of research methods, the spatial econometric model is used to investigate the impact of rural low-carbon logistics on rural economic development, which overcomes the assumptions of data irrelevance and homogeneity in the classical measurement methods and makes the research methods more closer to the objective reality. Third, in terms of research content, it further examines the factors that promote rural economic growth and broadens the research vision of rural economic issues.

III. RESEARCH METHODS AND DATA SOURCES

A. SPATIAL AUTOCORRELATION

Domestic and foreign scholars often use Moran's I to measure spatial correlations. Moran's I is divided into global Moran's I (Global Moran's Index) and local Moran's I (Local Moran's Index) [36], [37]. The global Moran's I is mainly used to test whether the entire space has spatial correlation, while the local Moran's I is based on the condition that the entire research space area has spatial correlation, decomposes the entire research space area into a single small local area for research, analyzes whether there is a correlation between each unit, and measures the size of the correlation [38].

1) THE WHOLE DEPARTMENT OF MORAN'S I

Global Moran's I studies and analyzes the overall economic distribution of the region and judges the correlation and amplitude according to the value of Moran's I and its positive and negative values [39]. The specific calculation method is as follows.

$$\mathrm{Moran'sI} = \frac{\mathrm{n}}{\sum_{\mathrm{i=1}}^{\mathrm{n}}\sum_{\mathrm{j=1}}^{\mathrm{n}}\mathrm{W_{ij}}} \times \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2}$$
$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{1}$$

In equation (1), xi represents the value of the research index of the $\mathrm{i_{th}}$ spatial region, n represents the total number of regional units, and $\mathrm{W_{ij}}$ represents the interrelationship of the studied sample space, that is, the spatial weight matrix.

$$W_{ij} = \begin{cases} 1, & \text{area I and area J are adjacent, } \mathrm{i} = 1, 2, \ldots, n \\ 0, & \text{area I and area J are not adjacent, } j = 1, 2, \ldots, n \end{cases} \tag{2}$$

Moran's I measures whether economic activities have a clustering effect. The clustering effect represents the spatial autocorrelation relationship, and its value is between (-1,1); if Moran's I is greater than 0, it means that there is a positive correlation between spatial samples, and the closer to 1, the greater this positive correlation, indicating that there will be spatial aggregation between adjacent areas of the sample area studied; if the spatial samples studied are independent of each other and there is no correlation, the Moran's I value is close to 0, which means that the spatial distribution characteristics are random, and the value of Moran's I is less than 0, indicating a negative correlation between the spatial samples studied [40], [41]. This study uses the standardized statistic Z to process the calculation of Moran's I exponent [42], which is calculated as:

$$\mathrm{Z}(Moran'sI) = \frac{Moran'sI - E(Moran'sI)}{\sqrt{VAR(Moran'sI)}},$$
$$E(Moran'sI) = -\frac{1}{n-1} \tag{3}$$

In the general result analysis, the normal statistical Z value of Moran's I is greater than the critical value at the 5% level, which indicates that the regional economy under study is spatially positive, and agglomeration effects occur between these regions.

2) LOCAL MORAN'S I

The global Moran's I index was used to evaluate overall spatial correlation. However, considering the local instability, when the global autocorrelation is significant, if you want to carry out more in-depth research, you must carry out local spatial autocorrelation analysis. To reveal the changes in local space and visualize invisible local spatial differences, local autocorrelation analysis must be used to measure the correlation between each region and its surrounding areas and the spatial differences between them. Moran's I scatter plot and local Moran's I index were used to analyze the local part of the study area. The local Moran's I was calculated as follows:

$$\mathrm{I}_i = \frac{n(x_i - \bar{x})}{\sum_{i=1}^{n}(xi - \bar{x})^2} \times \sum_j W_{ij}(x_j - \bar{x}) \tag{4}$$

The local Moran's I index is mainly used to analyze the local spatiality of sample areas in a single space and to analyze the correlation between these single sample spaces. If Moran's I>0, the characteristic values of the single sample area are similar to those of adjacent sample areas and are in the (high-high, low-low) quadrant; If Moran's I<0, the eigenvalue of the single sample area is not similar to that of the ad-jacent sample area, which is in the (high-low, low-high) quadrant [43]. Therefore, the local Moran's I can be used to analyze the correlation and spillover between sample regions. Similar to the global Moran's I, the local Moran's I must be treated with the standardized statistic Z, and the calculation formula of Z is as follows:

$$\mathrm{Z}(Moran'sI) = \frac{Moran'sI - E(Moran'sI)}{\sqrt{VAR(Moran'sI)}} \tag{5}$$

The results of the local Moran's I can be expressed by Moran's scatterplot in this study. The coordinates are divided into four quadrants. The horizontal axis represents the observed values of variables in Moran's I study of spatial econometrics, and the vertical axis represents the spatial lag of vectors in Moran's I study of spatial econometrics [44]. The first quadrant represents (high-high) agglomeration, indicating that the level of the single spatial unit studied and its adjacent spatial units is higher; the second quadrant represents (low-high) agglomeration, indicating that the level of a single spatial unit studied is low, while the level of its adjacent spatial units is high; the third quadrant represents (low-low) agglomeration, indicating that the level of a single spatial unit and its adjacent spatial units is low; and the fourth quadrant represents (high-low) agglomeration, indicating that the level of a single spatial unit studied is high, while the level of its adjacent spatial units is low.

B. REGRESSION MODEL OF CONSTANT SPACE NUMBER

After the global Moran's I test and the local Moran's I test, if it is proven that there is a relationship between the studied sample spatial data, then it is necessary to conduct further analysis, that is, to establish a suitable spatial econometric model. Spatial econometric models can be divided into three basic forms according to the different mechanisms of spatial autocorrelation: spatial lag model (SLM), spatial error model (SEM), and spatial Dubin model (SDM) [45]. Considering the applicable conditions of the three models and the research contents of this paper, this paper focuses on the spatial lag model (SLM) and spatial error model (SEM).

1) SPATIAL LAG MODEL (SLM)

In quantitative spatial analysis, the spatial lag model is mainly used to study the impact of the unit sample area on other sample areas in the entire spatial research area, and to study whether there is a diffusion phenomenon of each research variable in the sample area, that is, the spillover effect [46]. The spatial interaction of regional samples can be studied through the spatial lag of the explained variable, which is the spatial spillover effect in the study of spatial econometrics [47]. For example, the spatial lag model (SLM) in equation (6) adds the product of the studied dependent variable and spatial weight to the equation:

$$\mathrm{Y} = \rho WY + \beta X + \varepsilon\varepsilon \sim \mathrm{N}(0, \sigma^2 I) \tag{6}$$

In Formula (6), Y generally represents the dependent variable in the study of spatial econometrics, and X generally represents the observation matrix of independent variable in the study of spatial econometrics, which is n × The exogenous explanatory variable matrix of k, where n generally represents the number of regions in the study of spatial econometrics, and k generally represents the number of explanatory variables in the study of spatial econometrics; β is an independent variable parameter. In the study of spatial econometrics, the general meaning represents the influence factor of independent variable X on dependent variable Y; WY stands for the weighted average of surrounding dependent variables, which is a spatial lag dependent variable in the research of spatial econometrics; W generally means n × The n-order spatial weight matrix represents the network matrix relationship formed between n sample spaces in the studied sample space in the research of spatial econometrics; ρ In the research of spatial econometrics, it generally represents the spatial autoregressive coefficient ρ The value of will be between (−1,1). In the study of spatial econometrics, it generally indicates the degree and direction of influence between adjacent spatial regions of the studied sample spatial region; ε In the research of spatial econometrics, it generally means independent random error term vector [48].

2) SPATIAL ERROR MODEL (SEM)

In the econometric study of the spatial error model, to study the interaction between spatial sample regions, it is generally carried out through spatial dependency in the disturbance term. Due to the spillover effect of the explained variable, the impact of adjacent spatial sample regions on the sample region was studied. The interaction between sample regions is generally reflected in the error term. This effect is mainly caused by the inconsistency between the division of the studied sample space area and the administrative division boundary on which the data are actually collected, or the imperfection of the collected variables [49]. For example, the spatial error model (SEM) of equation (7) adds the product of residual and spatial weights to the equation:

$$Y = \beta X + \varepsilon(\varepsilon = \lambda W\varepsilon + \mu;\ \mu \sim N(0, \sigma^2 I)) \tag{7}$$

In equation (7): Y, X, n, k, β, ε the meanings of these variables generally represent the same meaning in the model study of spatial econometrics; Wε generally means the spatial hysteresis perturbation term in the study of spatial econometrics; λ generally represents the spatial error autocorrelation coefficient of the cross-sectional dependent variable vector of n × 1 in the study of spatial econometrics, and the value is generally between (−1,1) in the study of spatial econometrics, indicating the influence size and direction of the single sample region of the study on the adjacent sample region [50]; μ in the study of spatial econometrics generally represents the random error term of the normal distribution.

C. DATA SOURCE AND VARIABLE DEFINITION

1) DATA SOURCES

The data selected in this study to build a dynamic econometric model were mainly based on panel data of 31 administrative divisions in China from 2002 to 2019. The data sources are the China Statistical Yearbook disclosed on the official website of the National Bureau of Statistics, China Rural Statistical Yearbook disclosed on the website of provincial statistical bureaus, and local statistical yearbooks and national research website databases for each administrative region [51].

2) VARIABLE DEFINITION

All variables used in the following tests are logarithmic (Ln) variables, to eliminate the impact of heteroscedasticity and reduce the difference between variables.

The definitions of all variables in this study are shown in Table 1. As for the explained variables, this study examines the impact of rural low-carbon logistics on the level of rural economic development. Based on previous studies, we selected the per capita consumption (CPP) of rural residents in China as the dependent variable. The reason for choosing the consumption amount of farmers is that, when reviewing the level of rural economic development, economic growth can often be reflected in the consumption level of residents.

TABLE 1. Variable and definition.

Index	Economic implications	Economic symbols
Rural economic development level	Per capita consumption of rural residents （yuan）	CPP
Low carbon level of rural logistics	Number of employed persons in rural logistics industry （ ten thousand ）	PEIT
	Increase in rural logistics industry （ 100mn ）	ITITS
Investment level of rural low-carbon logistics facilities	Highway mileage （ Ten thousand kilometers ）	HM
	Rural fixed assets investment （100mn ）	INVT
External environment of rural low carbon Logistics	Increase in financial industry （100mn ）	IPP
	Per capita disposable income of rural residents （yuan）	IFS
	Education level of rural residents （%）	EL

As for explanatory variables, considering that this study mainly studies the impact of low-carbon rural logistics on the rural economy, the data selected in this study are all from rural areas. In addition to the limitations of statistical data combined with previous studies, three research perspectives are selected: the development level of rural low-carbon logistics in China's provinces, the investment status of rural low-carbon logistics infrastructure, and the external environment for the development of rural low-carbon logistics.

Development level of low-carbon rural logistics: To measure the development level of low-carbon rural logistics, we need a variety of information. Owing to the limitation of data collection, this study mainly selects two variables to replace them: the number of in-service employees in the rural logistics industry (PEIT) and the increase in the rural logistics industry (ITITS) [52].

Rural low-carbon logistics infrastructure: The length of highway mileage (HM) can, to a certain extent, indicate the traffic conditions in rural areas [53], providing possibilities for rural logistics. Investment in rural fixed assets (INVT) is the premise and foundation for a region to develop rural low-carbon logistics, and the investment in fixed assets can well represent the investment in rural low-carbon logistics in a region.

External environment for the development of rural low-carbon logistics: Many factors affect rural residents per capita consumption level. To minimize the estimation error, this study selects the relevant explanatory variables to measure the level of rural low-carbon logistics and adds a series of other variables that may affect the per capita consumption level of rural residents and the level of rural eco-economic development. Based on previous studies, we selected the rural financial development level IFS, the cultural level EL of rural residents, and the income level IPP of rural residents.

TABLE 2. Descriptive statistics.

Variable	Mean value	Median	Maximum value	Minimum value	Standard eviation
CPP	2.562	2.465	3.852	1.846	0.327
PEIT	1.023	1.015	3.248	0.058	0.435
ITITS	2.357	2.335	3.267	0.602	0.658
HM	0.754	0.856	1.589	0.125	0.405
INVT	3.689	3.528	5.125	1.158	0.756
IPP	3.629	3.526	4.895	2.258	0.314
IFS	2.244	2.223	3.784	0.005	0.765
EL	0.089	0.038	3.856	0.021	0.355

Table 2 presents the descriptive statistics of the variables. As shown in Table 2, the average per capita consumption of rural residents was 2.562, and the standard deviation was 0.327, indicating that although the residential consumption of rural residents has increased, it has not changed much. The average number of employees in the rural logistics industry is 1.023, with a standard deviation of 0.435. The average increase in the rural logistics industry is 2.357, with a standard deviation of 0.658. This shows that the change in the increase in the rural logistics industry is greater than the change in the number of employees in the rural logistics industry, indicating that the rural low-carbon logistics has a great range of development and development space; The average value of rural fixed asset investment is 3.689, and the standard deviation is 0.756, indicating that the amount of rural fixed asset investment has changed greatly in recent years; As for the external environmental factors that affect the development of rural low-carbon logistics, the standard deviation of the increase of the financial industry is 0.765, and the investment of the financial industry in rural low-carbon logistics changes greatly; The average educational level of rural residents is 0.064, the median is 0.029, and the standard deviation is 0.288, indicating that the overall educational level of rural residents has improved to a certain extent, but the overall cultural level is still low.

Table 3 presents the correlation coefficients of the variables. It can be seen from Table 3 that there is a positive correlation between the per capita consumption of rural residents and the number of employees in the rural logistics industry, the increase in the rural low-carbon logistics industry, the mileage of roads, the investment in rural fixed assets, the increase in the financial industry, the per capita disposable income of rural residents, and the cultural level of rural residents, which is significant at the 1% level. Although there is a positive relationship between the education level of rural residents and the number of employees in the rural logistics industry, the correlation is not significant.

TABLE 3. Correlation test among variables.

Variable	CPP	PEIT	ITITS	HM	INVT	IPP	IFS	EL
CPP	1							
PEIT	0.304*** (0.000)	1						
ITITS	0.719*** (0.000)	0.768*** (0.000)	1					
HM	0.346*** (0.000)	0.462*** (0.000)	0.594*** (0.000)	1				
INVT	0.849*** (0.000)	0.621*** (0.000)	0.936*** (0.000)	0.657*** (0.000)	1			
IPP	0.986*** (0.000)	0.293*** (0.000)	0.744*** (0.000)	0.327*** (0.000)	0.855*** (0.000)	1		
IFS	0.775*** (0.000)	0.749*** (0.000)	0.934** (0.000)	0.488*** (0.000)	0.904*** (0.000)	0.775*** (0.000)	1	
EL	0.125*** (0.000)	0.056*** (0.524)	0.115** (0.053)	0.237*** (0.000)	0.105* (0.103)	0.158*** (0.000)	0.145*** (0.000)	1

IV. RESEARCH RESULTS

A. ESTABLISHMENT AND VERIFICATION OF NON SPATIAL PANEL MODEL

1) ESTABLISHMENT OF NON SPATIAL PANEL MODEL

The Panel data model is also called "mixed data." In the research of panel data model, both time-series data and sectional data can be taken into account in the model test. It adds a time series in the spatial direction based on an ordinary data model, or adds a sectional series in the temporal direction. Compared with separate sectional data and time series data models, the estimation results are more comprehensive and comprehensive, and in recent years, scholars at home and abroad in econometrics research prefer to use panel data models. The formula is:

$$Y_{it} = \alpha_{it} + X_{it}\beta_{it} + \varepsilon_{it} \ (i = 1, 2, \ldots, N; t = 1, 2, \ldots, T) \tag{8}$$

Y_{it} in equation (8) is the explained variable, X_{it} is the explanatory variable, i=1, 2,….., N, representing N individuals; t=1, 2, …., T, represents T time points. N in economic research generally represents the number of section members, while T in economic re-search generally represents the total number of observation periods and parameters of each section unit α, which generally represents a constant term in economic research, and β refers to the k $*$ 1 dimensional coefficient vector corresponding to the explanatory variable vector X_{it}. In economic research, k represents the number of explanatory variables. In economics research, the random error items in the panel data model formula should meet the characteristics of mutual independence and also meet the zero mean hypothesis and equal variance hypothesis. In economic research, panel data models and quasi-maximum likelihood estimators, including the number of individuals (N), as well as the size and number of times (T), affect a certain impact on the accuracy of the final estimation results [54].

Based on the above analysis, the non-spatial panel model in this study was constructed as follows:

$$\begin{aligned} \mathrm{CPP_{it}} = \alpha_{it} &+ \beta_1 \ln PEIT_{i,t} + \beta_2 \ln ITITS_{i,t} + \beta_3 \ln HM_{i,t} \\ &+ \beta_4 \ln INVT_{i,t} + \beta_5 \ln IFS_{i,t} + \beta_6 \ln IPP_{i,t} \\ &+ \beta_7 \ln EL_{i,t} + \varepsilon_{it} \end{aligned} \tag{9}$$

Among them, subscript i generally represents the region of meaning expression in economic research, subscript t generally represents the year of meaning expression in economic research, β I In the study of economics, it generally means undetermined coefficient, ε In the study of economics, it generally means the random error term of the model. The consumption level of rural residents CPPit represents the per capita consumption of rural residents in year t in the ith region.

2) CORRELATION TEST

a: UNIT ROOT TEST

In general econometric research, before conducting a regression analysis of panel data models, it is necessary to ensure that the studied panel data is stable. Only by ensuring that the stability of panel data models can be inaccurate and "pseudo regression" phenomena occur in the estimation results. Therefore, the stationarity test, namely the unit root test, should be conducted first in the research. The unit root test of panel data in econometric research includes a homogeneous panel test (same unit root: LLC test) and a heterogeneous panel test (different unit root: IPS test, ADF test, PP Fisher test). The unit root test is conducted for each variable (CPP, HM, INVT, PEIT, ITITS, IPP, IFS, EL) as follows: If the test results show that the variable is stable at a 5% confidence level, then P<5%, and the test statistical value is less than the critical value; On the contrary, the variable is non-stationary, P>5%, and the test statistical value is greater than the critical value. At this time, the variable needs to be further divided into Δ CPP, Δ HM, Δ INVT, Δ PEIT, Δ ITITS, Δ IPP, Δ IFS, Δ EL, check the stability of variables as above; If it is unstable, the second order difference is performed, and the variable becomes ΔΔ CPP, ΔΔ HM, ΔΔ INVT, ΔΔ PEIT, ΔΔ ITITS, ΔΔ IPP, ΔΔ IFS, ΔΔ EL, the inspection process is de-scribed above.

The results of the stationarity tests are presented in Table 4. Most of the first-order test values of the original variables were higher than the critical value when the significance level was set to 5%, which means that these original variables had unit roots. Therefore, the sequences PEIT, ITITS, HM, INVT, IPP, IFS, EL are all unstable sequences; After the first order difference, the sequence Δ CPP, Δ HM, Δ INVT, Δ PEIT, Δ ITITS, Δ IPP, Δ IFS, Δ The test values of EL are also less than the critical value when the significance level is 5%, that is, there is no unit root, so the first-order series are stationary; On the whole, CPP, PEIT, HM, INVT, ITITS, IPP, IFS and EL all passed the test at the 95% confidence level, and the first

TABLE 4. Unit Root Test Results of Each Variable.

Variable	LLC	IPS	ADF	PP	conclusion
Horizontal value					
CPP	-253.522 (0.000)	-176.458 (0.000)	1298.556 (0.000)	1998.274 (0.000)	Stable
PEIT	13.956 (1.000)	11.985 (1.000)	11.325 (1.000)	18.956 (1.000)	Unstable
ITITS	24.568 (1.000)	14.986 (1.000)	0.968 (1.000)	1.562 (1.000)	Unstable
HM	13.997 (1.000)	9.864 (0.888)	3.659 (1.000)	3.987 (1.000)	Unstable
INVT	19.368 (1.000)	14.568 (1.000)	1.623 (1.000)	1.862 (1.000)	Unstable
IPP	101.658 (1.000)	22.125 (1.000)	0.324 (1.000)	1.569 (1.000)	Unstable
IFS	26.754 (1.000)	18.652 (1.000)	0.457 (1.000)	0.521 (1.000)	Unstable
EL	-0.865 (0.165)	-0.425 (0.348)	46.579 (0.841)	45.865 (0.823)	Unstable
1st difference					
ΔCPP	139.125 (1.000)	-19.147 (0.000)	588.954 (0.000)	1132.025 (0.000)	Stable
ΔPEIT	-17.024 (0.000)	-12.548 (0.000)	293.015 (0.000)	364.985 (0.000)	Stable
ΔITITS	-17.598 (0.000)	-11.568 (0.000)	258.657 (0.000)	308.274 (0.000)	Stable
ΔHM	-20.457 (0.000)	-14.258 (0.000)	290.147 (0.000)	310.458 (0.000)	Stable
ΔINVT	-14.236 (0.000)	-13.176 (0.000)	287.689 (0.000)	323.148 (0.000)	Stable
ΔIPP	-9.274 (0.000)	0.897 (0.000)	137.214 (0.000)	298.687 (0.000)	Stable
ΔIFS	-13.567 (0.000)	-5.128 (0.000)	206.127 (0.000)	303.784 (0.000)	Stable
ΔEL	-17.015 (0.000)	-11.965 (0.000)	257.968 (0.000)	302.984 (0.000)	Stable

Note: Δ Indicates the first-order difference of the variable; the value in parentheses is P.

order difference of all variables was stable, indicating that all data sequences were stable.

b: COINTEGRATION TEST

The above stationarity test proved the stationarity of the data. There was also a linear relationship between these data points. This linear relationship reflects the long-term stable equilibrium between variables, which is called the cointegration relationship [55]. The commonly used cointegration test methods in econometric research include the Pedroni, Kao, and Johansen tests, but these three cointegration test methods have different application scopes. When there are only seven or fewer sequences, the Pedroni test is generally used. The Johansen test method requires a large amount of data, but the Johansen test method cannot be used because the amount of data is too small, and the Kao test method is used under strict conditions in econometric research, which requires not only that there are variables with the same coefficient in the model, but also that there is only an individual fixed effect in the model. This study focuses on testing the cointegration relationship between farmers' consumption and the development level of rural low-carbon logistics, the status of rural low-carbon logistics transportation facilities, and the external environment of rural low-carbon logistics development using the Johansen cointegration test and Kao cointegration test. According to the results of the panel data in Table 5, the statistics of the two cointegration tests are $P<0.05$, indicating that there is a significant cointegration relationship between the per capita consumption of rural residents and the development level of rural low-carbon logistics, the investment level of rural low-carbon logistics infrastructure and the external environment for the development of rural low-carbon logistics, that is, the per capita consumption of rural residents and the development level of rural low-carbon logistics There is a long-term stable equilibrium relationship between the investment level of rural low-carbon logistics infrastructure and the external environment of rural low-carbon logistics development, which means that there is a long-term stable equilibrium relationship between the rural economic development and the development level of rural low-carbon logistics, the investment level of rural low-carbon logistics infrastructure and the external environment of rural low-carbon logistics development.

TABLE 5. Cointegration test results of panel data.

Variable	4 intra group statistics		3 intergroup statistics
PEIT、ITITS、CPP			
Kao cointegration test	ADF	-4.848(0.000)	
Johansen Cointegration test	Original hypothesis	Fisher stat Joint trace statistics	Fisher stat union λ-max statistic
	None	304.537(0.000)	210.054(0.000)
	At most 1	158.654(0.000)	94.874(0.000)
	At most 3	118.569(0.000)	118.597(0.000)
HM、INVT、CPP			
Kao cointegration test	ADF	-4.987(0.000)	
Johansen Cointegration test	Original hypothesis	Fisher stat Joint trace statistics	Fisher stat union λ-max statistic
	None	362.874(0.000)	312.985(0.000)
	At most 1	131.425(0.000)	107.867(0.000)
	At most 2	93.987(0.000)	93.979(0.000)
IPP、IFS、EL、CPP			
Kao cointegration test	ADF	-7.148	
Johansen Cointegration test	Original hypothesis	Fisher stat Joint trace statistics	Fisher stat union λ-max statistic
	None	414.211(0.000)	270.689(0.000)
	At most 1	209.054(0.000)	147.021(0.000)
	At most 2	112.587(0.000)	98.896(0.002)

TABLE 6. OLS fixed effect test results.

	test	Statistical value	free degree	P
Hausman test	Random cross section	57.024	7	0.000
Likelihood ratio test	cross section F	20.013	(30,549)	0.000
	cross section Chi-square	432.105	30	0.000
Variable	fixed	random	P	Significance
PEIT	0.029	-0.021	0.000	Yes
ITITS	0.049	0.020	0.000	Yes
HM	0.091	0.051	0.014	Yes
INVT	0.042	0.039	0.000	Yes
IPP	0.185	0.134	0.029	Yes
IFS	0.568	0.698	0.000	Yes
EL	0.028	0.019	0.031	Yes

c: FIXED EFFECT TEST

This study adopts provincial and time-series panel data. Generally, there are three types of panel data: random effects model (RE), fixed effects model (FE), and mixed effects. Therefore, the type of panel data should be determined before the empirical analysis. In the research of spatial econometrics, the random effect model is generally regarded as the original hypothesis of the Hausman test, and there is no relationship between the regression variables of the random effect model and individual effects in the research. Table 6 presents the test results for the fixed effects. It can be seen from Table 6 that Hausman has a large value, and its corresponding P=0<0.05; therefore, a fixed effects model should be established at this time. The likelihood ratio test was conducted to verify the accuracy of the Hausman test. The corresponding P=0<5% indicates that the original hypothesis should be rejected, and a fixed-effect model should be established. Combining the results of the Hausman test and the likelihood ratio test, the fixed effects model was selected for this study.

d: OLS INSPECTION

Table 7 presents the ordinary least squares (OLS) regression results. First of all, the Adj-R2 value is 0.892, which indicates that vigorously developing rural low-carbon logistics can stimulate employment and promote the development of rural economic level and farmers' consumption level; In addition, the increase of rural logistics employment can promote the rural economy; The increase of rural logistics can also promote the rural economy; The improvement of infra-structure construction required for rural logistics development also plays a positive role in promoting the development of rural logistics economy, and the perfect external environment required for rural logistics development will also promote the improvement of rural logistics economy.

TABLE 7. OLS Test Results.

Variable	Regression coefficient	Standard eviation	T Value	P Value	Significance
PEIT	0.029	0.017	1.652	0.111	Yes
ITITS	0.049	0.025	2.301	0.031	Yes
HM	0.091	0.031	3.324	0.002	Yes
INVT	0.042	0.017	2.615	0.011	Yes
IPP	0.185	0.023	8.548	0.000	Yes
IFS	0.568	0.045	12.905	0.000	Yes
EL	0.028	0.018	0.604	0.024	Yes
Const	0.892	0.102	8.957	0.000	Yes

B. ESTABLISHMENT AND VERIFICATION OF NON SPATIAL PANEL MODEL

When adding the spatial weight matrix in metrological research, this study refers to the methods commonly used in academia and adopts the geographical adjacency method. If two regions are adjacent to a geographical location, it is defined as 1; otherwise, it is defined as 0. Consider Beijing as an example: Beijing is numbered 1, Beijing is adjacent to Tianjin is numbered 2, and Hebei is numbered 3.

On this basis, Table 8 shows the overall Moran's I, from which it can be seen that the increase in rural low-carbon logistics has a positive correlation with spatial information from 2002 to 2019, and the Moran's I has increased over time, and has declined in the last two years, indicating that the spatial spillover effect of the increase in rural low-carbon logistics in China's provinces has weakened. The consumption level of rural residents had a positive correlation with spatial information from 2002 to 2019. As time goes on, the Moran index of the rural logistics economy has shown a downward trend, rising in the last two years, indicating that the provincial spatial spillover effect of rural residents' consumption level in various provinces in China has been declining in the past decade and has risen in recent years.

Local Moran's I can be used to analyze the spatial agglomeration of a single sample space based on the global Moran's I. To further study the distribution of rural logistics in various provinces in China, as shown in Figure 1, the local Moran's I value is marked on the map of China, which makes it more intuitive to see the spatial correlation of provincial low-carbon rural logistics in China. It can be seen from Figure 1 that the increase of China's rural low-carbon logistics industry is in the spatial structure of local agglomeration. In Moran's I analysis of spatial econometrics, low-carbon logistics in rural areas of most provinces in China does not have obvious spatial correlation, but it should also be noted that Qinghai and Tibet in the western regions of China belong to Low-Low agglomeration through Moran's I analysis of spatial econometrics, Beijing, Shanxi, Jiangsu and Shandong in the east belong to High-High cluster.

It can be seen from Table 8 and Figure 1 that, although the increase in China's rural low-carbon logistics industry from 2002 to 2019 shows significant global autocorrelation,

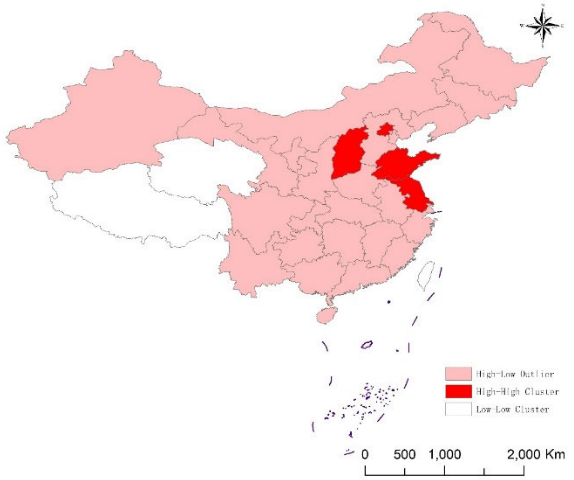

FIGURE 1. Spatial Distribution of LISA in 2019.

Figure 1 shows that there is no significant local correlation between the increase in the rural low-carbon logistics industry in most provinces of China. This is mainly because our country has a large land area, different landforms and living environments, and diversified spatial results, which makes the local relevance of rural low-carbon logistics development only exist in a few areas. The development of rural low-carbon logistics in China's provinces and regions is mainly distributed in (high-high) and (low-low), which shows that the provinces of rural low-carbon logistics development have an obvious cluster trend in geography, and regions with higher rural low-carbon logistics development level are surrounded by regions with higher rural low-carbon logistics development level, At the same time, regions with low rural low-carbon logistics development level are surrounded by regions with low rural low-carbon logistics development level. The global Moran's I and local Moran's I analyses of spatial econometrics prove that there is spatial autocorrelation between the development level of rural low-carbon logistics and rural residents' consumption in China. Therefore, this study established a spatial econometric model.

C. ESTABLISHMENT AND VERIFICATION OF SPACE PANEL MODEL

1) LM INSPECTION

OLS generally does not consider the spatial effect in the study, which leads to deviations in model estimation. The estimation results and inferences are not sufficiently scientific or convincing. To avoid this error, this study adds a spatial panel model. However, in this study, it is impossible to directly judge whether there is spatial dependency in the spatial panel model; therefore, it is necessary to establish a recognition standard [90] to judge whether the selected spatial panel model is appropriate. To judge whether to choose the spatial lag model (SLM) or spatial error model (SEM), this study uses the LM test. If only one of the LM Lag and LM Error statistics passes the significance test, the spatial model passing the significance test is adopted; if the results of spatial econometrics research show that both statistics are significant, it is necessary to compare LM Lag and LM Error in the results of spatial econometrics research. Table 9 presents the results of the LM tests. As shown in Table 9, both the LM Lag and LM Error statistics passed the significance test in the results of spatial econometrics research. Therefore, it is impossible to directly judge which model to choose in spatial econometrics research. At this time, which of the two statistics LM Lag and LM Error is more significant, we can see from Table 9 that LM Error is better, and we can see that Robust LM Error is also more significant by comparing the significance of the two statistics in spatial econometrics. Therefore, in the research of spatial econometrics, through the above analysis, judgment can be made between the two spatial models. This study was more suitable for a spatial error model (SEM).

2) SPACE PANEL MODEL INSPECTION

According to the above test results, we can draw a conclusion by comparing the results of the spatial econometrics. In the comparative analysis of the two spatial models, this study selected a spatial error model in the research of spatial

TABLE 8. Global Moran's I.

Time (year)	ITITS			Time (year)	CPP		
	Moran's I	mean value	Standard eviation		Moran's I	mean value	Standard eviation
2002	0.3135	2.0589	0.4597	2002	0.2914	3.2184	0.1664
2003	0.3102	2.1203	0.4635	2003	0.2597	3.2264	0.1634
2004	0.3107	2.1648	0.4486	2004	0.2796	3.2171	0.1671
2005	0.2997	2.2309	0.5021	2005	0.2636	3.2468	0.1672
2006	0.3315	2.3591	0.4251	2006	0.2591	3.2715	0.1739
2007	0.3102	2.2894	0.4015	2007	0.2721	3.2968	0.1832
2008	0.3205	2.1598	0.4287	2008	0.2719	3.3262	0.1831
2009	0.2989	2.0985	0.4356	2009	0.2749	3.3441	0.1741
2010	0.3125	2.1548	0.4789	2010	0.2435	3.4325	0.1669
2011	0.3205	2.3258	0.4467	2011	0.2891	3.4736	0.1665
2012	0.3096	2.2568	0.4502	2012	0.2103	3.5601	0.2741
2013	0.2989	2.3107	0.4538	2013	0.2224	3.5843	0.1608
2014	0.3104	2.2354	0.4414	2014	0.2224	3.6203	0.1631
2015	0.3146	2.3158	0.4513	2015	0.2231	3.6769	0.1572
2016	0.3157	2.2576	0.4325	2016	0.2481	3.7586	0.1531
2017	0.3158	2.2634	0.4564	2017	0.2004	3.8134	0.1476
2018	0.3205	2.3157	0.4954	2018	0.3371	3.8894	0.1356
2019	0.3089	2.2816	0.4998	2019	0.3294	3.9365	0.2514
mean value	0.3218	2.2763	0.4564	mean value	0.2467	3.5189	0.1705

TABLE 9. Spatial autocorrelation test.

Test	Statistical value	P Value
LM test no spatial lag	3.274	0.062
Robust LM test no spatial lag	1.784	0.184
LM test no spatial error	3.425	0.074
Robust LM test no spatial error	12.865	0.000

econometrics. The specific space panel model is as follows.

$$\begin{aligned} \text{CPPit} = {} & \beta 0 + \beta 1\text{lnPEIT1, i, t} + \beta 2\text{lnITITS2, i, t} \\ & + \beta 3\text{lnHM3, i, t} + \beta 4\text{lnINVT4, i, t} \\ & + \beta 5\text{lnIFS5, i, t} + \beta 6\text{lnIPP6, i, t} \\ & + \beta\alpha 7\text{lnEL7, i, t} + \text{Wij} + \varepsilon\text{it} \end{aligned} \tag{10}$$

In equation (10), W_{ij} is a spatial weight matrix that needs to be set according to different situations. Each province is adjacent to each other, taking the value 1, and each province is not adjacent to each other, taking the value 0. Table 10 presents the maximum likelihood estimation results of the SEM model. As shown in Table 10, the values of Adj-R2 in the test results of the three SEM effects are greater than the values of Adj-R2 in the OLS test, indicating that the SEM test results are more reasonable. Based on the analysis of the unfixed SEM test results, there is a positive correlation between farmers' consumption levels and rural logistics economic development levels. For every 1% increase in rural low-carbon logistics employment personnel input, farmers' consumption level will increase by 0.087, and the amount of transportation, warehousing, post, and telecommunications related to low-carbon logistics has also increased by 0.068 for every 1% increase, and there is a positive correlation between the investment level of rural low-carbon logistics infrastructure and the development level of the rural low-carbon logistics economy. Every 1% increase in road mileage in rural areas can increase farmers' consumption level by 0.134; for every 1% increase in social fixed asset investment in rural low-carbon logistics, the development level of the rural low-carbon logistics economy will increase by 0.062; at the same time, the impact coefficient of rural low-carbon logistics labor input is higher than that of rural low-carbon logistics capital input, which indicates that rural low-carbon logistics labor input is more important than capital input in order to improve farmers' consumption levels from 2002 to 2019, and the improvement of the external environment required for the development of rural low-carbon logistics is also positively related to the development level of the rural low-carbon logistics economy. For every 1% in-crease in the financial industry, the development level of rural low-carbon logistics economy will increase by 0.236; For every 1% increase in per capita disposable in-come of rural residents, the development level of rural low-carbon logistics economy will increase by 0.748; The improvement of education level is conducive to the development of low-carbon logistics in rural areas. The education level of farmers will increase by 1%, and the consumption level of farmers will increase by 0.135, owing to the development of low-carbon logistics. In the research results of spatial econometrics, it was found that the model estimation results of spatial fixed effects, double fixed effects, and non-fixed effects are basically the same. Among the relevant factors that impact rural low-carbon logistics and farmers' consumption, these factors have a positive pull effect on farmers' consumption levels. In the estimation result of the spatial fixed effect, the improvement of the rural low-carbon logistics development level has a positive pull effect on the improvement of farmers' consumption level, and the increase in employment, transportation, post, and telecommunications also has a positive pull effect on farmers' consumption, reaching 0.063 and 0.081, respectively. The input level of farmers' low-carbon logistics infrastructure also has a positive impact on their consumption. For every 1% increase in highway mileage and social fixed asset investment, the pulling effects on farmers' consumption levels are 0.201 and 0.021, respectively. The external environment required for farmers' low-carbon logistics development also has a positive impact on farmers' consumption. The growth of rural residents' per capita disposable income has the largest pulling effect on the increase in farmers' consumption level, reaching 0.406; an increase in the financial industry by 1% can stimulate the growth of farmers' consumption by 0.281, and the stimulating effect of education level on farmers' consumption is 0.034. In the estimation results of the dual fixed effects of space and time, the improvement in the development level of rural low-carbon logistics has a positive pull effect on the improvement of farmers' consumption level, and the increase in employment, transportation, and post-and telecommunications also have a positive effect on farmers' consumption of 0.004 and 0.044, respectively. The input level of farmers' low-carbon logistics infrastructure also has a positive impact on their consumption. Every 1% increase in highway mileage and social fixed asset investment has a pulling effect on farmers' consumption levels of 0.071 and 0.008, respectively. The external environment required for the development of low-carbon logistics for farmers also has a positive impact on farmers' consumption. The growth in per capita disposable income of rural residents has a pulling effect on the increase in farmers' consumption level of 0.069, while an increase of 1% in the financial industry can stimulate the growth of farmers' consumption by 0.112, and the stimulating effect of education level on farmers' consumption is 0.027.

V. DISCUSSION

This study analyzes the development of rural low-carbon logistics in China as well as the correlation between the development of rural low-carbon logistics in various provinces. To further study, this paper divides 31 administrative regions into eastern, central, and western regions according to the traditional method of economic belt division in China. The specific divisions are listed in the following table 11:

Table 12 shows the estimation results of the SEM models for the east, central, and west regions. It can be seen that the Adj-R2 in the west is higher than that in the central region, and that in the central region is higher than that in the east. In other words, among the driving effects of developing rural low-carbon logistics on farmers' consumption levels, the improvement of farmers' consumption in the west is most affected by the development of low-carbon logistics, and the improvement of farmers' consumption in the central region is less affected by the development of low-carbon logistics than that in the west; however, the impact is higher than

TABLE 10. Maximum Likelihood Estimation Results of SEM Model.

Model	OLS	SEM		
		No fixed effect	Spatial fixation effect	Double fixation effect
PEIT	0.035 (0.1081)	0.087*** (0.000)	0.063*** (0.000)	0.004*** (0.846)
ITITS	0.053** (0.026)	0.068*** (0.010)	0.081*** (0.000)	0.044* (0.077)
HM	0.091*** (0.001)	0.134*** (0.000)	0.201*** (0.000)	0.071 (0.258)
INVT	0.038** (0.010)	0.062*** (0.000)	0.021*** (0.251)	0.008 (0.444)
IFS	0.174*** (0.000)	0.236*** (0.000)	0.281*** (0.000)	0.112*** (0.000)
IPP	0.541*** (0.000)	0.748*** (0.000)	0.406*** (0.000)	0.069*** (0.003)
EL	0.007 (0.580)	0.135*** (0.000)	0.034*** (0.000)	0.027*** (0.009)
Const	0.847*** (0.000)	0.743*** (0.000)		
$Adj\text{-}R^2$ Log-likelihood	0.861	0.901 432.165	0.903 660.025	0.905 884.134

Note: *, * *, * * * are significant at the 10%, 5%, and 1% levels, respectively, and the values in brackets are P values.

TABLE 11. National Regional Division.

Area	Province
East	Beijing 1、Tianjin 2、Hebei 3、Liaoning 6、Shanghai9、Jiangsu 10、Zhejiang 11、Fujian 13、Shandong 15、Guangdong 19、Hainan 21
Central	Shanxi 4、Jilin 7、Heilongjiang 8、Anhui 12、Jiangxi 14、Henan 16、Hubei 17、Hunan 18
West	Neimenggu 5、Guangxi 20、Chongqing 22、Sichuan23、Guizhou24、Yunnan 25、Xizang 26、Shanxi 27、Gansu 28、Qinghai 29、Ningxia 30、Xinjiang 31

that of the eastern region. Due to the reform and opening-up policy, the eastern region, especially the coastal areas, has a higher level of economic development, and–n the rural integration has developed earlier. The consumption strength of farmers has improved to a certain extent, and low-carbon logistics have been developed. Therefore, the pulling effect of developing low-carbon logistics on farmers' consumption is not as obvious as that in the central and western regions. The same part of the results of this study in the eastern, central, and western regions is that the income of rural residents in these three regions has an important positive impact on the improvement of farmers' consumption levels. In contrast to the eastern region, the improvement of education level in the central and western regions has a huge impact on low-carbon logistics and farmers' consumption, while the impact of education on farmers' consumption in the eastern region is relatively small, mainly because the eastern region has a relatively high level of education and basically achieved high school education, but the central and western regions of China have not yet achieved full high school education, so the education level needs to be improved.

Among the factors that impact low-carbon logistics and farmers' consumption, these factors have a positive pull effect on the eastern region. For the eastern region, the improvement of the external environment required for the development of low-carbon logistics has the most obvious pulling effect on farmers' consumption level: the increase in the financial industry has the largest pulling effect on the increase in farmers' consumption level, which can stimulate the growth of farmers' consumption by 0.531. The growth of per capita disposable income of rural residents has driven the increase in farmers' consumption level to 0.528, which is in line with the actual economic situation, and the improvement in rural logistics development level has a positive pull effect on the improvement of farmers' consumption level. The increase in employment, transportation, and post-and telecommunications also has a positive effect on farmers' consumption of 0.192 and 0.394, respectively, and the investment level of low-carbon logistics infrastructure also has a positive impact on farmers' consumption. However, because the infrastructure related to low-carbon logistics in the eastern region itself has been relatively complete, the increase in infrastructure has little effect on the improvement in farmers' consumption level.

The research results for the central region are the same as those for the eastern region. Among the relevant factors that have an impact on low-carbon logistics and farmers' consumption, influencing factors have a positive pull effect in the western region. The per capita income level and education level of farmers have the greatest impact on their consumption level. The per capita disposable income of rural residents increased by 1%, consumption level of farmers increased by 0.724, education level income increased by 1%, and consumption level of farmers increased by 0.781. An increase of 1% in the financial industry can stimulate the growth of farmers' consumption by 0.092, and the improvement in low-carbon logistics development level has a positive pull effect on the improvement in farmers' consumption level. The increase in employment, transportation, and post-and telecommunications also have a positive effect on farmers' consumption of 0.016 and 0.162, respectively. The level of farmers' logistics infrastructure investment has a positive impact on their consumption. Highway mileage and social fixed asset investment increased by 1%, and the pulling effect on farmers' consumption levels was 0.043 and 0.011, respectively.

The estimation results for the western region are the same as those for the eastern region. Among the factors that have an impact on rural logistics and farmers' consumption, these factors have a positive pull effect in the western region. For the western region, the improvement of the external

TABLE 12. SEM Model Estimation Results in the East, Central and West of China.

Model	EAST	CENTRAL	WEST
PEIT	0.192*** (0.000)	0.016*** (0.000)	0.019*** (0.000)
ITITS	0.394*** (0.000)	0.162*** (0.000)	0.051*** (0.000)
HM	0.228*** (0.000)	0.043*** (0.000)	0.021*** (0.000)
INVT	0.052* (0.000)	0.011* (0.000)	0.002* (0.000)
IFS	0.531*** (0.000)	0.092*** (0.000)	0.015*** (0.000)
IPP	0.528*** (0.000)	0.724*** (0.000)	0.995*** (0.000)
EL	0.274*** (0.000)	0.781*** (0.000)	0.461*** (0.000)
Adj-R^2	0.894	0.897	0.898
Log-likehood	236.654	253.587	281.964
spat.aut.	0.0471	0.105	0.135

environment required for the development of rural logistics has a huge role in promoting the improvement of farmers' consumption levels; among them, the increase in income is the most important factor. The growth of per capita disposable income of rural residents has a very obvious pulling effect on the increase in farmers' consumption level, reaching 0.995, indicating that the overall income level of farmers in the western region is relatively low and needs to be improved urgently. The level of education is also an important factor hindering the development of the western region. Every 1% increase in the proportion of senior high school graduates can pull the consumption level of farmers to 0.461, which fully demonstrates that the educational resources in the western region of China are backward and the overall level of education is low, so the government needs to increase investment in education to improve the overall level of education. An increase in the financial industry by 1% can stimulate the growth of farmers' consumption by 0.015, and the improvement in rural logistics development level has a positive pull effect on the improvement of farmers' consumption level. The increase in employment, transportation, and post and telecommunications also has a positive effect on farmers' consumption of 0.019 and 0.051, respectively. The level of farmers' logistics infrastructure investment also has a positive impact on farmers' consumption, and the highway mileage and social fixed asset investment did not increase by 1%. The pulling effects on farmers' consumption levels are 0.021 and 0.002, respectively.

VI. CONCLUSION AND SUGGESTION

A. CONCLUSION

This study selected seven indicators to represent the development level of the rural low-carbon logistics industry from three research perspectives: the development level of rural low-carbon logistics, the investment status of rural low-carbon logistics infrastructure, and the external environment of rural low-carbon logistics development. The per capita consumption of rural residents was selected to represent the level of rural economic growth. Using quantitative methods such as the global Moran's I test, local Moran's I test, SEM model test, and analysis, this study examines the interaction effect between the development of the rural low-carbon logistics industry and rural economic construction in 31 provinces from 2002 to 2019. The main conclusions of this study are as follows:

First, the test results of the global Moran's I and local Moran's I show that there is spatial autocorrelation between the development level of China's rural low-carbon logistics and rural economic growth. The main distribution characteristics of rural low-carbon logistics development in China's provinces and regions are "high-high" agglomeration and "low-low" agglomeration. This shows that the province of rural low-carbon logistics development has an evident geographical cluster trend.

Second, the SEM test results show that the income of rural residents in the eastern, central, and western regions has an important positive impact on the improvement of rural economic growth. In the eastern region, the increase in the financial industry has the largest pulling effect on rural economic growth. In the central region, farmers' per capita income and educational level had the largest impact on rural economic growth. In the western region, an increase in income is the most important factor influencing low-carbon logistics in rural economic growth.

Finally, there is a long-term and sustainable interaction between the development of China's low-carbon rural logistics industry and rural economic growth. The interaction between the development of a low-carbon logistics industry and economic growth forms a feedback system. The analysis shows a positive pull relationship between rural low-carbon logistics and farmers' consumption in all provinces of China. The development of low-carbon logistics can promote farmers' consumption levels, and the improvement in consumption levels will also promote residents' online shopping demand. The development of low-carbon rural logistics in China's provinces has not been isolated, but there is a positive spillover effect. The coordinated and cooperative development of rural logistics among provinces can achieve the effect of "1+1>2".

B. SUGGESTION

1) STRENGTHEN THE CONSTRUCTION OF RURAL LOGISTICS INFRASTRUCTURE

The state should increase its support for rural logistics and provide policy and financial support for the development of rural logistics and improvement of rural infrastructure construction in rural areas. The condition of the rural logistics infrastructure is an important part of the rural logistics development environment. Improving the construction of rural logistics infrastructure in China can facilitate the outflow of rural agricultural products and inflow of urban consumer goods, stimulate rural market demand, enrich rural market resources, and improve farmers' income and consumption capacity.

2) ESTABLISH RURAL LOGISTICS SERVICE SYSTEM

In the service industry, good service quality can create a good external environment for the development of rural logistics. At the enterprise level, the development of rural logistics enterprises should pursue not only the speed of development, but also the quality of development. Rural logistics enterprises should learn the modern service concept of urban logistics; establish a modern rural logistics service system; establish a modern, intelligent, and efficient rural logistics service system; and improve the quality of rural logistics services.

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