

# Evolution of rural multifunction and its natural and socioeconomic factors in coastal China

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**Abstract:** Rural decline has become a global problem. To address this issue, the division of rural functions and identification of driving factors are important means of rural revitalization. Taking the town area as a unit, this study conducts a division and evolution analysis of rural regional functions in Jiangsu province in coastal China by constructing an evaluation system using the spatial econometric model to diagnose endogenous and exogenous driving factors of rural multifunction formation. The results show that the functions of agricultural supply and ecological conservation have decreased, while the functions of economic development and social security have increased. Agricultural production functions are concentrated in northern and central Jiangsu. The economic development function is mainly based on industrial development, and is the strongest in southern Jiangsu. Social security functions are concentrated in suburban area, county centers, and key towns. High-value areas of ecological conservation are concentrated along lakes, the coast, and hilly areas of southern Jiangsu. The multifunctional development of villages and towns is affected by endogenous and exogenous factors, including economic geographic location, natural resources, economic foundation, human capital, traffic conditions, market demand, infrastructure, and environmental governance. Natural factors have a significant impact on the supply of agricultural products and the formation of ecological conservation functions. The effects of socioeconomic factors on these four functions differ significantly. This study expands the theory of rural development functions, the classification and zoning paradigm, and the quantitative study of driving mechanisms. The results provide a reference for practical value and policy significance for the reconstruction of rural functions and rural revitalization.

**Keywords:** rural multifunction; influencing factors; spatial econometric analysis; coastal China

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## 1 Introduction

Urbanization is accelerating worldwide, and as most countries prioritize cities for economic development, rural decline has become a global problem (Christiaensen *et al.*, 2013; Chen *et al.*, 2014; Liu *et al.*, 2017). As of 2020, China had a rural population of 509.8 million providing agricultural products and services to 902 million urban dwellers (Li *et al.*, 2019). Rural functions gradually extend from the original residence and agricultural production to industrial production, life security, eco-tourism, and other functions (Wilson, 2008; Etxano *et al.*, 2018). The characteristics of rural functional diversification and spatial differentiation are becoming increasingly apparent (Huang *et al.*, 2015; Spataru *et al.*, 2020). An increasing number of studies have focused on multifunctional research in rural areas (van Berkel and Verburg, 2011; Torreggiani *et al.*, 2012; Wilson and Whitehead, 2012). Rural revitalization must rely on the differentiated division and classification of rural areas to formulate development strategies (Zasada, 2011; Zhang *et al.*, 2019).

Western rural geography has long been devoted to rural development theories and has gone through the theoretical discussion stages of rural productivism, agricultural multifunctional (Kaitlyn *et al.*, 2022): rural post-productivism (Murdoch and Pratt, 1993): rural diversification, and the global countryside (Wilson, 2001). This concept also focuses on the theoretical construction and influencing factors of rural development, and explores the path of rural governance and development from the perspective of community management and policy (Murray and Dunn, 1995; Cowling *et al.*, 2008; Renting *et al.*, 2009). Rural regional functions include multiple functions of the agricultural sector, rural landscape (Gulickx *et al.*, 2013): and rural space to provide multiple goods and services for society. Rural functions have become a core theoretical tool in the West to describe the different characteristics of rural areas, explain the process of rural change and development, and support or refute government policies and actions (Ye *et al.*, 2023). In addition, many studies have been conducted on rural types, spatial characteristics of rural functions, the impact of policies on rural functions, and the interaction of rural functions (Holmes, 2006; Bournaris *et al.*, 2014). Evolutionary theory, scenario analysis, and other methods are used to analyze the uncertainty and complexity of rural development paths, along with agricultural policies and rural revival in post-industrial societies and counter-urbanization stages from a functional perspective (Nizam and Tatari, 2020).

At the theoretical level of the influencing factors of rural development, post-war rural development theory has roughly undergone three stages of change: exogenous, endogenous, and comprehensive (Terluin, 2003; Sikorski *et al.*, 2020). Exogenous rural development theory emphasizes the role of external factors in rural development (Ottomano Palmisano *et al.*, 2016). According to endogenous growth theory, rural development is driven by itself and depends more on the orderly development of local resources (Marsden, 2010, Liu *et al.*, 2014). The integrated approach emphasizes the impacts of economic, social, and institutional relationships and internal and external linkages on the process of regional development (Krivokapic-Skoko *et al.*, 2018). At the level of the driving mechanisms of rural functions, some scholars have discussed and verified the mechanisms of regional rural transformation and development from the perspectives of institutional thickness, resource endowment, and the ability of local communities (Siciliano, 2012; Qiao *et al.*, 2016). Other scholars have conducted theoretical and empirical studies from the perspectives of endogeneity, market

regulation, new institutional arrangements, social capital, and novelty, among others (Murdoch, 2000; Li *et al.*, 2016). Geographical location, natural resources and the environment (Aggarwal, 2018; Yang, 2022): infrastructure, employment characteristics, agricultural vitality, entrepreneurship, and bottom-up partnerships have become internal and external factors influencing rural multifunctional development (Tu and Long, 2017; Robinson *et al.*, 2019; Deng *et al.*, 2020).

Many scholars have conducted multifunctional research in rural areas (Fan *et al.*, 2022); however, many gaps in knowledge remain (Long *et al.*, 2011; Martin and Lorenzen, 2016; Pribadi *et al.*, 2017). First, while there are studies on the division of regional functions or multifunctional type identification in terms of economic, agricultural product supply, leisure tourism, ecological, and social functions (Verburg and Chen, 2000): few have considered the functions of grain, aquaculture, and cash crops in detail. Moreover, relevant research on the supporting roles of main and auxiliary functions in regional development is weak. This study can enrich the classification and zoning methods and paradigms of rural functions. Second, there are few quantitative studies on the spatial distribution and evolution of rural regional functions (Jiang *et al.*, 2021). The existing research results lack the research on the evolution of different types of rural functions, especially in developed areas. This study has important theoretical significance for clarifying the evolution law of rural functions in developed regions. Third, in view of the factors influencing the formation of rural functions, research has focused on terrain, cultivated land area, traffic accessibility, and other factors, while neglecting factors such as the distance between rivers and lakes, large farms, domestic sewage and waste treatment rates, and trading market. Without these factors, it is impossible to comprehensively and accurately investigate important long-term rural development (Wang *et al.*, 2021). In addition, China's rural development function follows a unique development path (Gu *et al.*, 2019). Fourth, owing to the limitations of village and town data collection, spatial econometric models are mostly verified based on prefecture-level cities and counties. At smaller spatial scales, the effects of complex village and town regional units have not been verified (Liu *et al.*, 2011). It expands the research on the driving mechanism of explaining the rural development function from the micro-level of the village.

To address these issues, in this study, we consider towns as the basic unit to construct an evaluation index system of rural regional functions. We then explore the differentiation characteristics of rural agricultural product supply, economic development, social security, and ecological conservation functions in Jiangsu province in coastal China from 2005 to 2017. Based on our findings, we propose a primary and secondary classification scheme for the development function of villages and towns in Jiangsu. Using a spatial econometric model, we quantitatively identified the influencing factors and driving mechanisms of rural regional function evolution from the perspective of endogenous driving and endogenous corresponding combinations. The solution of these problems will have important practical value and policy significance for the reconstruction of rural functions and rural revitalization in China in the new era (Tian *et al.*, 2014).

## 2 Study area and data sources

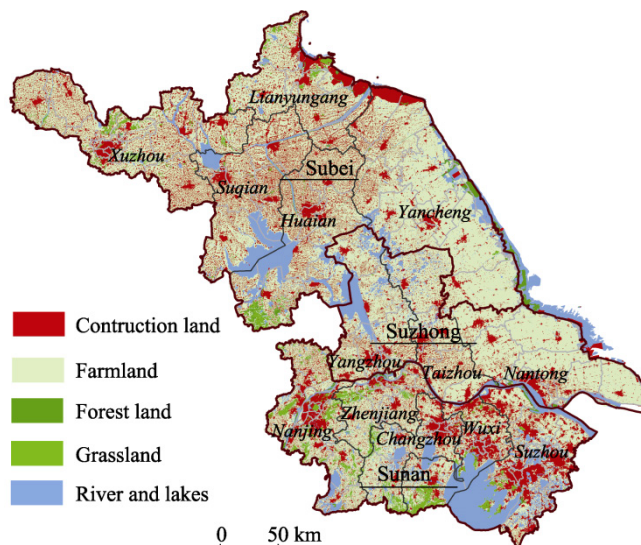
### 2.1 Study area overview

Jiangsu province is located in the center of the coastal areas of China. The terrain is flat and

vast, with good matching of water, soil, gas, biogenic, and other geographical elements. The regional functions of villages and towns in Jiangsu differ from north to south, with industrial development in the south and agricultural production in the north (Figure 1, Zang *et al.*, 2021).

In 2017, the province had a total population of 84.2 million, the urbanization rate was 68.8%, and the regional gross domestic product (GDP) was 8590.09 billion yuan. The ratio of primary, secondary, and tertiary industries was 6.0:53.1:41.0. The per capita disposable income of farmers was 19,100 yuan. The annual output of grain reached 3524 tons, and the ratio was self-sufficient. The transfer ratio of rural contracted land reached 60%, and the comprehensive mechanization level of agriculture reached 83%. The technological and material bases for the development of agricultural and rural areas have played a dominant role (Zhu *et al.*, 2020).

Urban–rural interactions in Jiangsu reflect the most intense urban–rural conflict in China. The transformation and spatial differentiation of rural functions are accelerating, and their complex and diversified characteristics are becoming increasingly obvious. At the same time, villages and towns in Jiangsu undertake a variety of production functions (e.g., agriculture, industry, and tourism) and multiple comprehensive regional functions (e.g., life, ecology, and culture) (Wang *et al.*, 2020). As a typical coastal area, Jiangsu has the strongest rural economy and the most diverse rural development functions. This area is typical and representative of rural functions around the country. At the same time, the rural areas in poor areas are mainly restricted by natural conditions, industrial economy, ecological environment, infrastructure and other factors, and the rural development function is relatively single and backward. Studying the developed areas of Jiangsu, and discover the inevitable and accidental objective and subjective factors can provide reference for the rural functional poverty alleviation and rural revitalization path in the less developed areas (Han *et al.*, 2021).



**Figure 1** Land use regional distribution of Jiangsu province

## 2.2 Data sources

The social and economic data and pollution treatment rate data of towns in Jiangsu were



taken from the Jiangsu Rural Statistical Yearbook (2006–2018): Jiangsu Rural Survey (2012): Jiangsu Provincial Statistical Yearbook, China County Statistical Yearbook (2006–2018): China County Economic and Social Statistical Yearbook (2006–2018): the statistical yearbooks of counties and cities, and statistical bulletins of national economic and social development.

The digital elevation model (DEM): annual precipitation, and river data were taken from the national 1:4 million database of the National Basic Geographic Information System (<http://nfgis.nsdi.gov.cn>). Road network data were obtained from China's 1:250,000 electronic map. Normalized difference vegetation index (NDVI) data were obtained from the Geospatial Data Cloud website, which was retrieved from remote sensing using MODIS and TM. Land use data were obtained from the interpretation data of Landsat Thematic Mapper (TM) images (30 m) provided by the Ministry of Land and Resources (2005, 2010, 2015, 2018); the classification system adopted the current land use classification standard (GB/T21010-2007).

### 3 Research methods

#### 3.1 Selection of evaluation indicators

The rural area has the objective attribute of multi-function, including not only the physical content of farmers, rural areas and agriculture, but also the non-material functions of leisure, entertainment, culture and so on. Rural areas first existed as agricultural production areas. As the subject of behavior changes from the traditional “economic man rationality” to “social turn” and “cultural turn”, the rural regional function is deduced from the leading role of agricultural production to the comprehensive space of economy, culture, society, tourism, ecology and agricultural production. The compound value of rural economy, society and environment is increasingly emphasized. Based on rural regional system theory and factor endowment theory, the impact of economic, social and resource differences on rural regional functions is comprehensively considered. Considering the availability of data and the difficulty of quantification, the evaluation index system covering agricultural product supply, economic development, social security, and ecological conservation functions in rural areas is constructed according to the scientific, systematic, and hierarchical principles (Plieninger *et al.*, 2013; Liu *et al.*, 2020; Yang *et al.*, 2020). In this study, we also conduct second-level refinement classification. The evaluation index system includes three levels: the function, index, and calculation methods (Table 1).

The supply of agricultural products is the primary function of rural areas, mainly refers to the ability to provide food, vegetables, meat, fruit and other agricultural products for residents (Marsden and Sonnino, 2008). The agricultural product supply function includes grain production, cash crop production, and aquaculture functions (Bustos *et al.*, 2016). Four indicators are selected: grain crop sowing area, vegetable crop sowing area, total meat yield, and aquatic product yield.

The functional index of economic development considers the economic development level of villages, industrial structure, labor force scale, and quality. The secondary classification of economic development include industrial, commercial, and tourism functions. It selects

six indicators: the number of industrial enterprises above scale, the output value of industrial enterprises above scale, the number of markets, the turnover of trade markets, the number of supermarkets above 50 m<sup>2</sup>, and the number of accommodation and catering enterprises.

**Table 1** Primary and secondary classification index system of rural functions

Primary classification target layer	Secondary classification target layer	Index layer	Weight
Agricultural product supply function	Grain production function	V <sub>1</sub> Sowing area of grain crops	0.054
	Cash crop production function	V <sub>2</sub> Planting area of vegetable crops	0.052
	Aquaculture function	V <sub>3</sub> Total meat production	0.059
		V <sub>4</sub> Aquatic product output	0.071
Economic development function	Industrial development function	V <sub>5</sub> Number of industrial enterprises above designated size	0.021
		V <sub>6</sub> Output value of industrial enterprises above designated size	0.033
	Business function	V <sub>7</sub> Number of markets	0.020
		V <sub>8</sub> Trade market turnover	0.114
		V <sub>9</sub> Number of supermarkets over 50 m <sup>2</sup>	0.038
	Tourism function	V <sub>10</sub> Number of accommodation and catering enterprises	0.064
Social security function	Living function	V <sub>11</sub> Location	0.006
		V <sub>12</sub> Number of branches of financial institutions	0.041
		V <sub>13</sub> Number of parks and leisure and fitness squares	0.036
		V <sub>14</sub> Minimum living security number of street residents	0.018
	Cultural function	V <sub>15</sub> Total number of students in school	0.026
		V <sub>16</sub> Number of libraries and cultural stations	0.040
		V <sub>17</sub> Area of public cultural facilities	0.121
	Medical function	V <sub>18</sub> Number of medical and health institutions	0.042
		V <sub>19</sub> Number of beds in medical and health institutions	0.048
Ecological conservation function	Biodiversity function	V <sub>20</sub> Vegetation coverage	0.021
	Water conservation function	V <sub>21</sub> Water area	0.076

The social security function index mainly considers the living security ability and level of farmers carried by villages (McCarthy, 2005; Plieninger *et al.*, 2015). The social security function focuses on the ability to provide public services such as transportation, medical care and education to farmers (Geoghegan, 2002). The secondary classifications of social security functions include residential, cultural, and medical functions (Gómez-Limón *et al.*, 2012). Infrastructure construction and supporting medical education are the indirect body of social security function (Kosec and Wantchekon, 2020). It includes nine indicators: location, number of financial institutions, number of parks and leisure fitness squares, minimum living security number of street residents, total number of students in school, number of libraries and cultural stations, area of public cultural facilities, number of medical and health institutions, and number of beds in medical and health institutions.

Jiangsu, as an important grain production area and ecological conservation area in the country, is particularly important for its ecology (Binder and Blankenberg, 2017). The level of rural ecological function affects the regional ecological security (Fernández-Martínez *et al.*, 2020). The ecological conservation function index mainly considers the basic conditions

of the rural ecological environment and ecological environmental pressure brought about by rural development (De Groot *et al.*, 2002). Ecological conservation reflects the ecological services and material information to maintain the stability of the ecosystem in rural areas (Wang and Tang, 2018). The ecological conservation functions include biodiversity and water conservation. It includes the two indicators of vegetation coverage and water area (Wolch *et al.*, 2014).

### 3.2 Rural function evaluation model

The original data of the index system are normalized and calculated using the extreme value method to reduce the influence of the original data dimensions on the evaluation results (Cheng *et al.*, 2022).

The formula for calculating the positive index  $V_{ij}$  is as follows:

$$V'_{ij} = \frac{V_{ij} - V_{\min}}{V_{\max} - V_{\min}} \quad (1)$$

If  $V_{ij}$  is negative, then index calculation formula is:

$$V'_{ij} = \frac{V_{\max} - V_{ij}}{V_{\max} - V_{\min}} \quad (2)$$

where  $V'_{ij}$  is the value of the  $i$ th sample  $j$  index after the normalization calculation;  $V_{ij}$  is the original data of the  $i$ th sample  $j$  index; and  $V_{\min}$  and  $V_{\max}$  are the minimum and maximum values of the  $j$  index, respectively.

The weight of each index is calculated by entropy method. The normalized data is multiplied by the index weight to sum up the evaluation indexes of different dimensions of rural regional functions in Jiangsu. It refers to the agricultural product supply, economic development, social security and ecological protection function index of each village. The agricultural product supply is calculated as:

$$APF_i = \sum V'_{ij} \times W_j \quad (3)$$

where  $APF_i$  is the agricultural product supply function index for town  $i$ ,  $W_j$  is the weight of index  $j$ , and  $V'_{ij}$  is the value of  $j$  index of the  $i$ th sample after the normalization calculation. The value is between 0 and 1. The higher the value is, the higher the corresponding function is, and vice versa. Other functional indices are calculated using analogies. Rural functions are classified from high to low using the natural discontinuity (Jenks) classification method in the ArcGIS software.

### 3.3 Classification of rural functions

This study uses the cluster analysis method of the weighted principal component distance and the weight of the index to determine rural functional classification. The calculation steps of the cluster analysis method for the weighted principal component distance were as follows (Wu and Li, 2022).

(1) Standardization of indicators. A total of 21 rural indicators from  $V_1$  to  $V_{21}$  are selected according to functional needs, and a sample matrix is obtained to compare the discrete de-

gree and order of magnitude of the original indicator data. To reduce the influence of the dimensions, it is necessary to standardize the data to obtain standardized dimensionless data and a standardized matrix.

(2) Construction of the relationship matrix and principal component analysis. The correlation coefficient matrix, Kaiser–Meyer–Olkin test, Bartlett sphericity test, and significance are calculated for the standardized data to determine whether the sample is suitable for principal component analysis. When starting the principal component analysis, the eigenvalues and vectors of the relationship matrix or covariance matrix are calculated, the principal component index factors are extracted, the loading matrix of the index factors is analyzed, and the extracted principal component factors are named. Let  $F_1, F_2, \dots, F_s$  ( $s \leq q$ ) be the  $q$  dimension index vector  $V = (V_1, V_2, \dots, V_q)$  and extract the principal component factor column vector. Then,  $I_1, I_2, \dots, I_n$  are the sample row vectors obtained after extracting principal component factors.  $F_{ij}$  is the  $j$ th principal component factor of the  $i$ th sample ( $i = 1, 2, \dots, n; j = 1, 2, \dots, s$ ). The cluster analysis of the weighted principal component distance defines the distance between samples  $I_i$  and  $I_j$  as:

$$d_{ij}(q) = \left[ \sum_{k=1}^s \beta_k |F_{ik} - F_{jk}|^q \right]^{1/q} \quad (4)$$

where  $\beta_k$  ( $k = 1, 2, \dots, s$ ) is the feature weight corresponding to the principal component factor  $F_k$ , and  $\sum_{k=1}^s \beta_k = 1$ . Adaptive weighting is calculated for the sample distances under different principal component factors, and the obtained weighted principal component distance matrix is:

$$D = \begin{bmatrix} d11 & d12 & \cdots & d1n \\ \vdots & \ddots & \ddots & \vdots \\ dn1 & dn2 & \cdots & dnn \end{bmatrix} \quad (5)$$

where  $d11 = d22 = \dots = dnn = 0$  and  $D$  is symmetric; therefore, only the upper triangle part (or the lower triangle part) need to be computed.

Cluster analysis. Cluster analysis is based on the characteristics and attributes of the indicators, and rural functions with high similarity are grouped into one category. In this study, we use hierarchical cluster analysis. Euclidean distance is used to characterize the similarity between the types, and the calculation formula is as follows:

$$d_{rk} = \min \{ I_{ik}, I_{jk} \} \quad (6)$$

where  $r$  is the new type after merging and  $k$  denotes the type before merging. The above steps are repeated until all towns were merged into one category. The merging process is depicted, and a phylogenetic clustering map is obtained. On the phylogenetic cluster map, combined with field investigation and expert opinions, the results are corrected, and rural functional zoning in Jiangsu is divided into several types.

(4) Determine the function type. For a certain type of function, the index coefficients correspond to the functions of all towns. We calculate the share of indicators in a single function type, and rank the functional importance of each town vertically. Subsequently, in a

certain town, the horizontal functions are sorted. The functions of a single type are compared based on the weight coefficient. The formula for calculating the weight coefficient is as follows:

$$\lambda_{ij} = \beta_{ij} / \sum_{j=1}^n \beta_{ij} \quad (7)$$

where  $\lambda_{ij}$  is the weight coefficient of the  $j$ th function in the  $i$ th area, and  $\beta_{ij}$  denotes the  $j$ th multifunctional comprehensive weight coefficient of the  $i$ th area. We comprehensively sort the functional types into cluster analyses, determine the type of rural function, and obtain the final classification scheme.

### 3.4 Spatial econometric regression analysis

The introduction of a spatial econometric model to explore factors influencing regional function evolution can compensate for the lack of spatial correlation in the traditional econometric model, which makes it difficult to consider the random error term of the explained variable (Anselin, 1995). The spatial econometric regression model used in this study include the spatial lag model (SLM) and spatial error model (SEM).

The SLM is used to explore whether neighboring villages in Jiangsu have spatial spillover effects on the region. The calculation formula is:

$$y_{it} = \delta \sum_{j=1}^n w_{ij} y_{jt} + \beta x_{it} + u_i + \lambda_t + \varepsilon_{it}, \quad \varepsilon_{it} \sim i.i.d(0, \delta^2) \quad (8)$$

where  $y_{it}$  is the value of the per capita net income of rural farmers in the  $i$ th section unit and  $t$ th period of the dependent variable;  $i$  is the section dimension, where  $i = 1, 2, 3, \dots$ ;  $t$  is the time dimension, where  $t = 1, 2, 3, \dots, T$ ;  $\delta$  is the spatial autoregressive coefficient;  $x_{it}$  is the value of the independent variable in the  $t$ th period of the  $i$ th section;  $\beta$  is the regression coefficient of the independent variable;  $u_i$  expresses the spatial fixed effect;  $\lambda_t$  represents the time fixed effect;  $w_i$  is an element of the space matrix; and  $\varepsilon$  is the error term.

The SEM is used to study the spatial dependence of the disturbance error term and to calculate the influence of the error impact of the dependent variable of neighboring villages on the function index of the village. The calculation formula is as follows:

$$y_{it} = \beta x_{it} + u_i + \lambda_t + \varphi_{it}, \quad \varphi_{it} = \rho \sum_{j=1}^n w_{ij} \varphi_{jt} + \varepsilon_{it}, \quad [\varepsilon_{it} \sim i.i.d(0, \delta^2)] \quad (9)$$

where  $\varphi_{it}$  is the error term for spatial autocorrelation;  $\rho$  expresses the spatial autocorrelation coefficient of the error term;  $\beta$  represents the regression coefficient of the independent variables;  $u_i$  represents spatial fixed effects; and  $\lambda_t$  represents the time-fixed effects.

## 4 Rural functional evolution and type identification

### 4.1 Spatiotemporal evolution of rural functions

#### 4.1.1 Spatiotemporal evolution of agricultural product supply functions

From 2005 to 2017, the supply function of agricultural products in rural areas of Jiangsu generally showed a downward trend (Figure 2). The average value of the agricultural prod-

uct supply function decreased from 0.416 to 0.325. In 2005, the agricultural product supply function index was between 0.006 and 0.984, and 395 towns had an index of  $> 0.5$ , accounting for 26.56% of the total number of units in the county. In 2017, the agricultural product supply function index was from 0.0002 to 1, and 364 towns had an index of  $> 0.5$ , accounting for 24.48% of the total number of units in the town.

Agricultural production functions are concentrated in northern Jiangsu (Subei) and central (Suzhong) Jiangsu. Northern Jiangsu is the main traditional grain-producing area, and the supply of agricultural products is generally greater than that of southern Jiangsu. Township industrial enterprises in southern Jiangsu (Sunan), expansion of construction land, occupation of farmland, and non-agriculturalization of cultivated land have reduced the supply of agricultural products in suburban areas (Peng *et al.*, 2015).

#### 4.1.2 Spatiotemporal evolution of economic development functions

From 2005 to 2017, the rural economic development function index of Jiangsu increased from 0.352 to 0.624. The proportion of index  $> 0.5$  increased from 40.12% to 58.86%. The value of the industrial development function dominates the economic development function, which is consistent with Jiang's research results. The production function shows an increasing trend, and is more prominent in the rural areas around the urban agglomeration (Jiang *et al.*, 2021).

Villages with higher economic functions are mainly located in southern Jiangsu or are rural villages in the suburbs of cities. Southern Jiangsu has a good economic foundation, good location conditions, developed rural industries, and high levels of per capita fiscal revenue and GDP output. By 2017, driven by the economic development of southern Jiangsu, rural industrial enterprises had gradually transferred and developed to central and northern Jiangsu.

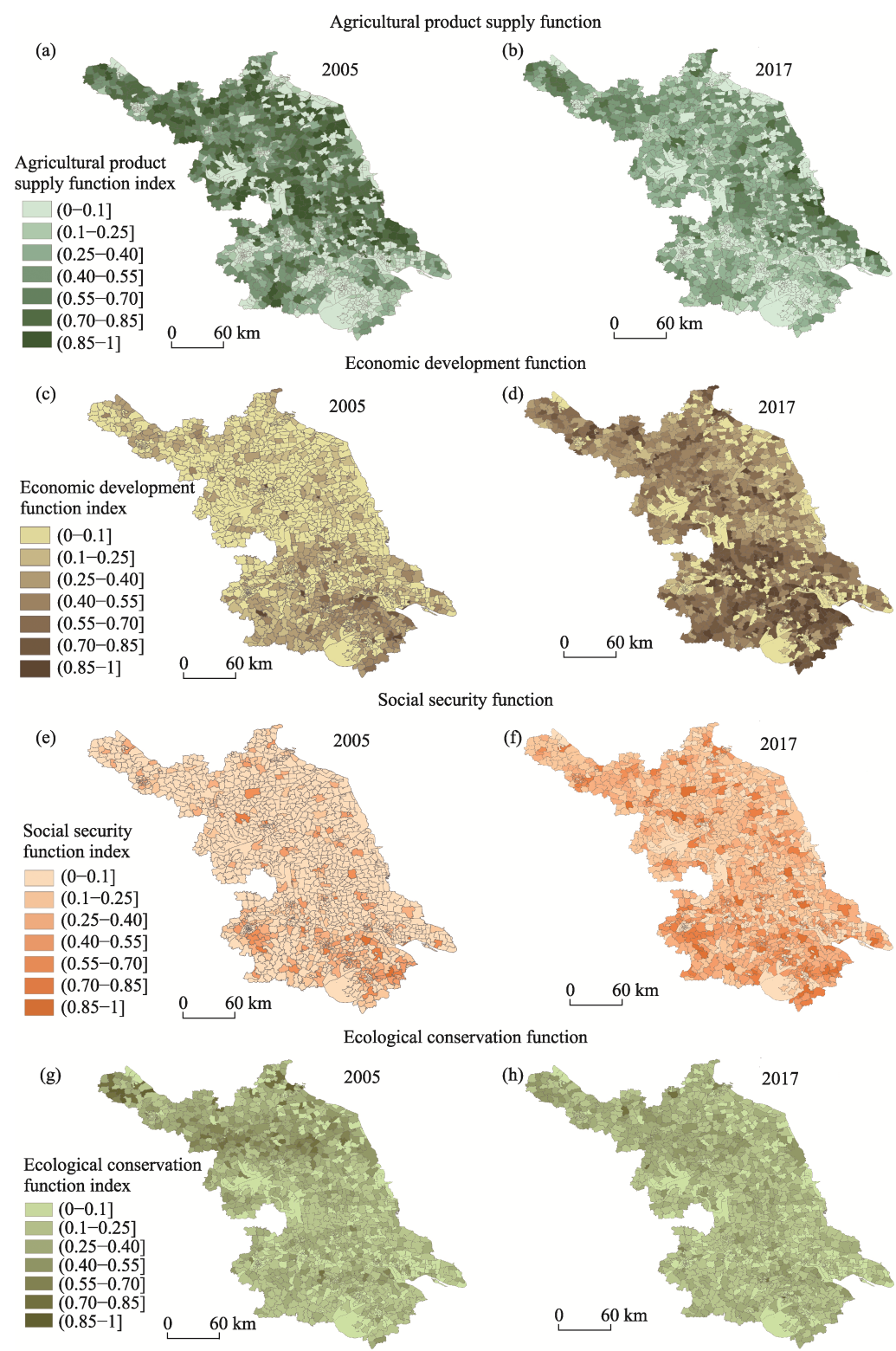
#### 4.1.3 Spatiotemporal evolution of social security functions

The social security function index showed an upward trend, increasing from 0.213 in 2005 to 0.486 in 2017. The social security function has a typical “center periphery” distribution feature. High social security function index values and significant improvements occurred in the suburbs of cities, county centers, and key towns. Farmers in these regions have high income levels, strong spending power, and guaranteed access to medical and educational facilities. This is due to the radiation-driven and diffusion effects of cities, as well as the policy changes that tend to be rural. The overall social security function in northern Jiangsu improve significantly, especially in Pizhou, Donghai, and Jintu counties.

#### 4.1.4 Spatiotemporal evolution of ecological conservation functions

The ecological conservation function index of Jiangsu was mainly between 0.162 and 0.512. The ecological function of the countryside shows a downward trend. This decline is most obvious in county centers and key towns and is mainly due to erosion and replacement of ecological functions with economic development functions (Hinojosa and Hennermann, 2012).

The ecological conservation function in Jiangsu shows a zonal spatial distribution. High-value areas of ecological conservation are concentrated along lakes, the coast, and hilly areas of southern Jiangsu. Coastal areas have a high proportion of tidal flats and wetlands,



**Figure 2** Spatiotemporal evolution of rural functions in Jiangsu province

high biodiversity, and extensive vegetation coverage. The water network along the coast of Taihu Lake is dense, the water conservation function is strong, the domestic sewage treatment rate is high, and ecological conservation awareness is strong.

## 4.2 Identification of primary and secondary rural functions

From the cluster analysis for towns in Jiangsu in 2017, the functional structure of towns is divided into 4 categories at the first level (agricultural product supply, economic development, social security, and ecological conservation) and 11 types at the second level (food production, cash crop production, aquaculture, industrial production, commercial, tourism, residential, cultural, medical, biodiversity, and water conservation functions) (Figure 3 and Table 2). The rural regional function of Jiangsu presents a spatial pattern of "social security function in the middle, economic development function in the periphery, agricultural product function dispersion, and ecological function agglomeration".

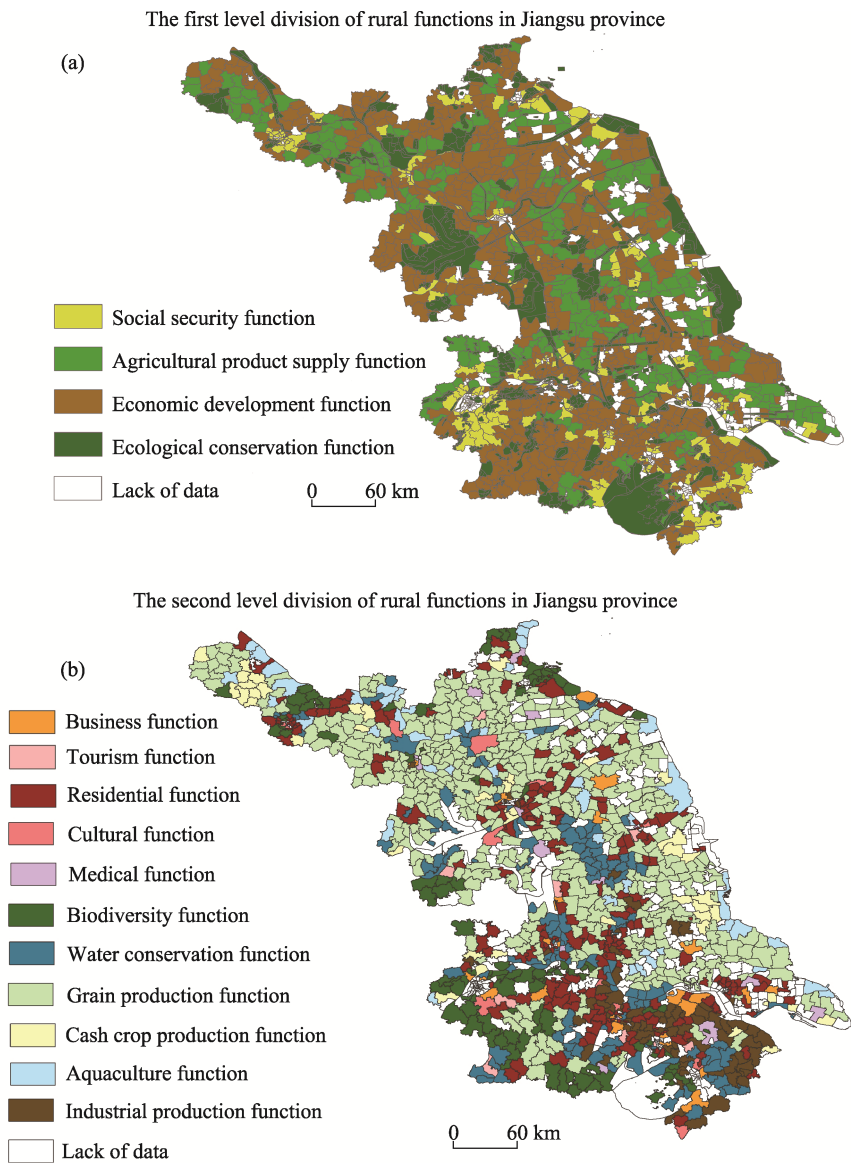
There are 396 villages in the functional area of agricultural product supply in Jiangsu province, accounting for 26.77% of all villages. These villages are mainly located in Dafeng district, Guanyun county, Suining county, and Sheyang county in central and northern Jiangsu. This area is a plain with flat terrain and fertile land. It is a national commodity grain base, and a base for wine production, aquatic products, and vegetable and non-staple foods. The grain production function is the most important agricultural function in Jiangsu (Kearney *et al.*, 2019). There are 423 villages with this function, accounting for 28.45%. The production functions of cash crops are mainly distributed in the villages of Liuhe district, Dongtai city, Dafeng district, Huaiyin district, and Peixian county, with a total of 101 villages (6.79%). The region mainly develops economic crops, such as fruits and vegetables, seedlings, and medicinal materials. Functional aquaculture villages are mainly distributed in Taixing city, Rudong county, and other villages along the coast and lakes, with a total of 50 villages, accounting for 3.36%.

There are 626 villages in the economic development functional area, accounting for 42.32% of all villages; these are mainly distributed in southern Jiangsu, with some in central and northern Jiangsu. Industrial villages, suburban villages, central villages, and villages with industrial characteristics have the highest levels of rural economic development (Ma *et al.*, 2018). The industrial production function is mainly located in Suzhou, Wuxi, and Changzhou cities in southern Jiangsu, with a total of 134 villages, accounting for 9.01% of the total. Rural industry in southern Jiangsu has become a model. The main industries in this rural area include chemical industry, food production, power supply, machinery manufacturing, which is consistent with the results reported by Su *et al.* (2010). Villages with commercial functions are mainly distributed in southern Jiangsu, Zhangjiagang city, Wuzhong district, and other villages, with a total of 29 villages, accounting for 1.95% of the total. Villages with tourism functions, such as those in Nanjing's Gaochun and Jiangning districts, are mainly distributed in the suburbs of cities, with a total of 21 villages, accounting for 1.41% of the total. They have complete tourism supporting infrastructure such as transportation, accommodation, catering and entertainment.

There are 137 villages in the social security functional area of Jiangsu, accounting for 9.26% of the total. The social security functional areas show zonal differences and are relatively agglomerated. Most of the areas are in southern Jiangsu, Nanjing, villages along rivers, and in key towns and suburban villages. Urban public services are easy to access and extend



to rural areas in the region; infrastructure such as education and medical care are common and comprehensive (Argent *et al.*, 2009). Villages with residential functions are scattered across the entire area of Jiangsu, with a total of 224 villages accounting for 15.06% of the total. Residence is the main bearing function of the villages. Rural residents in the region enjoy convenient conditions in terms of living services, and the rural residential function is relatively prominent (Gómez-Limón *et al.*, 2012). Villages with cultural and medical functions account for relatively small proportions, 12 and 16 (or 0.81% and 1.08%): respectively. The region has rich tourism resources and complete tourism supporting facilities, and the transportation location is superior. The government vigorously advocates the construction of rural tourism, making its cultural, tourism and leisure functions at a high level.



**Figure 3** Primary and secondary functional zoning of rural Jiangsu province

There are 235 villages with ecological conservation functions in Jiangsu, accounting for 15.89% of all villages. The distribution is relatively concentrated, with the overall blocky distribution characteristics of "close to mountains and rivers". These include the villages of the Dafeng Elk National Nature Reserve, Hongze Lake Wetland Nature Reserve, Yancheng Wetland Rare Birds National Nature Reserve, Taihu Lake Scenic Spot, Yangtze River Drinking Water Source Reserve, and other villages. The rural ecological conservation function of Jiangsu includes biodiversity and water conservation. A total of 114 villages has biodiversity functions, accounting for 7.67% of the total. Villages with a water conservation function are mainly distributed along Taihu Lake, Hongze Lake, and Gaoyou Lake, with a total of 147 villages, accounting for 9.89% of the total. The region has outstanding ecological service functions and is an important ecological protection barrier in Jiangsu (Gómez-Sal *et al.*, 2003).

**Table 2** Classification of primary and secondary functions of rural development

Primary function	Secondary function	Number of villages	Proportion of all villages (%)
Agricultural product supply function	Grain production function	423	28.45
	Cash crop production function	101	6.79
	Aquaculture function	50	3.36
Economic development function	Industrial production function	134	9.01
	Business function	29	1.95
	Tourism function	21	1.41
Social security function	Residential function	224	15.06
	Cultural function	12	0.81
	Medical function	16	1.08
Ecological conservation function	Biodiversity function	114	7.67
	Water conservation function	147	9.89
	Lack of data	216	14.53

**5 Influencing factors for spatiotemporal differentiation of rural functions**

**5.1 Selection of an influencing factor index**

Considering the availability of data and the difficulty of quantification, an evaluation index system covering agricultural product supply, economic development, social security, and ecological conservation functions in rural areas is constructed according to systematic, hierarchical, and scientific principles (Table 3). Both endogenous and exogenous factors affect the function of rural development. Following neoclassical growth theory, endogenous influencing factors include economic geographic location, natural resources, economic foundation, human capital, and transportation conditions (Aggarwal, 2018). Exogenous influencing factors include market demand, infrastructure, and environmental governance (Li *et al.*, 2019).

Geographical location ( $X_1$ ) affects the development of rural non-agricultural industries through transportation, markets, information, etc., and reshapes the economic geographic space. Natural resources have a profound impact on the distribution and structure of rural

production and life on a large scale. Hydrological resources (X<sub>2</sub>): topographic conditions (X<sub>3</sub>): cultivated land area (X<sub>4</sub>): and ecological conditions (X<sub>5</sub>) were selected as factors reflecting geographical conditions. Population factors are the main driving factors for rural development, which include the labor force of ordinary people (X<sub>7</sub>) and capable people of large farming households (X<sub>8</sub>) [Dasgupta and Beard, 2007]. The traffic accessibility (X<sub>9</sub>) of the density of the national road and provincial road network is selected to represent traffic conditions in the countryside. The number of trading markets for agricultural products (X<sub>10</sub>) and investments in fixed assets (X<sub>11</sub>) have become the main drivers of rural development and layout. The domestic sewage treatment rate (X<sub>12</sub>) and garbage treatment rate (X<sub>13</sub>) represent the rural environmental governance capacity.

**Table 3** Influencing factor variables for rural development in agricultural product supply function

Category	Variable	Variable factors		Unit	Variable description
Endogenous factors	Geographical location	Geographic conditions (X <sub>1</sub> )		km	Straight line distance from city and county center
	Natural resources	Hydrological resources (X <sub>2</sub> )		km	Distance from rivers above grade 4 and lakes above 10 km <sup>2</sup>
		Terrain conditions (X <sub>3</sub> )		m	Elevation size
		cultivated land area (X <sub>4</sub> )		km <sup>2</sup>	Cultivated land area/registered resident population
		Ecological status (X <sub>5</sub> )		%	Vegetation coverage
	Economic base	Economic basis (X <sub>6</sub> )		10,000 yuan	Rural collective economic income
	Human capital	Number of labor force (X <sub>7</sub> )		people	Number of permanent residents
		Able person factor (X <sub>8</sub> )		people	Numbers of large planting households, large livestock households, and poultry breeding households
		Traffic conditions	Transportation accessibility (X <sub>9</sub> )	min	Traffic accessibility of national and provincial road network densities
Exogenous factors	Market demand	Trading market (X <sub>10</sub> )		induvial	Number of trading markets dominated by grain, oil, vegetables, fruits, and aquatic products
	Infrastructure	Fixed asset investment (X <sub>11</sub> )		10,000 yuan	Fixed asset investment completed
	Environmental governance	Sewage treatment (X <sub>12</sub> )		%	Centralized treatment rate of domestic sewage
		Garbage collection (X <sub>13</sub> )		%	Domestic waste disposal rate

### 5.2 Model construction and testing

According to the correlation test, the fixed asset investment completion amount (X<sub>11</sub>): which is correlated with multiple variables, was eliminated, and ordinary least squares (OLS) regression analysis is performed (Table 4). The Moran’s I index of the four functions (agricultural product supply, economic development, social security, and ecological conservation) are all at the level of 0.05, indicating a strong degree of spatial dependence. The LMLAG and LMERR of the four functions pass the 0.1 significance test. The R-LMLAG of agricultural product supply function, and economic development function, along with the R-LMERR of ecological conservation function, and social security function all pass the 0.01 significance test. Therefore, a spatial error model (SEM) and a spatial lag model (SLM) are introduced.

The regression results of the SEM and SLM models of the four functions are consistent with the OLS results. The increase in the  $R^2$  value after considering the spatial correlation indicates that the interpretability of the model is improved. The estimated values of the SLM spatial lag terms of agricultural product supply, economic development, social security, and ecological conservation are 0.313, 0.347, 0.482, and 0.257, respectively, all of which are significant at the 5% level. This indicates that these four functions have large spatial endogenous interaction effects, and that improvements to the four functions of a village would positively promote improvement to the corresponding functions of surrounding villages. The SEM spatial error terms of the agricultural product supply function and economic development function are 0.274 and 0.189, respectively, both of which are significant at the 1% level. This indicates that these two functional variables have an interaction effect on spatial error terms.

**Table 4** Spatial dependence test of rural function evolution in Jiangsu province

Spatial dependence test	Agricultural product supply function	Economic development function	Social security function	Ecological conservation function
Moran's I (error)	4.257***	8.256**	6.523**	2.548**
LMMAG	20.715*	27.683**	22.683*	2.163*
R-LMLAG	8.264*	1.657**	0.851**	1.983**
LMERR	13.936**	34.151***	26.432*	1.269*
R-LMERR	0.539**	9.544**	10.956*	3.865*

Note: \* Significant correlation at the 10% significance level; \*\* Significant correlation at the 5% significance level; \*\*\* Significant correlation at the 1% significance level.

LMMAG, Lagrange Multiplier (lag); R-LMLAG, Robust LM (lag); LMERR, Lagrange Multiplier (error); R-LMERR, Robust LM (error).

**5.3 Analysis of regression results**

The driving factors and mechanism of multi-functional rural transformation are complex and heterogeneous. The regression results show that different factors have different degrees of influence on agricultural product supply, economic development, social security, and ecological conservation functions in rural areas (Table 5).

The supply function of agricultural products in rural areas and terrain conditions are significantly negatively correlated at the 5% significance level, with a correlation coefficient of  $-0.254$ . Agriculture-dominated villages in Jiangsu are dominated by vegetables (22.3%): fruits (21.9%): grains (19.8%): aquatic animals (12.1%): flowers and seedlings (10.3%): and tea (4.9%). Plain areas are conducive to the agglomeration of grains, vegetables, and farming villages, and hilly areas are conducive to the development of villages, such as fruit, tea, and forest trees.

The supply function of agricultural products in rural areas is significantly positively correlated with cultivated land area, the factor of capable people, and the economic base at the 5% significance level (correlation coefficients of 0.253, 0.152, and 0.243, respectively). The per capita arable land area is large and land resources are abundant, facilitating land transfer, large-scale planting, and scale benefits of agricultural products. Talents generally have keen insight into the market, understand government policies, have an adventurous spirit, and

spread new ideas among farmers in other village through mentoring, relatives, friends, and other relationships (Li *et al.*, 2011). The planting decisions of farmers and villages follow the theory of nearest neighbor diffusion; the closer the distance, the closer the planting intention. This is consistent with the results reported by Li *et al.* (2017). Farmers with a good economic foundation (e.g., initial capital accumulation and the transfer of land leases) purchase seeds, chemical fertilizers, pesticides, machinery, and equipment; at the same time, they expand the scale of planting, introduce technological innovation, and upgrade planting varieties, thereby increasing income. This is in line with the view of "path dependence" in industrial clusters.

The location factor, trading market, and per capita net income of farmers are all significant at the 10% level (correlation coefficients of 0.296 and 0.274, respectively). The influence of geographical location on agriculturally dominated rural development is first attributed to Thunen's agricultural location theory. Under the "isolated country" assumption, the closer you are to the market, the higher the ground rent and the lower the freight rate (O'Kelly and Bryan, 1996). Large and bulky crops or fresh and perishable consumer goods are planted in the suburbs of cities, forming an agricultural Thunen circular structure. The closer to the county seat or city center, the more conducive an area is to the development of agricultural and rural areas. County seats and city centers are distribution centers for markets and information, have higher demand for fruits, flowers, and vegetables markets, and have high proximity to consumer markets. This is consistent with the results of Jiang *et al.* (2021).

The economic function of rural areas has significant positive correlations with the number of industrial employees, rural collective economic income, traffic accessibility, river and lake water networks, and centralize sewage treatment rate at the 5% significance level (correlation coefficients of 0.214, 0.408, 0.341, 0.052, and 0.208, respectively). Labor-intensive enterprises in the handicraft industry of Jiangsu are relatively developed and highly dependent on the number of laborers. Clothing and textiles, food and beverages, and wood furniture are positively correlated with the number of laborers and labor-intensive industries. Entrepreneurs are an important driving force in the development of industrial villages (Rozelle and Boisvert, 1995). The approach of helping relatives and helping neighbors with neighbors' promote early family workshops in rural industrial enterprises. The rural industry relies on a large amount of raw material, production equipment investment, choice of production method, preparation of start-up capital, and increase in industrial scale, all of which depend on the economic foundation of townships and farmers. This is consistent with the research results of Qu *et al.* (2017). With improved infrastructure in industrial parks, rural industrial enterprises mainly form a "point axis" distribution pattern along national highways, provincial highways, and trunk line networks (Qiao *et al.*, 2016).

Papermaking, chemical metal smelting, and electromechanical equipment enterprises are mainly distribute along Taihu Lake and the Yangtze River, close to the ports of the Yangtze River, which is convenient for the transportation of raw materials such as oil. The production process of this enterprise is characterized by high water consumption, transportation, and discharge. The Yangtze River, Taihu Lake, and Beijing–Hangzhou Canal have all experienced water quality deterioration and water source pollution, especially in the Taihu Lake Basin (Yuan *et al.*, 2019). In response, environmental governance in Taihu Lake Basin has intensified (Qin *et al.*, 2010). To reduce the pressure of environmental pollution, the indus-

trial structure of the township industry has been upgraded, with the evolution of textile, electric power, chemical, machinery, electronic, and information technologies. The economic function of rural areas is significantly negatively correlated with cultivated land area at the 10% significance level (correlation coefficient of  $-0.240$ ). The less arable the land per capita, the better the rural industry's development. Less arable land allows more of farmers' labor force to be released, providing primitive labor resources for the initial development of the rural industry.

**Table 5** Spatial regression analysis of rural function evolution influencing factors in Jiangsu province

Impact factor	Agricultural product supply function			Economic development function			Social security function			Ecological conservation function		
	OLS	SLM	SEM	OLS	SLM	SEM	OLS	SLM	SEM	OLS	SLM	SEM
Geographic conditions ( $X_1$ )	0.138*	0.184*	0.296*	0.089	0.134*	0.149	0.159*	0.286**	0.216**	-0.188	-0.057	-0.134*
Hydrological resources ( $X_2$ )	0.028	0.042	0.125	0.104	0.089*	0.052**	-0.047	-0.058	0.049	0.027*	0.034**	-0.009
Terrain conditions ( $X_3$ )	-0.194*	-0.176	-0.254**	0.078	-0.057	0.098	0.077*	0.098	0.034	1.002	1.355	1.286
Cultivated land area ( $X_4$ )	0.152	0.085**	0.253**	-0.208**	-0.247*	-0.240*	-0.208	-0.247	-0.187	-1.222	-1.035	-1.004
Ecological conditions ( $X_5$ )	-0.097	-0.088	-0.059	-3.007	-3.078	-0.357	-0.157	-0.089	-0.114	2.871**	2.958**	2.903*
Economic basis ( $X_6$ )	0.095**	0.105*	0.243**	0.342**	0.379**	0.408**	0.148*	0.198	0.217*	-0.889	-0.994	-0.971
Number of labor force ( $X_7$ )	-0.023	0.058	0.218*	0.101	0.127*	0.214**	0.178	0.207	0.197	0.135	-0.148	-0.120*
Able person factor ( $X_8$ )	0.104	0.154*	0.162**	0.047*	0.089	0.186	0.187	0.259	0.209*	-0.187*	-0.207*	-0.183
Transportation accessibility ( $X_9$ )	0.259	0.287*	0.387	0.189*	0.246**	0.341**	0.105*	0.187**	-0.127	-0.113*	-0.127	0.198
Trading market ( $X_{10}$ )	0.141	-0.058	0.274*	0.008	-0.027	0.087	-0.049	0.087	-0.031	0.035	-0.040	-0.007
Sewage treatment ( $X_{12}$ )	0.004*	0.008	0.025	0.187*	0.118	0.208**	0.182*	0.196*	0.146*	-0.007	-0.098	0.054
Garbage collection ( $X_{13}$ )	-0.025	-0.085	0.095	-0.008	0.014*	0.027	-0.089	0.152*	0.144	0.029	0.152**	-0.067
$\rho$ (Spatial lag term)		0.313**	0.274***		0.347**	0.189***		0.482**	0.187**		0.257**	0.206**
$\lambda$ (Spatial error term)		(2.47)	(4.95)		(3.24)	(4.87)		(5.12)	(1.24)		(2.98)	(-0.87)
$R^2$	0.513	0.554	0.581	0.615	0.664	0.698	0.581	0.605	0.594	0.453	0.497	0.462
Adjust $R^2$	0.504			0.589			0.572			0.412		
$F$	21.719			27.179			24.357			15.247		
LogL		380.34	398.67		890.71	896.23		618.12	602.34		157.95	150.44
AIC (Akaike information criterion)		-935.57	-953.89		-1675.94	-1685.24		-1255.22	-1204.95		-824.12	-795.18
SC (Schwarz Criterion)		-785.22	-792.51		-1358.18	-1458.87		-924.11	-902.23		-548.24	-507.33

Note: \*, \*\*, and \*\*\* indicate significant correlations at the 10%, 5%, and 1% levels, respectively. OLS, ordinary least squares; SEM, spatial error model; SLM, spatial lag model.

The social security function of rural areas is significantly positively correlated with location conditions and traffic accessibility at a significance level of 5% (correlation coefficients of 0.286 and 0.187, respectively). The distance between villages, cities, and counties affects the radiation of infrastructure, culture, and information (e.g., education and medical treatment). Good “village to village” traffic conditions improve the life and production of farmers. The treatment rate of domestic waste and centralized treatment rate of domestic sewage increase by 1%, and the per capita net income of farmers increase by 0.196% and 0.152%, respectively. Vigorous construction of infrastructure plays an important role in improving the quality of the rural residential environments.

The ecological conservation function of rural areas is significantly positively correlated with vegetation coverage, domestic garbage collection rate, and the distance between rivers and lakes at the 5% significance level (correlation coefficients of 0.296, 0.152, and 0.034, respectively). The ecological conservation function of rural areas is rich in species, and they have a high biodiversity index. Environmental policies have reversed the function of rural development to an environmentally friendly ecological conservation function. This limits the function of economic development and the supply of agricultural products that are heavily polluted by point and non-point sources. Villages close to important rivers and lakes have become important ecological sources for regional water, soil, and biodiversity conservation, along with ecological conservation activities (Vollmer *et al.*, 2016). At the 10% significance level, there is a negative correlation with the able-bodied factor (correlation coefficient of  $-0.207$ ). Villages with ecological protection function generally lack capable villagers and make little contribution to village development. (Cao *et al.*, 2019).

## 6 Conclusions

Previous studies have focused on a small number of rural functional categories and lacked quantitative research on the driving mechanism at the village level. In this study, we attempted to fill these gaps by establishing the internal and external driving factors of regional rural functions in Jiangsu, including the comprehensive influence of natural and socioeconomic factors. The main conclusions of this study are as follows.

From 2005 to 2017, the supply and ecological conservation functions of rural agricultural products in Jiangsu decreased, whereas economic development and social security functions increased. Agricultural production functions were concentrated in northern and central Jiangsu. The main function of economic development was industrial development in southern Jiangsu. Social security functions were concentrated in the suburbs of cities, county centers, and key towns. Areas with high ecological conservation functions were concentrated along lakes, the coast, and in hilly areas of southern Jiangsu. The main functions of secondary rural areas in Jiangsu were grain production (28.45%); industrial production (9.01%); and residential (12.06%).

Rural development is affected by both endogenous and exogenous factors, including economic geographic location, natural resources, economic foundation, human capital, traffic conditions, market demand, infrastructure, and environmental governance. The influence of geographical location on rural development of the agricultural product supply function is consistent with Thunen’s agricultural location theory. County seats and urban centers are

distribution centers for markets and information that are beneficial to the development of agricultural and rural areas. Rural industrial enterprises are mainly distributed along national highways, provincial highways, and trunk line networks to form a point axis. The garment, textile, wood, and furniture industries depend on the number of laborers. Rivers and lakes are important sources for ecological conservation.

Owing to the limited availability of data, the selected explanatory variables of rural function indicators and influencing factors need to be further improved in the future. Cultural and tourism functions, business services, and other rural scale factors are difficult to measure. The interaction between the internal geographical background, influencing mechanisms, and factors of rural functions still need to be studied in detail.

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