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Understanding rural system with a social-ecological framework: Evaluating sustainability of rural evolution in Jiangsu province, South China

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ABSTRACT

Rural evolution is a multifaceted combination of social, economic and ecological changes. Existing research about rural evolution focused on the socioeconomic transformation but paid inadequate attention to the ecological aspects and the links to external settings. In this research, we structured the cognition of rural evolution with a social-ecological framework, evaluated the sustainability of rural evolution with multisource data, and analyzed its external driving forces. Taking Jiangsu Province as a case study, we found that, (1) Rural evolution showed spatial heterogeneity in Jiangsu Province. From 2000 to 2015, rural evolution in South Jiangsu demonstrated a sustainable trend, while the rural system in North and Central Jiangsu was on the decline. (2) Population, social outcomes and ecological environment were predominant internal variables that determined the trend of rural evolution. With developed economy, good human well beings and large immigration, South Jiangsu surpassed North and Central Jiangsu in terms of rural sustainability. Although North and Central Jiangsu got higher scores on ecological environment, it was not sufficient to offset the negative effects of population loss and economic depression on rural sustainability. (3) Both the socioeconomic and ecological settings at larger scale had effects on rural evolution. Flat terrain, mild climate, advantageous location, good socioeconomic base as well as progress in infrastructures, globalization and marketization provided favorable conditions for rural development. However, over rapid urbanization had negative impacts on rural sustainability due to the urban-biased policy. Based on the results, we proposed to develop small towns and promote bottom-up urbanization to reconcile the conflicts between rural development and urbanization. To pursuit rural sustainability, a problem-driven, solution-oriented approach was also needed to avoid one-size-fits-all implementation of policy design.

1. Introduction

Pursuit of sustainability has become a consensus of human society. Rural areas are essential arenas for achieving SDGs (sustainable development goals) (Ravallion and Chen, 2007; Cheng et al., 2018). Since the end of World War II, both developed countries and developing countries have been focusing on advancing rural development through national or beyond national policy design. America and Australia provided considerable subsidies for developing large-scale farms and modern agriculture (Marsh and Pannell, 2000; Winders, 2009). The EU published CAP (common agriculture policy) and initiated LEADER program (Liaison entre actions de développement de l'économie rurale) to promote integrated rural development in Europe (Baldock et al., 2001; Râmniceanu and Ackrill, 2007). Asian countries devoted much attention to village constructions to enhance rural development (e.g., New Communities Program in South Korea and One Village One Product Scheme in Japan) (Boyer and Ahn, 1991; Fujimoto, 1992). In China, series of rural policies have been implemented to narrow urban-rural gaps and promote sustainable rural development (e.g., The Comprehensive Agricultural Development Plan, Rural Tax-fee Reform, Targeted Poverty Alleviation and Rural Revitalization Strategies) (Bryan et al., 2018; Liu et al., 2020).

In recent years, scholars also shed some lights on rural sustainability issues (Li et al., 2018; Deng et al., 2020). Liu and Li (2017) warned that rural decline phenomenon, featured by rural outmigration, economic depression and facility abandonment, was a potential menace to sustainability. Case studies showed bottom-up initiative as well as mediation between self-governance and external intervention were effective

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approaches to enhancing rural sustainability (Li et al., 2016; Zang et al., 2020). Land use policy and land engineering project with purpose of coordinating human-land relationships also played an important role in promoting rural sustainable transition (Li et al., 2018; Liu, 2018a; Wang and Li, 2019; Liu and Wang, 2019).

To understand dynamics of rural system, science community developed multiple methods to characterize rural evolution process. The initial works dated back to the measurement of rurality in England and Wales (Cloke, 1977). Based on rurality indices, four categories of rural system, ranging from "extreme rural" to "extreme non-rural" were identified to present spatial heterogeneity along the rural-urban continuum (Cloke and Edwards, 1986; Harrington and O'Donoghue, 1998). With access to remote sensing data, more indicators were applied to quantify features of rural system, bringing about more structured frameworks to understand rural evolution (Liu et al., 2016). Long and Liu (2016) summarized rural evolution as a process of spatial restructuring, economic restructuring and social restructuring. Corresponding to this conceptual framework, a three-dimensional model was developed to evaluate rural transformation, in which rural system was decomposed into population subsystem, industry subsystem and land subsystem (Li et al., 2017, 2018; Tu et al., 2018; Yang et al., 2018; Cheng et al., 2019).

Another knowledge line about rural evolution is based on urban-rural dynamics. Long et al. (2011) embedded rural evolution into the context of urban-rural interactions and characterized rural evolution with three types of indicators: rural development level, rural transformation level, and urban-rural coordination level. Parallelly, Liu et al. (2013, 2014) claimed that sustainable rural evolution should be a process of eliminating development gaps between urban and rural department. They proposed theoretical concepts of urban-rural equalized development as well as urban-rural transformation development to denote sustainability of rural evolution (Liu et al., 2013, 2014; Wang et al., 2016; Ma et al., 2019).

Existing research showed rural evolution was a multifaceted process, including nonfarm trend in economic structure, social transformation and land use changes etc. (Li et al., 2015), which conformed to the scientific findings in developing countries (Gibson et al., 2010; Belton and Filipski, 2019; Li et al., 2019; Majumdar, 2020). Yet, most of the observations focused on the socioeconomic features of rural evolution, lack of adequate attention to the ecological aspects and deeper driving forces. We argue that rural system is a coupled social-ecological system and rural evolution is rooted in human-natural interactions as well as influenced by external driving forces. Accordingly, in this paper, we attempt to establish a social-ecological framework to incorporate ecological perspective into understanding rural evolution and to explore its driving mechanism.

The rest of this paper is organized as follows: The second section introduces the social-ecological framework, indicator system, methods and study materials for evaluating sustainability of rural evolution and exploring its external drivers. The third section presents the spatial pattern of rural evolution and its external drivers. The fourth section explains the spatial pattern and driving mechanism of rural evolution. The last section is conclusions.

2. Methods and materials

2.1. A social-ecological framework for understanding rural evolution

Most of the existing research divided rural system into three subsystems, namely economic subsystem/industry subsystem, social subsystem/population subsystem, and land subsystem/spatial subsystem. This conceptual framework captures the major characteristics of socioeconomic transformation in rural areas, but neglected the dynamic interplays between human system and natural system. To develop a comprehensive understanding of rural evolution, we proposed a social-ecological framework to structure the cognition of rural evolution.

The social-ecological framework was adapted from the SESs framework developed by Ostrom and her colleagues, which decomposed complex social-ecological systems into four subsystems (resource system, resource units, users and governance system) (Ostrom, 2007, 2009). Differing from the SESs framework, our framework incorporated resource units into resources system and combined resource users with governance system. Then, we defined rural system as a coupled social-ecological system composed of two core subsystems, namely resources subsystem and actors subsystem (Fig. 1).

Actors system is dominated by local human society, which has multiple attributes, like population density, population migration, institutional infrastructures and social networks etc. Resources system refers to local resources (e.g. forests and water body), which provides essential materials for human living. Development of human society depends on utilization of natural resources and is limited by stock of resources. The focal rural system is an open system with links to economic, social and ecological settings at larger scale (Fig. 1). To explain driving forces of rural evolution, we defined the related system at larger scale as external system, and defined focal rural system that we analyzed as internal system. Identification of the boundaries between external system and internal system depends on which scale our analysis is based on. In this research, we set counties as basic analysis units, so the economic, social and ecological settings at regional scale were deemed as external drivers.

Based on the social-ecological framework, rural evolution is a complex process that actors system interacts with resources system and produces outcomes (Fig. 1). The attributes of actors system and resources system would influence the interactions and outcomes. Correspondingly, the outcomes would affect the style of interactions and inform readjustments of actors as well as dynamics of resources. Since rural system is an open system, external changes would have some impacts on rural evolution. Socio-economic changes like globalization and industrialization would bring about transformation of rural employment, economic structure and social network (Woods, 2007). Ecological changes like global warming and extreme weather would expose rural system to natural hazards and impair rural sustainability (Saldaña-Zorrilla, 2008; Dumenu and Obeng, 2016). Rural evolution is embedded into the changes of external systems, learning, adaption and self-organization capacity of rural system are the essential power of rural evolution.

2.2. Indicator systems for assessing rural evolution and analyzing driving forces

According to the social-ecological framework, the evolution trend of rural system is determined by four dimensions, including actors system, resources system, human-natural interactions and outcomes. By quantifying the attributes and characteristics of the four dimensions, we established an indicator system for assessing the trend of rural evolution (Table 1). In the indicator system, actors system is characterized by spatial attribute, demographic attribute and labor attribute, resources system is assessed with the volume of natural resources, human-natural interactions mainly refer to the utilization of natural resources, and outcomes are divided into three aspects of economic, social and ecological outcomes.

To explore the driving mechanism of rural evolution, we proposed another indicator system to quantify the potential external drivers (Table 2). Both the natural conditions and socio-economic conditions of external system may have some effects on the evolution of rural system. Given the dynamic socioeconomic settings of external system, we assumed that both the initial status and variation of external drivers would influence rural evolution. Hence the indicators of socioeconomic drivers (except for location) are analyzed from two perspectives: the initial value at the beginning of study period and the variation value amid the study period (Table 2).

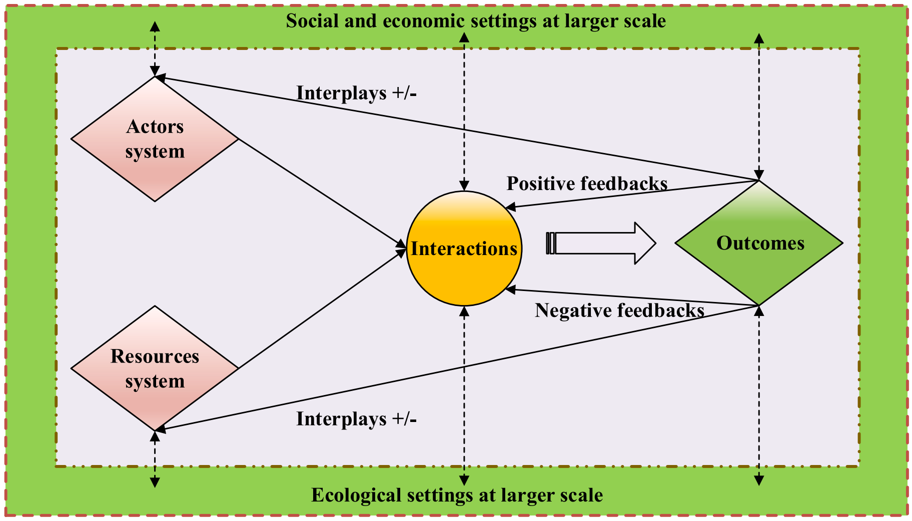

Fig. 1. A social-ecological framework for understanding rural evolution.

Table 1
Indicator system for evaluating sustainability of rural evolution.

Dimensions	Attributes and characteristics	Indicators
Actors system	Spatial attributes of actors system (SAAS)	Population density Outmigration rate Immigration rate
	age attributes of actors system (AAAS)	Proportion of aged population
	Attributes of labors in actors system (ALAS)	Total volume of rural employees Proportion of female employees
Resources system	Volume of natural resources (VNR)	Arable land per capita Forest land per capita Grass land per capita
Human-natural interactions	Utilization of natural resources (UNR)	Proportion of occupied arable land by construction Rural residential land per capita
Outcomes	Economic outcomes (ENO)	Efficiency of agricultural production Efficiency of grain production Mechanization of crop production Diversification of rural employment Diversification of agricultural production Diversification of crop planting structure
	Social outcomes (SO)	Disposable income per capita in rural areas Consumption expenditure per capita in rural areas Electricity consumption per capita in rural areas Medical service Education service
	Ecological outcomes (ELO)	Vegetation coverage Habitat quality index Habitat degradation index

Table 2
Indicator system for analyzing external drivers.

Classifications	Potential drivers	Indicators
Natural conditions	Topography	Terrain niche index (TNI)
	Climate	Temperature (TEM) Precipitation (PRE)
Socioeconomic conditions	Location	Distance from metropolis (DM) Distance from waterway (DW)
	Infrastructures	Initial value of fixed assets investment (IFAI) Variation of fixed assets investment (VFAI)
	Globalization	Initial value of foreign investment in actual use (IFIAU) Variation of foreign investment in actual use (VFIAU)
	Marketization	Initial status of private enterprise development (IPED) Variation of private enterprise development (VPED)
	Urbanization	Initial value of urbanization rate (IUR) Variation of urbanization rate (VUR)

2.3. Analysis methods

With multiple indicators, we calculated a comprehensive rural evolution index (CREI) to denote the sustainability of rural evolution. A higher index means a more sustainable trend of rural evolution. The CREI is calculated as follows:

$$CREI_j = \sum_{i=1}^{n} y_{ij} \times w_i$$

$$y_{ij} = x_{ij(t+1)} - x_{ij(t)}$$

$CREI_j$is the comprehensive rural evolution index of county$j$. $y_{ij}$is the variation of indicator$i$in county$j$ during the study period. To avoid any distortion of the results due to different dimension of indicators, y_{ij} was normalized to a range between zero and one through range method before calculation of CREI. $w_i$is the weight of indicator$i$. Weight is determined by the entropy of indicators. $x_{ij(t+1)}$is the value of indicator$i$in county$j$at the end of study period, $x_{ij(t)}$is the value of indicator$i$in county$j$at the beginning of study period. The effects of indicators on rural sustainability were classified into positive impacts and negative impacts, which was based on documentation of related literatures and expertise (Appendix 1). Details of indicators' calculation and data source were depicted in Appendix 1.

To compare the rural evolution trend among analysis units, we mapped the CREI with ArcGIS 10.2 and illustrated the spatial heterogeneity with Hotspot Analysis Module of ArcGIS 10.2. Then, based on the indicator system, we split CREI into eight fractional scores to demonstrate characteristics of rural evolution. With the fractional scores as analysis variables and the CREI as observation variable, we applied Latent Class Analysis through StataMP 16 (McCutcheon, 1987; Hagenaars and McCutcheon, 2002) to identify rural evolution clusters. Lastly, we quantified the potential drivers and applied Geographical Weighted Regression (GWR) analysis to identify the links between rural evolution and external driving forces. (Data source and calculation details of external drivers can be found in Appendix 2) To develop a more reliable regression model, we implemented Factor Analysis to eliminate multi-collinearity of driver indicators. With CREI as dependent variable and factors composite scores as independent variables, a GWR model was established to explore the driving mechanism of rural evolution.

2.4. Study area

In our research, we took Jiangsu Province as a case study to evaluate sustainability of rural evolution from 2000 to 2015 and analyzed its driving mechanism. Jiangsu Province is located in the southeast of China, adjacent to Yangtze River Delta and Shanghai City (Fig. 2). There are 13 prefecture-level cities and 96 county-level cities in the jurisdiction of Jiangsu Province. Traditionally, Jiangsu Province is divided into three parts according to statistic specification, namely, North Jiangsu, Central Jiangsu and South Jiangsu (Fig. 2). This division also coincides with the economic disparity in Jiangsu Province, manifested by the huge development gaps between South Jiangsu and North Jiangsu. Considering the availability and continuity of statistical data, we took county-level cities as the basic analysis units, cities without rural statistics are not considered in our research (Fig. 2).

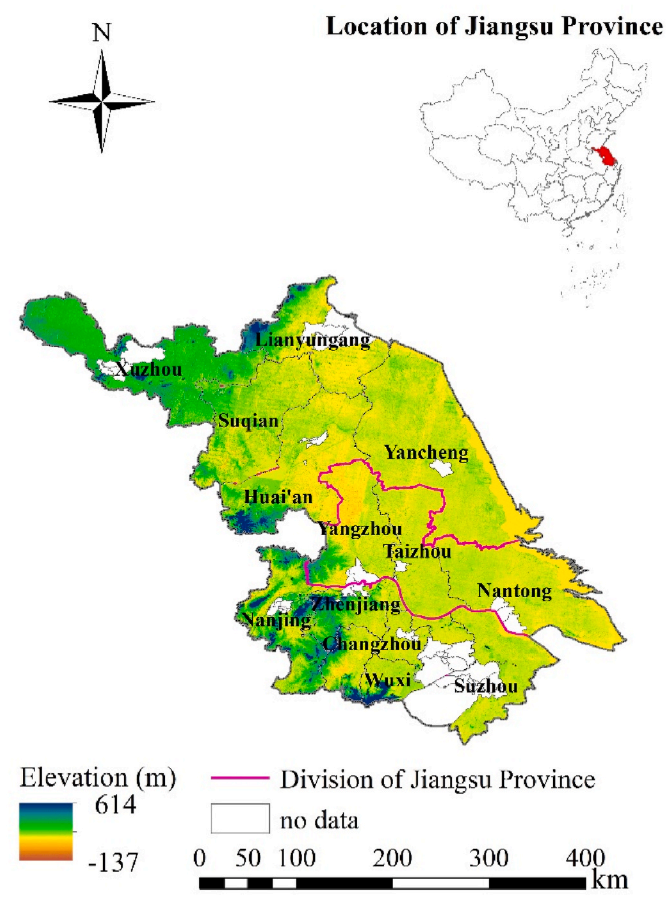

Fig. 2. Location of Jiangsu province.

3. Results

3.1. Spatial pattern of rural evolution

With the social-ecological framework and multi-source data, we evaluated the sustainability of rural evolution in Jiangsu Province and identified the hot spots as well as cold spots of CREI. From 2000 to 2015, the dynamics of rural evolution in Jiangsu Province demonstrated spatial heterogeneity. Rural evolution in South Jiangsu showed a more sustainable trend than the northern and central counterpart, demonstrated by a degressive CREI from south to north (Fig. 3). The hot spots of CREI were located in Nanjing, Wuxi, Changzhou, and Suzhou City, indicating a higher sustainability of rural evolution (Fig. 4). Conversely, the cold spots of CREI were concentrated in Suqian, Huai'an, Lianyungang, and Xuzhou City, where the rural revolution was less sustainable than other places (Fig. 4).

Based on the fractional scores of eight attributes/characteristics of rural evolution, four clusters of rural evolution pattern were identified in Jiangsu Province (Fig. 5, Fig. 6). Cluster 1 was mainly located in Suzhou and Nanjing City, with the highest score in terms of rural social outcomes, spatial and age attributes of rural population. Cluster 2 was adjacent to cluster 1, mainly covering Wuxi, Changzhou and Zhenjiang City, which showed lower fractional scores than Nanjing and Suzhou City. Cluster 3 was mainly situated in the middle of Jiangsu Province, composed of Nantong, Taizhou, Yangzhou and Yancheng City. Differing from cluster 1 and cluster 2, cluster 3 had a highest fractional score of natural resources utilization and a lowest score of age features of population. Cluster 4 was mainly distributed in North Jiangsu, featured by a highest fractional score of ecological outcomes but lowest fractional scores of social outcomes as well as spatial attributes of population. Generally, North and Central Jiangsu were dominated by cluster 3 and cluster 4, which showed a higher fractional score of ecological outcomes, yet a lower fractional score of social outcomes and spatial attributes of population. On the other hand, South Jiangsu was mainly covered by cluster 1 and cluster 2, which showed a higher fractional score of social outcomes and spatial attributes of population, but a lower score of ecological outcomes.

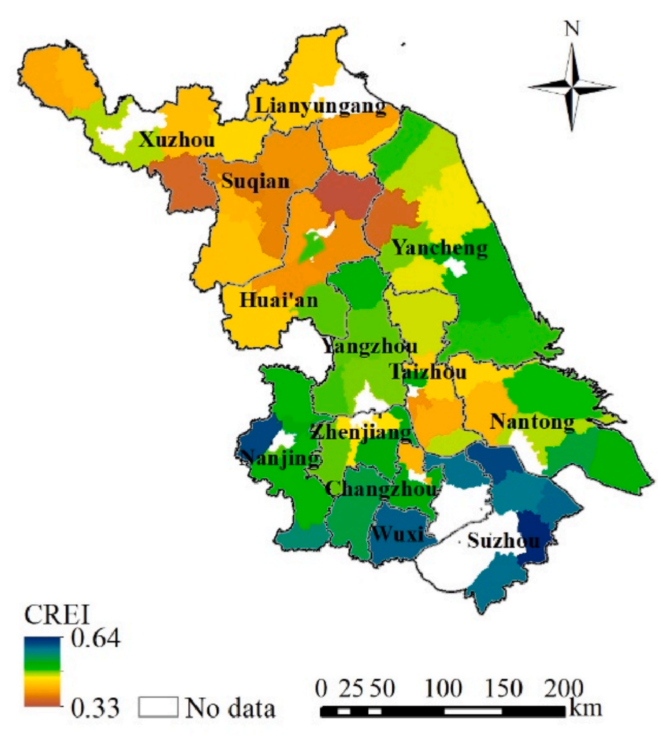

Fig. 3. Spatial distribution of CREI.

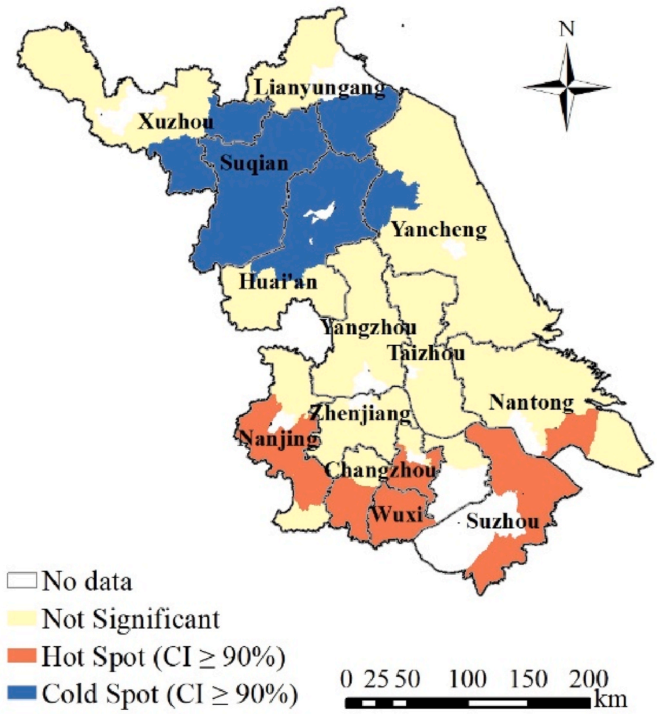

Fig. 4. Hot spots and cold spots of CREI in Jiangsu Province (CI: confidence interval).

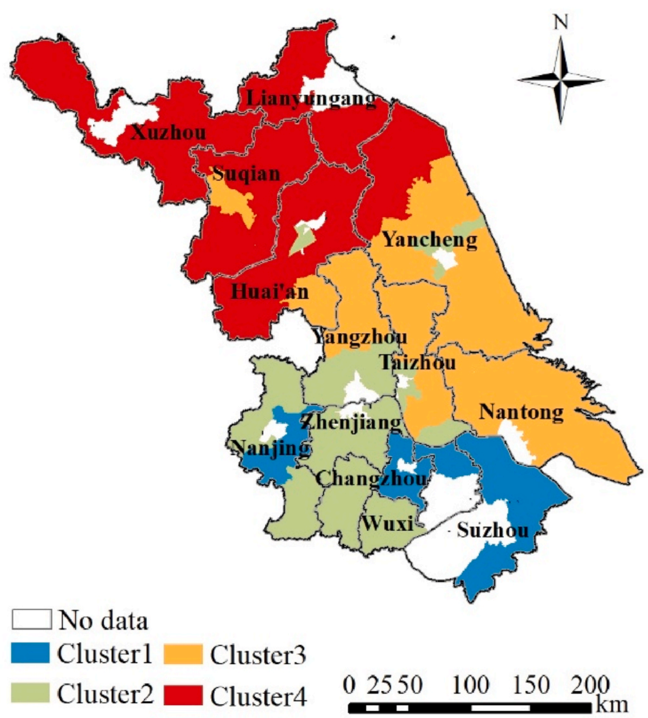

Fig. 5. Clusters of counties with similar rural evolution pattern in Jiangsu Province.

3.2. External drivers of rural evolution

Factor analysis identified four main factors that explained 86.69% variance of the driver indicators (Table 3). The communality of each indicator is larger than 0.4, meaning that the four main factors abstracted effective information from all indicators (Table 4). Loading reflects the extent to which the information of driver indicators is represented by the four main factors. A higher absolute value of loading means more information is represented by the four main factors.

Factor 1 explains 27.04% variance of the driver indicators, among which indicators of IFAI, VFAI, IFIAU, and VFIAU showed loading larger than 0.8. Hence factor 1 is assigned to represent the influence of "Infrastructures & Globalization". Factor 2 is loaded with more diversified information than factor 1, although it explains a lower proportion of variance. Given the relative significance of indicator's loading, we labeled factor 2 with "Climate & Marketization". Factor 3 is defined as driving force of "Urbanization & Marketization" due to the notable indicator loading of IPED, IUR and VUR. Similarly, factor 4 is defined as driving force of "Topography & Location" because of the larger loading of TNI and DW.

Taking the composite scores of the four main factors as independent variables and CREI as dependent variable, we established a GWR model to explore the links between rural evolution and external driving forces. With R square of 0.5897, the GWR model explains 58.97% of the variation of dependent variable. Coefficient reflects the effects of the four main factors on rural evolution. Although all coefficients were positive, there was subtle difference in terms of spatial pattern (Fig. 7). The coefficient of factor 1 and factor 4 showed a descending trend from north to south, while the coefficient of factor 2 and factor 3 showed a reverse trend in the same direction. The spatial variation of coefficients signified the varied magnitude of influence from external driving forces on rural evolution, although the difference is very small.

Based on the indicators' loading on the four main factors, we inferred the impact of external driving forces on rural evolution. Since coefficients of all the four main factors were positive, a negative loading on the four main factors denoted a negative correlation between the indicator and the CREI. Except for the indicators of TNI, DM and VUR, all the remaining indicators showed a positive loading on the four main factors, which meant that these drivers had positive correlation to the CREI. Yet, the negative loading of TNI, DM, and VUR indicated that these drivers had negative correlation to the CREI.

4. Discussions

4.1. Dynamics of internal variables of rural system

Based on the social-ecological framework, the results of cluster analysis indicated that the internal variables of population, social outcomes and ecological outcomes dominated the spatial pattern of rural evolution.

Population is the dominant factor of rural actors system, which has an essential influence on rural vitality. In recent four decades, an exodus of young labor triggered severe rural declining issues in China (Liu and Li, 2017; Wu et al., 2020). In terms of Jiangsu Province, outmigration was concentrated in the north and central part, while the south part has transformed into an immigration-dominated pattern in 2015 (Fig. 8).

With growing mobility of population from 2000 to 2015, rural population density decreased in most areas of Jiangsu Province, except for SuXiChang Economic Zone (Suzhou, Wuxi and Changzhou City) (Fig. 8), which are well-known for their success of Sunan Model in China (Shen and Ma, 2005). The developed economy, higher revenues and more job opportunities in SuXiChang Economic Zone attracted a large quantity of rural migrants and kept local farmers working in their hometown. Agglomeration of population in South Jiangsu provided sufficient labor elements for rural development, yet the north and central part of rural Jiangsu was confronted with great challenges caused by labor loss.

Paralleling with population growth, the developed economy in South Jiangsu also brought about higher incomes and better social welfare than its north and central counterpart (Table 5). From 2000 to 2015, increase of both incomes and consumption expenditures in rural South Jiangsu were higher than the average level of the whole province. A

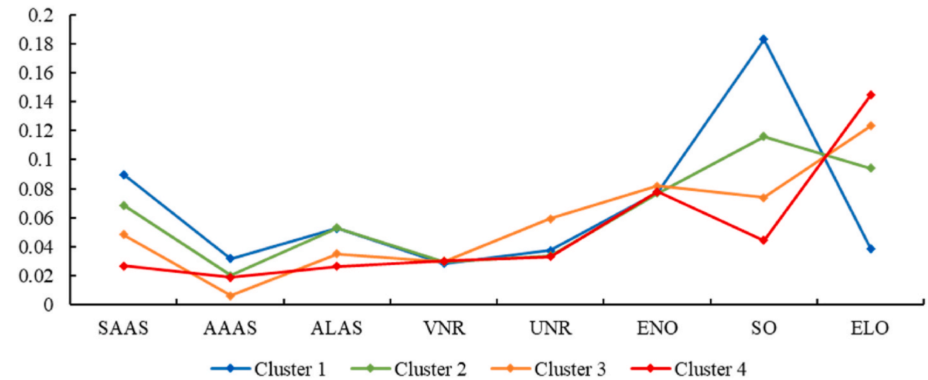

Fig. 6. Fractional scores of the eight attributes/characteristics of rural evolution (Abbreviations are illustrated in Table 1).

Table 3
Explained proportion of variance after orthogonal transformation.

Factors	Eigenvalue	Explained rate of variance (%)	Accumulated proportion (%)
1	3.52	27.04	27.04
2	2.90	22.27	49.31
3	2.76	21.22	70.53
4	2.10	16.15	86.69

similar trend was also observed in medical and education service in South Jiangsu. However, in North Jiangsu, from 2000 to 2015, only the medical care saw significant progress than other places.

The affluence of rural residents in South Jiangsu largely benefited from its prosperous rural collective economy. Since the early 1980s, many villages in South Jiangsu began to develop small manufacture factories to raise households' incomes. The collective economy not only provided job opportunities for local residents, but also paid villagers with share dividend annually. The most successful example of rural collective economy is Huaxi Village, which is located in Jiangyin City, South Jiangsu. At the end of 2019, the annual economic output in Huaxi Village has surpassed seven thousand million dollars. The prosperity of rural economy and employment contributed to rural sustainability in South Jiangsu, while North and Central Jiangsu were still trapped in rural economic depression (Wei and Fan, 2000; Jin and Lu, 2009).

Opposed to its blooming economy and social welfare, South Jiangsu lagged behind its northern and central counterpart in terms of ecological environment. As shown by the ecological indicators (Table 6), the vegetation coverage and habitat quality in South Jiangsu degraded faster than North and Central Jiangsu from 2000 to 2015.

Variation of vegetation coverage and habitat quality was highly related to land use/cover changes. From 2000 to 2015, the land use/cover change in Jiangsu Province was dominated by loss of arable land and expansion of construction land (Fig. 9). In South Jiangsu, a majority of land use/cover inflow lay in construction land, 74.53% in cluster 2 and 85.67% in cluster 1. The gain intensity of construction land in North and Central Jiangsu is generally lower than the south, 53.95% in cluster 3 and 76.87% in cluster 4.

Expansion of construction land was regarded as an important reason for arable land loss (Tan et al., 2005). From 2000 to 2015, the arable land loss intensity in South Jiangsu was approaching to 90% (88.42% in cluster 1 and 89.95% in cluster 2), far beyond than North and Central Jiangsu (55.58% in cluster 3 and 84.32% in cluster 4). The massive arable land loss and expansion of construction land in South Jiangsu accounted for its faster degradation of vegetation coverage and deterioration of habitat quality than North and Central Jiangsu.

Although the ecological environment had positive contributions to CREI in North and Central Jiangsu, it couldn't offset the negative effects of population loss and lower social welfare (Fig. 6). Generally, rural evolution conformed to the spatial pattern of population and social outcomes in Jiangsu Province. South Jiangsu with intensive population distribution, developed economy and good social welfare showed a more sustainable trend in rural evolution than Central and North Jiangsu. The spatial heterogeneity of rural evolution indicates that

Table 4
Loadings from Factor Analysis of driver indicators.

Indicators	Loading·				Communalities[b]·
	Factor1 Infrastructures & Globalization	Factor2 Climate & Marketization	Factor3 Urbanization & Marketization	Factor4 Topography & Location	
TNI	0.07	−0.07	0.02	−0.86[a]	0.76
TEM	0.25	0.69[a]	0.27	0.58[a]	0.95
PRE	0.24	0.81[a]	0.44[a]	0.11	0.92
DM	−0.36	−0.67[a]	−0.35	−0.51[a]	0.96
DW	0.20	0.03	0.11	0.78[a]	0.66
IFAI	0.88[a]	0.31	0.19	0.15	0.93
VFAI	0.85[a]	0.34	0.02	0.01	0.84
IFIAU	0.82[a]	−0.05	0.45[a]	0.07	0.87
VFIAU	0.81[a]	0.39	0.03	0.15	0.84
IPED	0.39	−0.03	0.79[a]	0.26	0.84
VPED	0.28	0.87[a]	−0.04	−0.08	0.84
IUR	0.40[a]	0.39	0.80[a]	0.11	0.96
VUR	0.10	−0.19	−0.93[a]	0.05	0.91

Abbreviations: driver indicators' abbreviations are illustrated in Table 2.
[a] Loading ≥ |0.40|. Loading with abstract value less than 0.4 means the corresponding indicator doesn't contribute effective information to the main factor.

[b] Proportion of the variance of external driver indicators explained by the four main factors.

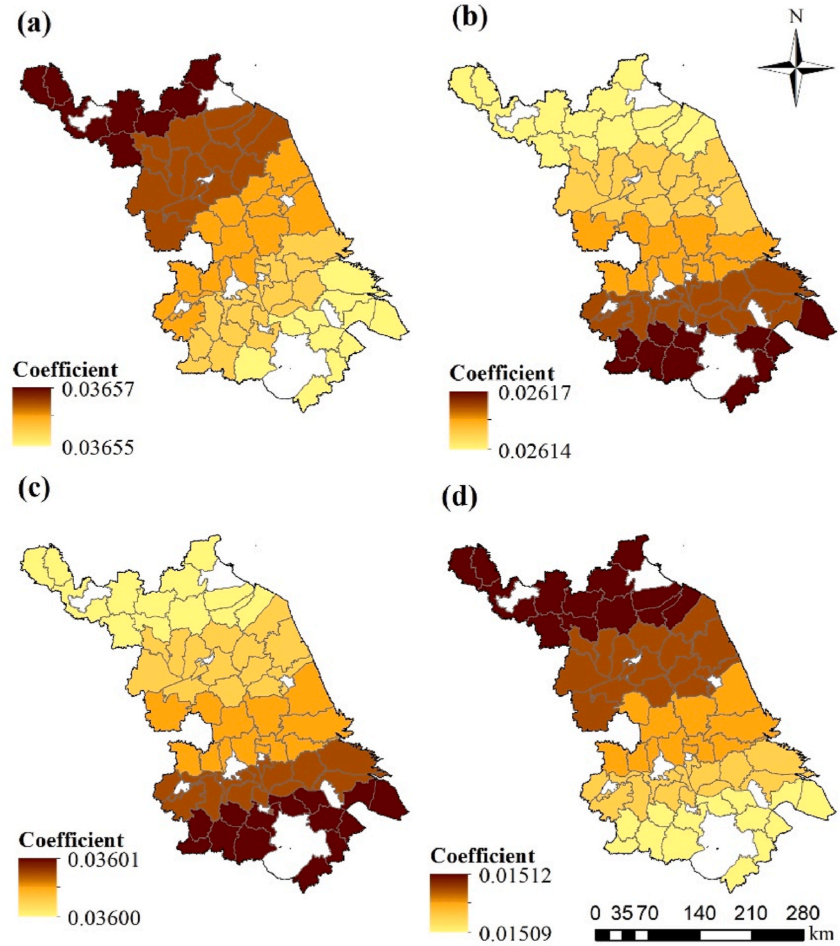

Fig. 7. Coefficient of the four main factors in GWR model (a. factor 1; b. factor 2; c. factor 3; d. factor 4).

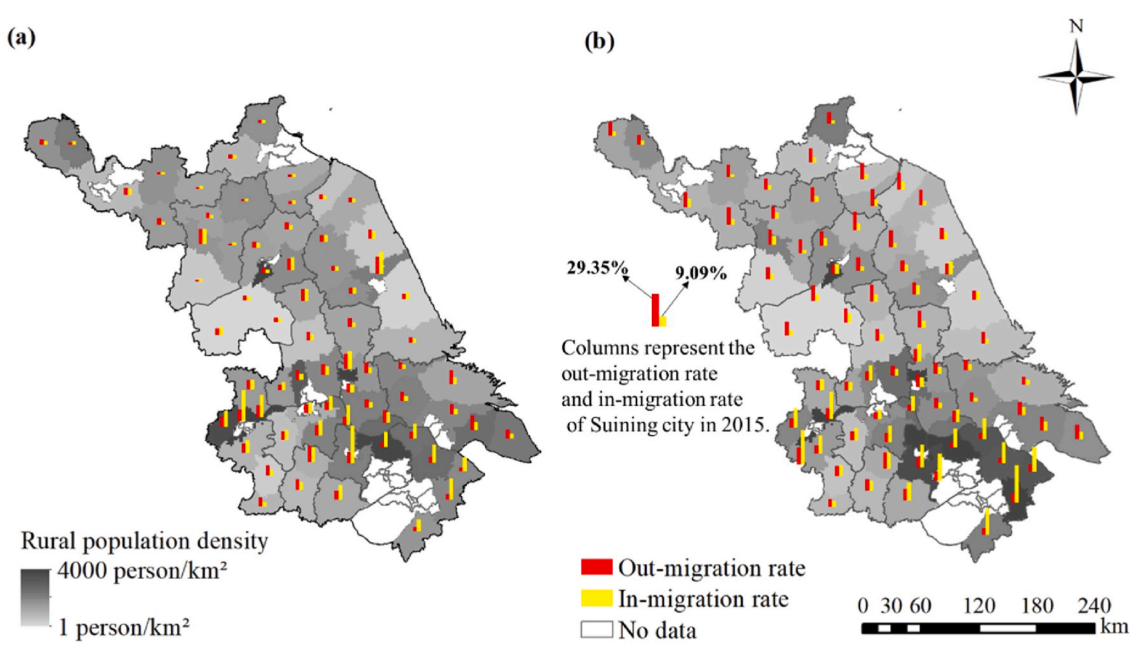

Fig. 8. Population density and migration rate of Jiangsu Province (a. 2000; b. 2015).

Table 5
Changes of human-wellbeing in Jiangsu Province from 2000 to 2015.

	Variation of income[a]	Variation of consumption[b]	Variation of medical service[c]	Variation of education service[d]
Jiangsu Province	13490.71	9625.29	220.62	1.23
North Jiangsu	10929.16	7595.19	266.28	1.06
Central Jiangsu	13350.09	10068.07	129.18	1.16
South Jiangsu	17176.96	12053.27	268.00	1.57

[a] Annual disposable income of rural residents (Yuan per person).

[b] Annual expenditure on consumption of rural residents (Yuan per person).

[c] Number of beds in health institutions (Beds per thousand person).

[d] Average schooling of population (Years).

Table 6
Changes of ecological indicators in Jiangsu Province from 2000 to 2015.

	VNDVI	VHQI	VHDI
Jiangsu Province	−0.0320	−0.0318	0.0048
Cluster1	−0.1287	−0.0930	0.0106
Cluster2	−0.0549	−0.0411	0.0063
Cluster3	−0.0189	−0.0156	0.0038
Cluster4	0.0220	−0.0089	0.0015

Abbreviation; VNDVI: variation of NDVI from 2000 to 2015; VHQI: variation of habitat quality index from 2000 to 2015; VHDI: variation of habitat degradation index from 2000 to 2015.

socioeconomic factors are still the predominant internal variable that determines the evolution trend of rural system in Jiangsu Province.

4.2. Links between external drivers and rural evolution

Rural evolution is determined by internal variables and is influenced by external drivers simultaneously. As examined by the GWR model (Table 4 and Fig. 7), both the ecological and socioeconomic settings at larger scale had impacts on rural evolution.

Ecological settings mainly refer to the natural conditions that is hard to be altered by human activities. As most of rural livelihoods directly depend on utilization of natural resources, rural development is significantly influenced by natural conditions. In China, a large proportion of rural poor population are concentrated in mountainous areas with high topography niche index (Liu et al., 2017). Instead, the plain areas with higher temperature and more precipitation are favorable to develop farming and facilitate rural development.

Location is another stable variable that affects rural evolution. Villages near metropolis or major transportation lines are more inclined to develop nonfarm industries and get involved in urban markets to make more profits (Gu et al., 2019; He et al., 2019; Li et al., 2019). In Jiangsu Province, villages in South Jiangsu are more accessible to urban market due to its advantageous location adjacent to the core of Yangtze River Delta Urban Agglomeration, one of the growth poles in China. Additionally, rural areas that are located on the shore of Yangtze River obtain more opportunities to develop commercial trade, as Yangtze River is known as the "Golden Waterway" in China. Locations combined with socioeconomic context contribute to the polarization of rural development to some degree.

Differing from stable variables, the dynamic drivers, including infrastructures, globalization, marketization and urbanization, are more active and easier to be changed by human activities, so the links between dynamic drivers and rural evolution is more complex. The initial status of dynamic drivers play an important role in laying foundation for rural evolution. Regions with well-developed infrastructures, advanced market mechanism, good links to foreign economy and robust urban consumption could provide favorable socioeconomic context for rural development (Chen et al., 2019). However, the dynamic process of these socioeconomic drivers would have different feedbacks on rural evolution.

The progress of infrastructures, globalization and marketization was conducive to promote sustainable rural evolution (Table 4), which was exemplified by the successful transition of Sunan Model. In recent years, the FDI (Foreign Direct Investment) and domestic private enterprise have become major catalyst for economic development in South Jiangsu, known as post-Sunan Model (Wei, 2002; Wei and Gu, 2010; Yuan et al., 2014). However, a negative feedback loop was observed between urbanization progress and rural evolution (Table 4). With more rapid urbanization pace, the CREI tended to fall down, indicating a less sustainable trend of rural evolution (Fig. 10).

The decoupling between rapid urbanization progress and sustainable rural evolution has raised growing concerns in science community (Liu

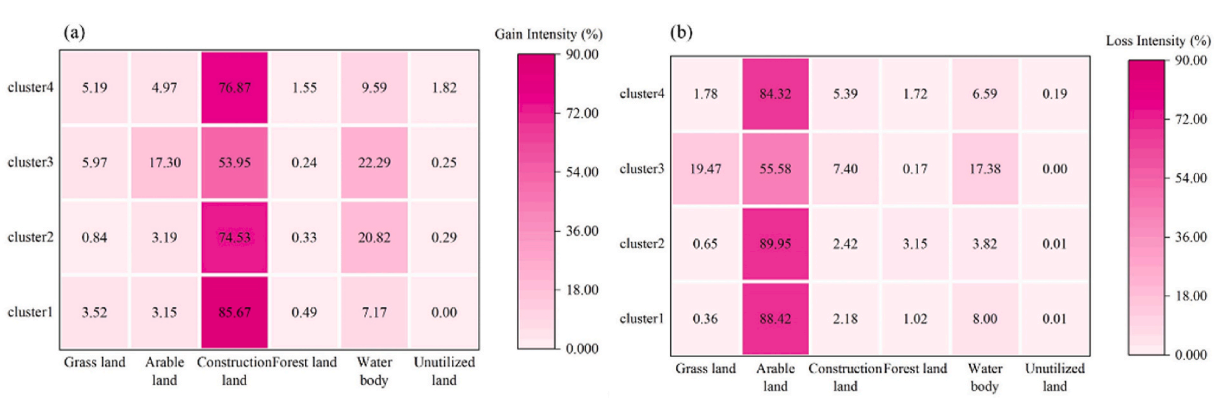

Fig. 9. Land use/cover change intensity in Jiangsu Province from 2000 to 2015. (a. land use/cover gain intensity, b. land use/cover loss intensity. Details of calculation can be found in Appendix3).

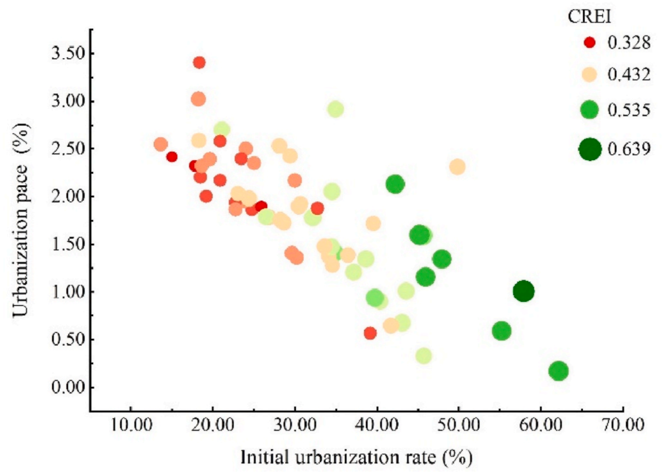

Fig. 10. Coupling map between urbanization and rural evolution in Jiangsu Province.

et al., 2010; Zhan, 2015; Liu and Li, 2017; Li et al., 2018; Long et al., 2018). It is argued that the urban-biased policy was the main reason for urban-rural gaps in China (Li et al., 2018). Income gap is the most convincing indicator for unequal urban-rural development. In Jiangsu Province, with rising urbanization rate, the income gaps between urban and rural areas were widening constantly, although it marginally slowed down since 2010 (Fig. 11).

The encroachment of urbanization on rural department is characterized by rural-urban migration and unfair land expropriation (Liu et al., 2014). This phenomenon was more universal in North and Central Jiangsu than South Jiangsu. As labor and land are essential production factors, outmigration and land loss impair the capability of rural system to adapt to the changing world. Although urbanization creates more opportunities for developing and improving human well beings, it is also accompanied by rural declining in some areas. Hence a more scientific and considered design is needed to balance urbanization and sustainable rural development.

4.3. Implications for sustainability design

The contradictory trend of rural evolution to rapid urbanization pace revealed a distorted urban-rural relationship. To achieve an equilibrium between urbanization and sustainable rural evolution, policy designs need to incorporate rural demands into urbanization blue print (Li et al., 2018). In the past four decades, China's top-down urbanization strategy gave more priorities to developing big cities and urban agglomeration, which brought about shrinkage of small towns. Actually, small towns play an important role in serving rural residents and sustaining rural vitality. In South Jiangsu, the thriving small towns provide employment for daily rural commuters and supply rural residents with public services, which accounts for its rural sustainability to a large extent (Laurence and Ming, 1994; Shen and Ma, 2005).

Given the spatial attributes of urban-rural continuum, small towns assume important function of connecting urban and rural areas (Liu, 2018b). To reconcile the conflicts between rural vitalization and urban development, growth of small towns should be encouraged to spur a bottom-up urbanization process and advance rural sustainability (Liu et al., 2014). Since the end of 2014, the central government in China began to implement New Type Urbanization Strategy to guide urbanization along a sustainable trajectory (Chen et al., 2018). In 2017, a new national strategy of Rural Revitalization was proposed by central government to facilitate rural development. Combination of these two strategies will provide new platform to embed rural sustainability into urbanization agenda.

Conforming to the policy design at macro scale, an elaborate plan is

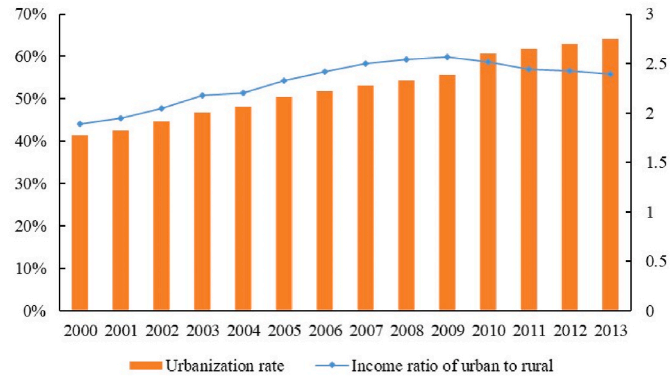

Fig. 11. Urban-rural income gaps in Jiangsu Province from 2000 to 2013.

needed when it is applied to certain areas. As shown by the analysis in Jiangsu Province, rural evolution demonstrated evident heterogeneity at spatial scale. The multifaceted characteristics and attributes of internal variables result in varied interactions and outcomes in rural system. Some rural villages are restructuring due to entrepreneurship and collective actions, while others with similar endowments are declining (Li et al., 2019). To pursuit rural sustainability, a diagnostic approach is needed to identify unsustainability syndromes and prescribe solutions congruent with local conditions (Ostrom, 2007). The problem-driven, solution-oriented approach will help us to avoid the misguiding of one-size-fits-all viewpoint in the domain of sustainability design.

5. Conclusions

This research contributes to a more comprehensive understanding of rural sustainability, through structuring the cognition of rural evolution with a social-ecological framework, evaluating sustainability of rural evolution with multisource data, and identifying the links between rural evolution and external driving forces. We deemed rural evolution as a nonlinear, dynamic process with interactions between human and natural systems. This process was influenced by the socioeconomic and ecological settings at larger scale. By applying this conceptual framework to the study of Jiangsu Province, we found that rural evolution manifested spatial heterogeneity. The developed South Jiangsu showed more sustainable trend in rural evolution than its northern and central counterpart. The spatial pattern of rural evolution revealed that internal variables of population, social outcomes and ecological environment were dominant factors determining the direction of rural evolution.

It is worth noting that rural evolution is also a cross scale process, intertwined with ecological and socioeconomic context at larger scale. Analysis of external drivers showed that both natural and socioeconomic settings at larger scale had impacts on rural evolution. Flat terrain, mild climate, advantageous location, good socioeconomic basis as well as progress of infrastructures, globalization and marketization were conducive to advance sustainable rural evolution. Conversely, progress of urbanization showed negative feedbacks on sustainability of rural evolution. This finding reminds us to attach importance to the interplays between urbanization and rural development. We argued that a bottom-up urbanization strategy was critical to achieving the urban-rural equilibrium. Moreover, a diagnostic approach was also vital to avoid the one-size-fits-all implementation of policy design.

Author statement

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jrurstud.2021.05.008.

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