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Analysis of regional differences in the influence of China's urbanization modes on rural sustainable development

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During the process of rapid urbanization in China, rural development has become increasingly dependent on cities. Policies to promote rural development emphasize the formation of an urbanization mode for the coordinated development of large, medium, and small cities as the driving force for rural development, but the policies do not specify the spatial organization relationship between cities in a given region. This study uses provincial panel data of China from 2004 to 2017, and analyzes the effect of regional spatial structure on rural sustainable development in different regions through the dynamic system generalized method of moments. The results show 1) that China's urban spatial structure has significant regional differences: it is flat in the eastern region and more concentrated in the central and western regions. 2) China's rural sustainable development efficiency has been declining. It is higher in the central region than in the eastern and western regions. 3) At present, the provincial urbanization modes in different regions of China mainly stimulate rural sustainable development through three factors, that is, urban population scale, industrial structure, and foreign direct investment. This study will help optimize the provincial spatial structure according to local conditions and promote rural sustainable development and regional balance.

KEYWORDS

spatial structure, urban population scale, industrial structure, foreign investment, agglomeration effect

1 Introduction

The rapid urbanization of China has caused dramatic impacts on rural development, especially the life of rural registered residents, and the rural ecological environment (Zhu and Zhao, 2013; Li et al., 2018a; Zhao, 2018). After the reform and opening-up, China's urbanization rate rose sharply, by approximately 45% (Zheng, 2014; Huang, 2018). In particular, in the 21st century, China's urban–rural income gap has been significantly reduced, but the urban and rural income ratio remains above 2.5:1 (Chen and Lin, 2013). Farmers and their offspring's health and education are still a big gap compared with urban residents. Most rural areas without prominent resource advantages face serious pollution threats from agricultural production and the transfer of urban and rural industries. They

have become the "nostalgia" of most people leaving the countryside. The unsustainable development of rural areas not only increases the burden of migrants but also hinders their free movement and promotions for the realization of the goal of common prosperity between urban and rural areas in China (Li et al., 2019a).

The positioning of this study on regional spatial structure of urbanization on rural sustainable development is motivated by two main factors: 1) Unreasonable urbanization has posed severe challenges to rural development, including rural residents' income, farmers' social security, and rural ecological environment; 2) There is a research gap in this aspect in the existing literature. First, it is well established that inadequate urbanization poses a critical burden on rural development. In China, a large number of farmers have moved to cities. The floating population living in some regional large cities chooses to move to some small- and medium-sized cities after their income reaches a certain level, while some older workers will directly choose to return to their hometowns because it is difficult for them to meet the requirements of settlement policies and welfare security in big cities (Huang, 2018). In this case, the rural surplus labor cannot flow freely to cities with more development potential, resulting in the inability of regional core cities to fully develop advantageous industries and optimize the division of labor, thus forming agglomeration effects and scale gains, and it cannot effectively radiate and drive rural development. At the same time, the large amount of labor stranded in rural areas will hinder the increasing returns to the scale of land and reduce the marginal output of rural labor (Lu and Chen, 2004; Chen and Lin, 2013).

Second, according to the aforementioned analysis, there is a growing body of literature analyzing the impact of urbanization on rural development as the rural labor force shifts to large and small cities. Scholars have long been stuck in the debate over whether rural labor should transfer to big cities or small- and medium-sized cities. Scholars represented by Lu believe that in the future, the urbanization mode should priority to the development of big cities, which have higher agglomeration effect of big cities can improve the level of specialization and labor productivity, promote the optimization of industrial structure and scientific and technological progress, and radiate the rural development through the diffusion effect (Jiang et al., 2008; Wang, 2010; Lu et al., 2011). However, other scholars believe that China should encourage the urbanization mode of rural labor flow to small- and medium-sized cities because the close distance between small- and medium-sized cities and rural areas is conducive to agricultural manufacturing and agricultural producer services to directly drive the development of rural economy (Zheng, 2014). At the same time, migrant workers are easy to integrate into small cities with low economic and psychological costs and often return to their hometowns to take care of the left-behind elderly and children (Cheng and Zhai, 2015).

One of the major drawbacks of the current literature is that they have isolated the radiation effect of the close connection between large- and medium-sized cities and the overall effect generated by their common development on the sustainable development of rural areas. There is no doubt that no matter the scale, there are real and close, geographical, or political and economic relationships among cities. They form the spatial structure of a certain region together, which determines the comprehensive development level of provincial cities and influences the radiation and driving effect of rural sustainable development. When the previous academic points of view are put into the system theory, the urbanization model supporting the transfer of rural labor to big cities is essentially a kind of development with concentrated regional spatial structure, while the other is a form with a flat regional spatial structure. Obviously, previous studies have ignored the important influence of regional spatial structure on rural development.

The second deficiency of existing studies is that China has a vast territory, and there are obvious regional differences in the economic and social development of the eastern, central, and western regions. This is a very significant feature, which has been ignored by the existing research. Li and Sun et al. (2018) found that single centers of prefectural regions had better performance when analyzing whether single-center or multi-center spatial structure could bring higher productivity, but they did not further analyze regional heterogeneity (Wan et al., 2018). Lan and Da et al. (2019) took urban agglomerations as the basic unit of research and found that urban agglomerations showed an obvious trend and had an important impact on regional functions and sustainable development; while they did not study regional differences from the perspective of spatial correlation (Lan et al., 2019). However, it is very important to discuss regional heterogeneity of urbanization spatial structure, which involves the formulation of urbanization policies at the national level. If regional differences are small, a common urbanization policy is appropriate; otherwise, it means that one standard is not applicable to all regions (Yacouba and Oluyemi, 2022).

Aiming at the deficiencies of previous research, this research attempts to study the impact of China's provincial spatial structure on rural sustainable development. Compared with existing research, the main contribution of this research is to develop the spatial structure of urbanization in different ways according to local conditions. To the best of our knowledge, the agglomeration effect promotes sustainable rural development and provides a reference for decision-making. The reason is that the province is the basic unit and carrier of China's economic development, and China's regional and policy differences are mainly reflected at the provincial level. Therefore, it is more practical to discuss the relationship between regional spatial structure and sustainable rural development from the perspective of the province value (Tian, 2015; Mao et al., 2019). In addition, this study is closely related to China's

urban and rural development policies. In recent years, policies related to urbanization and rural revitalization and development issued by Chinese governments have all pointed out the need to build a coordinated development pattern of large, medium, and small cities and enhance the ability of cities to stimulate rural development, but have not clarified the scale structure relationship between large and small cities in each region.

Compared with previous studies, our second contribution is to comprehensively measure the level of sustainable rural development from three dimensions: economy, society, and environment. This is the first study to observe rural development from multiple dimensions. It is very important to comprehensively detect the multi-dimensional development level of rural areas, which can avoid the overestimation of the sustainable development level of rural areas by existing studies. Only by accurately understanding the level of regional rural sustainable development and its evolution trend can we provide more targeted guidance for the policy-making of regional urbanization spatial structure.

The third contribution is that we discuss three intermediate influence paths of urbanization spatial structure on rural sustainable development, which comprehensively reflects the impact of different provincial spatial structure types on rural sustainable development in three ways. In this way, it can directly provide a reference for provinces with corresponding spatial structure types to make development path decisions.

The fourth contribution is to explore the heterogeneity of the urbanization mode's impact on rural sustainable development, which involves the convergence of regional urbanization policy-making in China. A notable feature of China that has also been overlooked is its vast territory and large population, with distinct regional disparities in economic and social development between the east, central, and western regions. Therefore, similar development plans may help backward areas to promote sustainable rural development and achieve common progress of urban and rural areas by adjusting urbanization spatial planning. However, from the perspective of long-term development goals, the subsequent development process may need to be adjusted and updated from specific development approaches.

Only a reasonable spatial structure of urbanization can give full play to the effect of a regional-scale economy, improve the level of economic development, and increase the demand for rural factors and products, thereby promoting the sustainable development of rural areas. Under the cyclic accumulation effect, the agglomeration externalities (sharing effect, matching effect, and learning effect) generated by the concentration of spatial structure will affect the sustainable development of rural areas through the three factors: regional urban population size, industrial structure, and foreign investment (Udemba and Keles, 2021). First of all, the size of the regional urban population, especially the size of central cities, largely determines the scale economy effect of regional development, thus affecting farmers' income and rural ecological environment. The continuous concentration of regional spatial structure will expand the population scale of central cities, promote the reasonable division of labor of specialized producers, improve labor productivity, and thus enhance the absorption capacity of the labor force. Under the cyclic accumulation effect, the rural labor force is more inclined to transfer to central cities and increase labor income (Ke and Zhao, 2014; Wang and Li, 2015). In the face of the decreasing rural labor force and the expansion of per capita agricultural production scale, agricultural technologies that substitute the labor force and improve land productivity will be constantly updated to improve agricultural productivity and reduce environmental pollution caused by low-level technological production conditions (Li and Shao, 2017; Edmund, 2021).

Second, the regional industrial structure will affect the absorption capacity of the rural labor force and agricultural science and technology innovation ability. With economic development, developed regions will continue to face severe constraints on the price of labor, land, and other factors, and the labor-intensive secondary industry will gradually shift to central cities in underdeveloped regions (Sun et al., 2018). Therefore, the concentration of the spatial structure is helpful to give play to regional comparative advantages, improve the efficiency of resource allocation, promote industrial development, increase the output value and government tax revenue, and promote the government to improve farmers' social welfare. At the same time, it can enhance the employment absorption capacity of the labor force and increase farmers' income. Of course, it is also conducive to expanding agricultural production scale and improving agricultural mechanization and other scientific production levels to improve the rural ecological environment.

Finally, the scale advantage formed by the agglomeration development of regional central cities can attract foreign-invested enterprises to settle in, stimulate the employment of the labor force in the investment area and increase the tax revenue of local governments (Lan et al., 2012). Foreign investment in agriculture can directly improve the level of agricultural science and technology, improve the production efficiency of land per unit area, increase farmers' income and improve their welfare level (Edmund, 2022). At the same time, it can also reduce the excessive use of chemical fertilizers caused by labor fragmentation and small-scale operation, and the resulting pollution of the rural ecological environment (Lan et al., 2012; Edmund, 2021). Under the effect of cyclic accumulation, economic development in different regions forms different path-dependent characteristics. Therefore, different regional spatial structures influence rural development in three ways, that is, urban population size, industrial structure, and foreign investment.

Based on the aforementioned discussion, we propose the following scientific questions: 1) how do different spatial

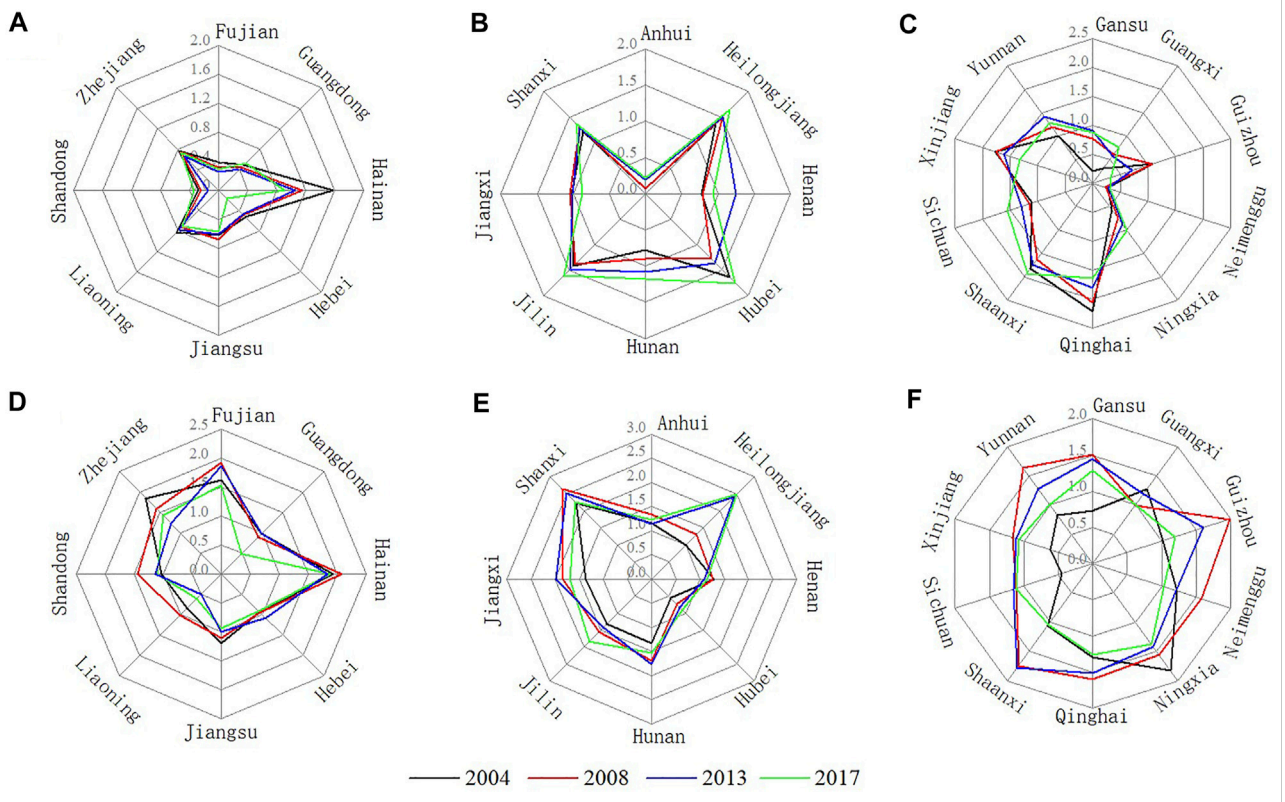

FIGURE 1
Temporal and spatial evolution trends of the spatial structure index of urbanization **(A–C)** and rural sustainable development efficiency **(D–F)**.

structures affect rural sustainable development? 2) Are there differences in the influence of provincial spatial structure between the three regions (eastern, central, and western) with different development levels? 3) How do the three factors of urban scale, industrial structure, and foreign investment serve as mediators? To answer these questions, this study collects panel data from 26 provinces in China from 2004 to 2017 and uses data envelopment analysis (DEA) and the rank-size rule to measure rural sustainable development and the provincial spatial index. It then constructs an econometric model based on rural development and the urban scale structure index to analyze the impact of provincial spatial structure on rural development and its influencing factors.

2 Data and methods

2.1 Determination of rural sustainable development efficiency

The concept of sustainable development has been widely used, which involves multi-dimensional comprehensive development (Wei, 2015). Generally speaking, it mainly includes three major systems: economic development, social security, and ecological environment, which are also the core elements of sustainable rural development (Giovanni et al., 2016; Zhang et al., 2016; Li et al., 2019b; Li et al., 2019c). According to existing studies, the measurement of rural sustainable development can be divided into two categories. One is to measure the level of sustainable development by using the entropy weight method. After selecting multiple indicators in the three systems, the entropy weight method is used to calculate the weight of the three systems, respectively, and the final level of rural sustainable development is summed up (Liu, 2013; Xiao and Chen, 2013; Qin et al., 2016). The second type uses the data envelopment analysis (DEA) method to measure sustainable development efficiency from the perspective of input and output, which is relatively rare. Ye (2016) used DEA method to measure the efficiency of sustainable development in rural areas of Yunnan Province.

The advantages of this method are as follows: First, there is no need to manually set the functional relationship between input and output, and input–output efficiency is measured more objectively (Ren et al., 2018). Second, the non-expected output factors can be included in efficiency calculation to evaluate the

development effect from two aspects of "good" and "bad" (Cooper et al., 2007). Third, this method can further distinguish effective DMU and avoid the problem that the efficiency of DMU cannot be measured because there may be multiple DMUs with the maximum efficiency of 1 in the results of the traditional DEA model (Andersen and Petersen, 1993). Accordingly, the second method is adopted in this study. However, the complexity and regional differences in the evolution process of rural development make some output factors zero. Therefore, the input-oriented–super-efficient SBM model with unexpected outputs is finally selected in this study. The model is set as follows:

$$\min \rho = \frac{1 + \frac{1}{m}\sum_{i=1}^{m}\left(s_i^- / x_{ik}\right)}{1 - \frac{1}{q_1+q_2}\left(\sum_{r=1}^{q_1} s_r^+ / y_{rk} + \sum_{t=1}^{q_2} s_t^{b-} / b_{rk}\right)} \quad (1)$$

$$s.t. \sum_{j=1, j\neq k}^{n} x_{ij}\lambda_j - s_i^- \leq x_{ik}$$

$$\sum_{j=1, j\neq k}^{n} y_{rj}\lambda_j + s_r^+ \geq y_{rk}$$

$$\sum_{j=1, j\neq k}^{n} b_{tj}\lambda_j - s_t^{b-} \leq b_{tk}$$

$$1 - \frac{1}{q_1+q_2}\left(\sum_{r=1}^{q_1} s_r^+ / y_{rk} + \sum_{t=1}^{q_2} s_t^{b-} / b_{rk}\right) > 0$$

$$\lambda, s^-, s^+ \geq 0$$

$$i = 1, 2, \ldots, m;\ r = 1, 2, \ldots, q;\ j = 1, 2, \ldots, n;\ j \neq k$$

Equation 1 is used to measure the efficiency ρ of the evaluated DMU_k. There are m input factors x_i, q_1 expected output factors y_{rk}, and q_2 unexpected output factors b_{rk}; s_i^-, s_r^+, s_t^{b-} are the redundancy of input factors, the deficiency of expected output factors, and the redundancy of unexpected output factors, respectively; and λ_j is the coefficient of DMU_j.

2.2 Determination of regional urbanization spatial structure index

In this study, the province is used as the basic spatial scale, and the rank-size rule is used to measure regional urban scale structure index (Batty, 2008; Meijers, 2008; Burger et al., 2014; Li and Liu, 2018). The province is the basic unit and carrier of China's economic development, and regional and policy differences in China are also mainly reflected at the provincial level. Therefore, it is most practical to explore the relationship between regional spatial structure and rural sustainable development from the provincial perspective (Tian, 2015; Mao et al., 2019).

$$lnP_i = C - q\,ln(R_i - 1/2) \quad (2)$$

In Eq. 2, P_i and R_i are the total population of city i and the rank of the population in its province, respectively. To eliminate the deviation caused by the autocorrelation problem of small samples, we change the dependent variable (logarithm of bit order 1) to the logarithm of (i-1/2) (Gabaix and Ibragimov, 2011). According to the method of Meijers and Burgeret (2010), Eq. 2 is used to regress the top two, top three, and top four cities, and for provinces with fewer than four cities considered, the highest rank is used. Then, the average of q of the three regressions is used as the provincial spatial structure index (Meijers and Burger, 2010). The larger the q, the more concentrated the provincial spatial structure. When the q is equal to 1, the urban scale structure fully follows the rank-size rule.

2.3 Econometric model setting and estimation method

In this study, three econometric models are used to test the relationship between the provincial spatial structure and rural sustainable development efficiency (Batty, 2008; Meijers, 2008; Burger et al., 2014; Li and Liu, 2018). In the test process, the logarithm of all variables is taken to reduce the heteroscedasticity. The final models are as follows:

$$lnre = c + \beta_0\, ln\, q_{i,t} + \beta_1\, ln\, control_{i,t_{i,t}} + \delta\, ln\, re_{i,t-1} + \mu_i + \theta_t + \varepsilon_{i,t} \quad (3)$$

$$lnre = c + \beta_0\, ln\, q_{i,t} + \beta_1\, ln\, up_{i,t} + \beta_2\, ln\, q_{i,t} * lnup + \beta_3\, ln\, control_{i,t_{i,t}} + \delta\, ln\, re_{i,t-1} + \mu_i + \theta_t + \varepsilon_{i,t} \quad (4)$$

$$lnre = c + \beta_0\, ln\, q_{i,t} + \beta_1\, ln\, is_{i,t} + \beta_2\, ln\, q_{i,t} * lnis_{i,t} + \beta_3\, ln\, control_{i,t_{i,t}} + \delta\, ln\, re_{i,t-1} + \mu_i + \theta_t + \varepsilon_{i,t} \quad (5)$$

$$lnre = c + \beta_0\, ln\, q_{i,t} + \beta_1\, ln\, sfdi_{i,t} + \beta_2\, ln\, q_{i,t} * lnsfdi_{i,t} + \beta_3\, ln\, control_{i,t_{i,t}} + \delta\, ln\, re_{i,t-1} + \mu_i + \theta_t + \varepsilon_{i,t} \quad (6)$$

Equation 3 is the basic model for judging the relationship between urbanization spatial structure and rural sustainable development. Eqs 4–6 are used to examine the influence mechanism of urban population size, industrial structure, and foreign investment on the aforementioned relationship. In the equations, i represents the province, t indicates the year, re is rural sustainable development efficiency, $q_{i,t}$ is the urbanization spatial structure index, and $\ln re_{i,t-1}$ is the spatial structure index with a 1-year lag, which is used to control and examine the time-lagging effect of the changes in rural sustainable development efficiency. Control variables include environmental regulation, technological progress, urban population size, and economic development level. The variables $c, \beta_0 - \beta_3$ are the coefficients to be estimated, δ is the coefficient of the time lag term for the urban scale structure index, μ_i represents the regional fixed effect, θ_t represents the time fixed effect, and $\varepsilon_{i,t}$ is the random disturbance term.

In this study, generalized moments of dynamic systems (SGMM) were used to test the impact of urbanization spatial structure on rural sustainable development (Lu and Feng, 2014;

Li et al., 2019c). It is mainly to avoid potential endogenous bias in the following problems. First of all, there may be a mutually causal relationship between the spatial structure of urbanization and sustainable rural development, and the current efficiency of sustainable rural development will also be affected by previous development. Secondly, in the economic and social system, there are often unobservable factors that affect the sustainable development of rural areas, and fixed-effect or random-effect estimation methods will reduce the validity of the estimation results to a certain extent. Although the generalized moment of difference can avoid the aforementioned problems, the generalized moment of the system combines the difference equation and the horizontal equation at the same time, which has more advantages in the estimation effect (George and Epameinondas, 2013; Hao et al., 2015; Yue et al., 2018).

2.4 Data specification

When measuring rural sustainable development efficiency, this study uses five variables as input factors (Han and Liu, 2018; Huang et al., 2018): 1) land: the total sown area of the major crops (in thousands of hectares); 2) water: the total agricultural water use (in 100,000 km^3); 3) electricity: rural electricity consumption (in 100,000,000 kWh); 4) people: total rural laborers (in 10,000) (Huang et al., 2018); and 5) technical facilities: total power of agricultural machinery (10,000 kW). Six variables are selected as the output factors, which are divided into two categories, expected factors and unexpected factors, and they are 1) the level of rural economic development, which is represented by the per capita income of farmers (in RMB) and the proportion of salary income to total income; 2) the level of agricultural modernization, which is represented by the total power of agricultural machinery (in 10,000 kW); 3) the level of rural social security, which is represented by the number of doctors and health workers per thousand agricultural population and funds for rural minimum subsistence allowances (in 100 million RMB); and 4) the rural ecological–environmental level, which is represented by forest coverage as the expected factor and the excess of soil total nitrogen (STN) over the standard as the unexpected factor. In this study, when calculating the excess of STN over the standard, the factors of 180 kg of STN per hectare and the sown area are used, and only the excess over the standard is calculated (%). If the STN is lower than the standard, the value is set to 0; and the output elements of the first two dimensions are all expected elements. The per capita income of farmers and the funds of rural minimum subsistence allowances are converted using the constant price in the year 2000.

When calculating the spatial structure index of provinces, we adopted the year-end population of each prefecture-level city in each province. Furthermore, when estimating the impact of urban scale structure on rural sustainable development efficiency this study introduces six variables described as follows: 1) Urban population scale (up): the urban population at the end of the year is adopted (Lu and Chen, 2004). 2) Industrial structure (is): the proportion of tertiary industry relative to the added value of the secondary industry is adopted (Zhang and Dou, 2015). The industrial structure will affect the non-agricultural employment and income of the rural labor force, and the supply of agricultural production machinery and equipment, chemical fertilizers, and pesticides. 3) Foreign investment (sfdi): the proportion of the total utilized foreign investment in total GDP is adopted, and the currency conversion is performed based on the currency ratio of US dollars to RMB of that year (Shao et al., 2019). 4) Environmental regulation (sitis): the proportion of the total investment in industrial pollution control to GDP is adopted. Environmental regulations may exert great pressure on enterprises to reduce emissions, and enterprises' technological innovation and adoption of green production methods increase production costs significantly, thus inhibiting their demand and plans for labor recruitment and salary increase (Lan et al., 2012). 5) Technological progress (stmt): the proportion of the volume of the business of the technology market to GDP is adopted. Technological progress can promote social development and improve people's quality of life, thus putting forward higher requirements for agricultural products and rural environmental quality (Li and Zhou, 2006; Shao et al., 2019). 6) Economic development level (pgdp): the per capita GDP is adopted. The improvement of regional economic development level can increase the financial expenditure for rural development, providing more employment opportunities, and improving the social security treatment of the rural labor force and rural ecological environment (Cui and He, 2018).

The data sources of this study are the China Statistical Yearbook on Environment, and China Rural Statistical Yearbook. The basic spatial scale analyzed in this study is inland provinces, so Hong Kong, Macao, Taiwan, and municipalities directly under the Central Government, are not taken into account, and Tibet is not included in the scope of this study because there are many missing data.

3 Results

3.1 Spatiotemporal characteristics of urbanization spatial structure and rural sustainable development efficiency

From the perspective of regional spatial structure, during the study period, except for Hainan Province, the spatial structure index of other provinces in the eastern region was less than 1, and the spatial structure index showed a downward trend (Figure 1A), indicating that eastern China has been flat since 2004, and there is a possibility that the spatial structure flattening will intensify as time goes by. However, the spatial structure index of the central and western regions is greater than 1 and has

an upward trend (Figure 1A), indicating that the spatial structures of provinces in central and western regions are relatively concentrated and developing in a more central direction.

From the perspective of regional sustainable development efficiency of rural areas, during the study period, most of rural sustainable development efficiency in the eastern region was higher than 1.5 at the initial stage and gradually decreased to below 1.5 (Figure 1D), indicating that rural areas in the eastern region have not achieved sustainable development. However, the sustainable development efficiency of rural areas in most provinces in the central region was less than 1 at the beginning of the study but exceeded 1 at the end of the study, and some exceeded 1.5, indicating that rural areas in central China have maintained a relatively stable sustainable development trend (Figures 1E and F); in addition, the average efficiency of rural sustainable development in central China at the end of the study period also exceeds that in eastern China. Compared with the eastern and central regions, the efficiency of rural sustainable development in the western region reached its peak in 2008, and then gradually declined. By the end of the study, the efficiency of rural sustainable development in all provinces fell below 1.5. The aforementioned results indicate that there is no advantage to backwardness in western China, and the efficiency of rural sustainable development in most provinces is in a declining state (Figure 1F).

3.2 Impact of urbanization spatial structure on rural sustainable development

Table 1 shows the estimation results of Eq. 3, which examines the impact of provincial spatial structure on rural sustainable development. The *p*-values of the transition identification test results are all greater than 10%, indicating that the instrumental variables are all valid through the transition identification test. The *p*-values of the second-order sequence autocorrelation are all greater than 10%, indicating that there is no second-order sequence autocorrelation in the disturbance term. Therefore, it is reasonable to use the system generalized moment method for data analysis in this study.

Generally, the centralization of provincial spatial structure in China has a negative impact on the reduction of the efficiency of rural sustainable development (negative 0.046%, Table 1). Regionally, the negative impact of provincial spatial structure on rural sustainable development is related to the eastern and western regions of China, and the positive impact is only related to the central region of China.

Among the other variables, 1) the coefficient of *lnis* is 0.108, and significantly positive only in column 2, indicating that an industrial structure upgrade only in the east region could stimulate rural sustainable development; 2) the coefficient of *lnsfdi* is significantly negative only in column 4, showing that foreign investment reduces rural sustainable development efficiency in the western region only; 3) the coefficient of *lnup* is significantly negative in all columns, showing that the expansion of the urban population has no positive effect on rural sustainable development; 4) the coefficient of *lnsitis* is significant in column 2 and 3, implying that environmental regulation promotes rural sustainable development both in the east and central regions; 5) the coefficient of *lnstmt* is significantly negative only in column 3, implying that technological progress in the central region reduces rural sustainable development efficiency; 6) the coefficients of *lnpgdp* are 0.073 and 0.065, significantly positive in columns 2 and 3, indicating that the improvement in the economic development level in the east and central regions can promote rural development; 7) the coefficient of *L.lnre* is significant at the level of 1%, indicating that the low rural sustainable development efficiency in the current period

TABLE 1 Regional differences in the impact of urbanization spatial structure on rural sustainable development.

Explained variable	(1)	(2)	(3)	(4)
lnre	Full	Eastern	Central	Western
L.lnre	0.692***	0.888***	0.508***	0.666***
	(0.081)	(0.055)	(0.111)	(0.094)
lnq	−0.046**	−0.063**	0.016***	−0.150**
	(0.065)	(0.034)	(0.055)	(0.076)
lnis	−0.240**	0.108***	−0.226***	−0.686**
	(0.103)	(0.102)	(0.109)	(0.494)
lnsfdi	−0.021**	0.029***	−0.011*	−0.032**
	(0.018)	(0.020)	(0.013)	(0.094)
lnup	−0.199**	−0.007***	−0.023*	−0.257***
	(0.085)	(0.037)	(0.091)	(0.094)
lnsitis	−0.051**	0.012**	0.070***	−0.091**
	(0.034)	(0.020)	(0.031)	(0.083)
lnstmt	−0.036	0.016	−0.180***	0.008
	(0.025)	(0.020)	(0.048)	(0.013)
lnpgdp	0.141*	0.073**	0.065**	0.187
	(0.091)	(0.043)	(0.235)	(0.375)
Time effect	Yes	Yes	Yes	Yes
Province effect	Yes	Yes	Yes	Yes
Constant	−1.064	−0.479	0.156	4.891
	(0.784)	(0.734)	(0.522)	(1.750)
N	338	105	103	130
F (Wald) [P]	0.000	0.000	0.000	0.000
AR (1) [P]	0.003	0.008	0.019	0.009
AR (2) [P]	0.180	0.129	0.556	0.169
Sargan [P]	0.244	0.978	0.363	0.116

Note: ***, **, and * represent significance levels of 0.01, 0.05, and 0.1, respectively. Standard errors are reported in parentheses.

could reduce the level of rural sustainable development in the next period.

It can be seen from the fact that the coefficients of the interaction term are significantly negative in column 1 of Table 2, from the overall point of view, the expansion of the urban population in China's provinces has not enhanced the radiation and driving effect of concentrated development of spatial structure on rural sustainable development. From a regional perspective, the same is true in the eastern and western regions (the cross coefficient of column 2 and Column 4 is negative), but the difference is the expansion of urban population size in the central region enhances the radiating and driving effect of provincial spatial structure concentration on rural sustainable development.

In the first column of Table 3, the coefficient of the interaction term of *lnis* and *lnq* is significantly negative, indicating that industrial structure has a significant impact, but the upgrading of industrial structure cannot enhance the stimulation effectively enhance the positive impact of spatial structure concentration on rural sustainable development nationwide. From a regional point of view, the upgrading of industrial structure is helpful to enhance the promotion effect of spatial structure concentration in eastern China on rural sustainable development. However, the central and western regions are on the contrary.

In order to further verify the difference in the effect of industrial structure on rural sustainable development in different regions of urbanization, Table 4 shows the test results after using the proportion of secondary and tertiary industries out of total GDP (is2, is3) as the indicators of industrial structure upgrading in representative in Table 3. In column 1 of Table 4, the interaction term of *lnis2* and *lnq* is significantly negative (−0.273), while the interaction term of *lnis3* and *lnq* in column 4 is significantly positive (0.453), indicating that the agglomeration of the tertiary industry is conducive to enhancing the radiation driving effect of the centralized development of spatial structure on rural areas in eastern China. In columns 2 and 3, the coefficient of the interaction term are positive, while in columns 5 and 6, the coefficient of the interaction term is significantly negative, which further indicates that the upgrading of industrial structure is not conducive to enhancing the promotion effect of centralized spatial structure on rural development in central and western China.

From Table 5, we can see that *lnq* is significantly negative in columns 2 and 3, but the coefficient of the multiplication term with *lnsfdi* is significantly positive (0.13, 0.043) in columns 2 and 3, indicating that foreign investment can enhance the role of current urban structure in promoting sustainable rural development in eastern and central China, and this role is greater in eastern China than in central China. The interaction coefficient in Column 1 and column 4 is significantly negative at the confidence level of 5 and 10%, respectively, indicating that foreign investment has not strengthened the positive impact of the current urbanization pattern in the western region and China as a whole on sustainable rural development.

TABLE 2 Estimation results of urban scale influence.

Explained variable	(1)	(2)	(3)	(4)
lnre	Full	Eastern	Central	Western
L.lnre	0.742***	0.858***	0.548***	0.648***
	(0.075)	(0.078)	(0.099)	(0.076)
lnq_up	−0.080**	−0.094***	0.246***	−0.224***
	(0.036)	(0.050)	(0.113)	(0.073)
lnq	0.541*	0.082**	−0.639**	0.466***
	(0.280)	(0.406)	(0.865)	(0.474)
lnup	−0.170**	−0.106***	−0.072**	−0.160**
	(0.061)	(0.062)	(0.042)	(0.082)
Control variables	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
Province effect	Yes	Yes	Yes	Yes
Constant	−0.594	−0.471	0.065	0.732
	(0.806)	(0.846)	(2.265)	(2.932)
N	338	105	103	130
F (Wald) [P]	0.000	0.000	0.009	0.000
AR (1) [P]	0.004	0.007	0.018	0.016
AR (2) [P]	0.181	0.103	0.497	0.200
Sargan [P]	0.581	0.775	0.775	0.105

Note: ***, **, and * represent significance levels of 0.01, 0.05, and 0.1, respectively. Standard errors are reported in parentheses.

4 Discussion

4.1 Impact of the urbanization spatial structure on rural sustainable development and regional differences

In China, the provincial urbanization pattern in the developed eastern regions is not characterized by continuous high concentration, while the spatial structure is neither very flat in the central nor western regions (Figures 1A–C). It is consistent with the study of Lu Ming and Li et al. (2019), who adopted the ratio of urban population size as the proxy for the spatial concentration of regional population. By comparing it with developed countries and developing countries with similar development stages, it is found that the regional concentration of the urban population in China is very low (Lu et al., 2019). However, it is not conducive for us to have a more microscopic understanding of the urbanization mode in a smaller geographical range in China for the basic unit of this study is the country. A study using city area and urban agglomeration as basic units makes up for the aforementioned deficiency. For

TABLE 3 Estimated results of the industrial structure influences (1).

Explained variable	(1)	(2)	(3)	(4)
lnre	Full	Eastern	Central	Western
L.lnre	0.894***	0.874***	0.481***	0.649***
	(0.041)	(0.072)	(0.112)	(0.078)
lnq_is	−0.125***	0.155***	−0.140***	−0.733***
	(0.068)	(0.089)	(0.073)	(0.139)
lnq	0.535**	−0.694**	0.593**	3.050***
	(0.286)	(0.380)	(0.305)	(0.592)
lnis	0.043**	0.120***	0.359***	−0.433**
	(0.063)	(0.133)	(0.157)	(0.238)
Control variables	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
Province effect	Yes	Yes	Yes	Yes
Constant	0.175	−0.161	0.230	2.737***
	(0.293)	(1.127)	(1.258)	(1.059)
N	338	105	103	130
F (Wald) [P]	0.000	0.000	0.000	0.000
AR (1) [P]	0.008	0.007	0.045	0.031
AR (2) [P]	0.181	0.123	0.513	0.367
Sargan [P]	0.941	0.887	0.670	0.110

Note: ***, **, and * represent significance levels of 0.01, 0.05, and 0.1, respectively. Standard errors are reported in parentheses.

example, Wang and Ni et al. (2019) found in their research on the spatial structure and polycentric evolution of China's urban agglomeration system that the spatial form of China's urban agglomeration system is reflected in the concentration of population in the eastern and central regions and the dispersion of population in the western and northeastern regions (Hua and Sun, 2015). Li and Sun et al. (2019) take the city area as the research scale and point out that the spatial structure of Chinese cities is bounded by Hu Huanyong Line. They found the urban spatial structure on the west side of the line is flat, while the urban spatial structure on the east side is obviously concentrated (Li et al., 2018b). Additionally, they analyzed the causes of this feature. But unfortunately, they did not further analyze the possible impact of this spatial structure feature on the sustainable development of rural areas. Some researchers have analyzed the spatial structure of the top ten urban agglomerations in China and found that their average primacy gradually increases from east to west, and regional differences are very obvious. They further pointed out that the western region should imitate the developed eastern region and promote the polycentric pattern structure in policy to achieve the balanced development goal (Huang et al., 2016; Wang et al., 2019). Although the above studies have positive policy implications from both macro and micro perspectives, and regional differences in China's urbanization model have also been clearly pointed out, the policy implications are difficult to translate into practical operation. As the basic development unit of provinces is the main carrier of government policy formulation and implementation, and also the main factor affecting the flow of population, it has been shelved in an invisible corner.

Figure 1F shows that rural sustainable development in the central region of China remains stable, while it does not maintain its good state in the eastern and western regions. The measurement and analysis of the evolution characteristics of the efficiency of rural sustainable development (Figures 1D–F) mentioned in this study are rarely seen in relevant studies. Pang and Chen et al. (2016) focused on the exploration of the significance of ecological efficiency of rural agriculture for rural sustainable development and found that most of the places with high agricultural ecological efficiency in China are located in areas with a more concentrated population (Pang et al., 2016). Zhang and Wu (2015) believed that infrastructure is crucial for balanced urban–rural development and sustainable development in rural areas should start from coordinated public facility projects (Zhang et al., 2015). Huang and Scott et al. (2020) found that rural economic development requires the common progress of agriculture and other industries when analyzing the important role of continuous institutional reform, technology, and capital investment in promoting China's rural development achievements in recent decades (Huang et al., 2020). It can be seen that the research findings of this study are a synthesis of various existing studies on rural development.

No matter from the perspective of the whole or in terms of sub-regions, flat regional spatial structure is not conducive to the sustainable development of rural areas (Table 1). First, eastern China presents a flat structure and has a negative impact on sustainable rural development. The balanced development policies in eastern China have resulted in flat provincial spatial structure, thus hindering the full play of the scale effect and spreading the effect of large cities (Ding et al., 2015). From the perspective of city primacy, the primacy of big cities in eastern China is far lower than that of London, Seoul, Lima, and other cities (Chen and Lu, 2014). Therefore, it will be more beneficial to promote the synchronous and sustainable development of rural areas in terms of policy-making to continue the centralized development of the spatial structure of the eastern region. For this point in the central region, the central region belongs to the centralized spatial structure, and the central city has a certain scale, the potential market scale effect, which can promote the urban expansion of the rural labor force and the demand of the agricultural and rural environment. At the same time, it also helps the diffusion of funds and technologies to rural areas (Lu and Wan, 2014), and supports the development of rural agriculture and the promotion of welfare security.

TABLE 4 Estimated results of the industrial structure influences (2).

Explained variable	(1)	(2)	(3)	(4)	(5)	(6)
lnre	Eastern	Central	Western	Eastern	Central	Western
L.lnre	0.906***	0.514***	0.733***	0.902***	0.489***	0.695***
	(0.066)	(0.135)	(0.068)	(0.071)	(0.106)	(0.055)
lnq_is2	−0.273**	0.357**	1.316***			
	(0.144)	(0.163)	(0.332)			
lnis2	−0.185*	−0.296**	1.029**			
	(0.147)	(0.214)	(0.623)			
lnq_is3				0.453**	−0.351**	−1.144***
				(0.262)	(0.183)	(0.390)
lnis3				0.419***	0.282**	−0.212**
				(0.230)	(0.331)	(0.527)
lnq	−0.047**	−0.308**	−1.064***	−1.663**	1.288**	0.940***
	(0.588)	(0.630)	(1.374)	(0.975)	(0.658)	(1.374)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes
Province effect	Yes	Yes	Yes	Yes	Yes	Yes
N	105	103	130	105	103	130
F (Wald) [P]	0.000	0.025	0.000	0.000	0.028	0.000
AR (1) [P]	0.007	0.015	0.019	0.007	0.029	0.019
AR (2) [P]	0.101	0.586	0.296	0.104	0.484	0.317
Sargan [P]	0.610	0.656	0.241	0.798	0.584	0.120

Note: ***, **, and * represent significance levels of 0.01, 0.05, and 0.1, respectively. Standard errors are reported in parentheses.

It is easy to draw attention to the fact that the western region also presents a centralized spatial structure, but it has a negative impact on rural sustainable development. It may be because western China is still in the stage of accumulation and development of large cities, the scale effect of large cities is not strong, and the population of most large cities is only about 2 million. It is difficult for the small-scale market to provide more employment opportunities for redundant rural laborers and produce a large demand for agricultural products. At the same time, it is difficult to reduce the production cost of enterprises, promote enterprises to increase capital and innovation, and improve the technical level. Ultimately, it is difficult to significantly improve the development of rural economy, social security, and ecological environmental protection system (Lu et al., 2011).

The aforementioned findings do not agree with those of Liu and Li et al. (2017), they point out that the provincial urbanization should be developed into a polycentric spatial structure. Because it helps to improve the efficiency of urban economic development, however, the development of the city is inseparable from rural areas (Liu et al., 2017). In addition, they ignore the characteristics of China, which is the bigger difference in regional development. Other studies have found that the economic radiation effect is more obvious in the surrounding areas with a higher level of economic development, better infrastructure conditions, and larger urban scale (Liu, 2018). Obviously, the premise of this result is that the region has a strong development core, but there is no multi-dimensional analysis of rural sustainable development. Our findings clarify the impact of regional spatial structure on rural sustainable development, rather than stay in the impact of urban economic development and rural development of a single dimension.

4.2 Influencing ways of urbanization spatial structure on rural sustainable development

In the eastern, central and western regions of China, urban population scale, industrial structure and foreign investment have played different roles in the impact of urbanization spatial structure on rural development (Figure 2).

In eastern China, industrial structure and foreign investment have a positive impact on the sustainable development of rural areas, while the expansion of urban population has a negative impact (Figure 2A). However, the eastern region is still the main destination of China's population flow. Therefore, adjusting the

TABLE 5 Estimated results of the FDI influence.

Explained variable	(1)	(2)	(3)	(4)
lnre	Full	Eastern	Central	Western
L.lnre	0.731***	0.905***	0.524***	0.688***
	(0.071)	(0.051)	(0.100)	(0.106)
lnq_sfdi	−0.084***	0.130***	0.043***	−0.126***
	(0.045)	(0.055)	(0.025)	(0.059)
lnq	−0.028**	−0.119***	−0.035**	0.033***
	(0.058)	(0.060)	(0.030)	(0.121)
lnsfdi	−0.002**	0.038**	−0.040***	−0.041**
	(0.022)	(0.034)	(0.009)	(0.025)
Control variables	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes
Province effect	Yes	Yes	Yes	Yes
Constant	0.734*	−1.514**	0.518*	2.097**
	(0.594)	(0.730)	(1.044)	(1.094)
N	338	105	103	130
F (Wald) [P]	0.000	0.004	0.016	0.000
AR (1) [P]	0.002	0.006	0.029	0.017
AR (2) [P]	0.185	0.178	0.469	0.186
Sargan [P]	0.224	0.931	0.917	0.158

Note: ***, **, and * represent significance levels of 0.01, 0.05, and 0.1, respectively. Standard errors are reported in parentheses.

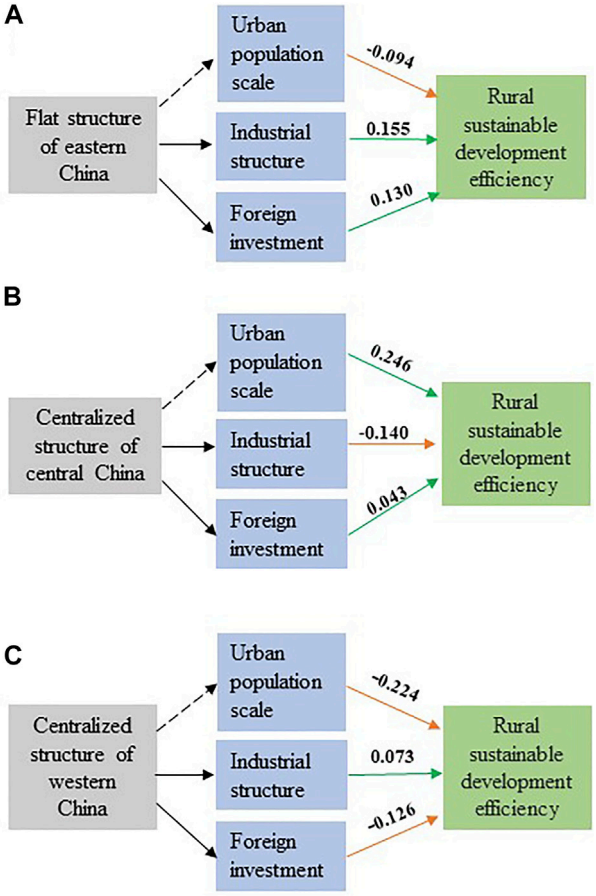

FIGURE 2
Influencing ways of provincial spatial structure on rural sustainable development. Note: The value is the coefficient of an interaction term between spatial structure and corresponding path.

spatial structure is one of the most powerful measures for urbanization to drive rural development.

The urban population scale and foreign investment in central China can promote the sustainable development of rural areas, while the upgrading of industrial structure can only have the opposite effect (Figure 2B).

The impact of the three approaches on the western region is just opposite to that of the central region (Figure 2C). Although the impact of the urban population scale and foreign investment on the sustainable development of rural areas is negative, they are also the key points to be adjusted in the following urbanization plan in the western region.

4.2.1 Influences of urban population size

We find that the urban population scale in the eastern, central, and western regions showed an expanding trend during the study period, but such expansion is only conducive to the driving effect of centralized urbanization mode in the central region, which can affect rural sustainable development (Figure 2; Table 2). The expansion of the urban population in central China is mainly reflected in the central cities of the province, and the agglomeration advantage of big cities has been fully brought into play. For example, Hubei province, a powerful province in central China, has 16 prefecture-level cities. In 2018, the total urban population was 35.68 million, 680,000 more than in 2017, among which 26% of the newly increased urban population was in the central city of Wuhan.

In the eastern region, the expansion of the urban population is the simultaneous expansion of multiple cities in the province, and the proportion of the expansion of central cities is not prominent in the newly increased urban population of the province, gradually losing the scale effect accumulated in the past urbanization process, and the form of spatial structure will also show flatness. It is not conducive to improving production efficiency, promoting enterprise innovation, and radiating rural development (Yu et al., 2013). In western China, the expansion of the urban population does not enhance the effect of the centralized spatial structure on the sustainable development of the countryside. The possible reason is that the overall development of the provincial cities is insufficient. Although resources in the western region are concentrated and developed in big cities, big cities themselves are in the accumulation and

development stage of scale effect, and their influence on rural areas is mainly the siphon of resource elements and capital accumulation, with limited driving effect on rural development (Li and Zhang, 2015). However, in the long run, the rapid agglomeration development of big cities can accelerate the end of the siphoning effect on rural areas and realize the radiation driving of rural areas (Liu, 2014). In short, the eastern and western provinces should fully develop big cities according to their own development characteristics, ensure the development scale of big cities, and ensure the primacy of big cities, so as to improve the agglomeration effect and scale return of big cities, enhance the comprehensive strength of regional development, and radiate and drive rural development.

Although the aforementioned results show that in different regions of China's urbanization spatial structure, the expansion of the urban population will have different effects on the sustainable development of rural areas, it is consistent that the expansion of the urban population in central cities has a positive impact on sustainable development. This point is consistent with the existing literature; at the same time, our results once again indicate that there is a gap in the current literature on research objects in this kind of research. For example, When Lan and Da et al. (2019) studied the impact of spatial structure on the sustainable development of urban agglomerations in China, they found that only the expansion of population size in small- and medium-sized cities could have a positive impact. However, the premise of its establishment is a few developed flat urban agglomerations, which are very different from the basic administrative unit provinces, and the constituent cities of urban agglomerations themselves are relatively mature (Lan et al., 2019). An urban agglomeration at a moderate level of development may be able to compare with a province to a certain extent, such as China's Changsha-Zhuzhou-Xiangtan urban agglomeration, Wuhan Urban agglomeration, and Chengdu-Chongqing urban agglomeration. Tan and Ouyang et al. (2019) took the Changsha-Zhuzhou-Xiangtan urban agglomeration as an example to analyze the functional evolution and driving factors of rural development in the urban agglomeration and found that the expansion of the urban population in central cities has a stronger impact on the overall development of surrounding rural areas. Meanwhile, the latest driving force is urbanization, which is the ultimate guiding force for sustainable rural development (Tan et al., 2019). Li and Jia et al. (2018) pointed out that the expansion of the urban population posed severe challenges to the sustainable development of rural areas, such as overexploitation of agricultural land and increase of crop fertilizer application, hollowing out of rural areas, and reduction of agricultural human resources, but they did not take into account the important impact of regional urbanization spatial structure. Moreover, through the intermediary factor of urban population size, there are obvious regional differences in rural multi-dimensional development (Li et al., 2018a; Miquel et al., 2018; Pan et al., 2018; Guo et al., 2019). Therefore, this study has positive policy implications for promoting rural development by promoting a rational urban scale according to local conditions.

4.2.2 Influences of industrial structure

In China, even for provinces with concentrated urbanization spatial structure, only upgrading industrial structure according to local conditions can improve the radiation and driving effect of concentrated urbanization spatial structure on rural sustainable development, such as the developed eastern regions (Tables 3, 4). On the contrary, blindly choosing to upgrade the industrial structure will get the opposite result. As is known to all, the tertiary industry, which is dominated by the service industry, is a dense economy, which requires a large-scale market, and its production and consumption are mostly conducted face-to-face. Therefore, the advanced industrial structure will continue to promote the development of economic agglomeration and form a larger scale. It is not only conducive to driving the development of surrounding small- and medium-sized cities, forming a good economic division of labor and functional complementarity, but also helping to increase jobs and attract rural labor transfer; increasing the market demand for the quantity and quality of agricultural products, to improve rural farmers' income level and ecological environment; and more tax revenue generated by industrial upgrading will help to improve the level of medical care and social security as well as some infrastructure for farmers (Liang and Lu, 2016).

In terms of development basis and location factors, the central and western regions are not as good as the eastern regions. The spatial unbalanced development strategy of the eastern regions has further intensified the ladder of economic development of the three regions, making the dominant industries in the central and western regions gather and develop mainly the second industry closely related to the labor force (Liu et al., 2020). Therefore, if these two regions blindly upgrade the industrial structure, it will only lead to the loss of local industrial advantages and economic support. How can cities radiate and drive rural sustainable development?

The positive significance of the interaction between regional spatial structure concentration and industrial structure on rural sustainable development has been verified in existing studies. Some studies take urban agglomeration as a research unit and find that the agglomeration development of core cities is conducive to promoting the upgrading of industrial structures. For example, Xu and Hu et al. (2015) studied the population agglomeration gradient and frontal structure optimization of urban agglomerations in the Yangtze River Delta and found that the population agglomeration density of urban agglomerations in the Yangtze River Delta was significantly lower than that of similar developmental stages in Japan and South Korea, resulting in a large

gap in the elevation of industrial structure (Xu et al., 2015). Other studies point out that only when cities gather to a certain scale can they extend their strong industrial and service industry chains to rural areas and spread the knowledge and technology spillover effects generated by economies of scale to rural areas to meet the increasingly diversified needs of cities. For example, when Liu and Shen et al. (2020) explored the dynamic mechanism for megacities to enhance rural industrial development, they found that the larger the city scale, the more conducive it is to extend the secondary and tertiary industrial chains to rural areas, integrate with agriculture, and drive agricultural development (Liu et al., 2020). These studies indirectly show that the upgrading of industrial structure can play a role in promoting sustainable rural development in the development of urbanization agglomeration, which is consistent with our findings; however, none of them made a subdivision and comparison of the study area. The further study in this research is a supplement to the existing research. To sum up, China's urbanization should still adhere to the centralized development model of spatial structure, and develop industries with comparative advantages according to local conditions, instead of blindly upgrading the industrial structure to narrow the differences between urban and rural development.

4.2.3 Influences of foreign investment

On the whole, foreign investment had no positive impact on the sustainable development of China's rural areas during the study period (Table 5). Compared with urban population size and industrial structure, foreign investment in the eastern and central regions can effectively promote rural sustainable development, and this effect is larger in the eastern region than in the central region. In contrast, the western region did not enjoy the positive impact of foreign investment on the sustainable development of rural areas. The aforementioned results also indicate that the promotion effect of foreign investment on China's rural sustainable development is mainly hindered by the western region. However, compared with the early stage of reform and opening up, the phenomenon that China lowered the threshold of environmental regulation and introduced a large number of environmentally problematic foreign investment enterprises due to economic development has been improved (Wang and Luo, 2020).

After China's reform and opening-up, foreign investment has been concentrated in the eastern region for a long time due to its path dependence. After the continuous integration with the local market, the foreign investment industry chain gradually extends outward to rural areas, which definitely increases the scale of investment in agriculture. Moreover, it also optimizes the structure of investment in agriculture, and capital and technology investment are gradually increasing become its prominent feature (Zheng and Wang, 2018), which has promoted the development of rural economy and science and technology in the eastern region, and improved the level of rural sustainable development (Kan, 2014). The "crowding" effect has prompted a large number of labor-intensive–foreign-invested industries to be transferred from the east. Due to the gradient of the development stage and the proximity of the distance, the central region is given priority to undertake it, and a large number of rural surplus labors have been absorbed. At the same time, foreign investment in advanced technology and management experience has improved labor productivity and rural labor income level. In addition, these foreign-invested enterprises have also induced the local government to continuously increase investment in education and training, actively promote infrastructure construction, and effectively improve the welfare level of the agricultural registered population through various ways such as cooperation and market expansion (Xiao and An, 2019). However, due to the urgency of economic development and the tendency of some foreign investors to avoid environmental regulations, the western region mainly undertakes high-polluting–foreign-invested enterprises (Edmund and Lucy, 2022). Although foreign investment has played a significant role in promoting economic development and improving infrastructure in western rural areas, environmental degradation will eventually lead to a decline in economic and social welfare.

The aforementioned results also indicate that the promotion effect of foreign investment on China's rural sustainable development is mainly hindered by the western region. However, compared with the early stage of reform and opening up, the phenomenon that China lowered the threshold of environmental regulation and introduced a large number of environmentally problematic foreign investment enterprises due to economic development has been improved (Wang and Luo, 2020). The previous content verifies the previous statement that there is a close relationship between regional spatial structure, foreign investment, and rural sustainable development, among which foreign investment plays an important role, and it is a way for the regional urbanization model to affect rural sustainable development. Existing literature does not directly point out it, but rather places two of them in a single study. For example, Hymer and Kiminoet (2007) pointed out that cities with a large market size in a region will increase their attraction to foreign investment through a specialized economy and diversified economy (Satomi et al., 2007). Hu and Miao et al. (2018) also pointed out that regional core cities often have a large market scale and are easier to attract foreign investment (Hu et al., 2018). Huang and Li et al. (2018) pointed out that in order to promote cluster development, some underdeveloped regions in China significantly lowered the entry threshold for foreign-invested enterprises, resulting in a sharp decline in the overall ecological efficiency of these regions (Liu, 2014; Yue et al., 2018). Other scholars pointed out that foreign investment is an important factor to promote rural development and narrow the gap between urban and rural

areas (Liu et al., 2010; Lan et al., 2012; Wang and Luo, 2020). Udemba (2020) found that foreign investment had a significant negative impact on the ecological footprint when studying the mediating impact of foreign investment and agriculture on the ecological footprint in India (Edmund, 2020). It can be seen that foreign investment plays an important role as an intermediate bridge, and there are obvious regional differences in its role, which has been fully considered in this study.

5 Conclusion

In summary, the results of this study mainly emphasize two aspects: 1) During the study period, China's overall spatial structure concentration of urbanization is low. Meanwhile, the spatial structure of urbanization at the provincial level is flat in eastern China and concentrated in central and western China. 2) In the three regions (eastern, central, and western) with different development levels in China, urban population size, industrial structure, and foreign investment have different effects on rural sustainable development.

This study makes two policy proposals: 1) With the economic and social development, a regional urbanization mode with a concentrated urban scale structure in the future should be more conducive to rural sustainable development in China. The gradual elimination of the restrictions on the citizenization of big cities can promote the full and free flow of urban and rural factors, form the scale effect of central and large cities, and radiate and drive rural sustainable development; 2) China's regional development varies greatly, and it is necessary to take advantage of comparatively advantageous industries and foreign investment according to local conditions. At the same time, the central and western regions should pay special attention to avoiding the blind pursuit of advanced industrial structure and negative externalities of foreign investment environment on the sustainable development of rural areas.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization, DH and QZ; Methodology, DH; Validation, DH; Data curation, DH; writing—original draft preparation, DH; All authors have read and agreed to the published version of the manuscript.

Conflict of interest

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

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.938897/full#supplementary-material

References

Andersen, P., and Petersen, N. C. (1993). A procedure for ranking efficient units in data envelopment analysis. *Manag. Sci.* 39, 1261–1264. doi:10.1287/mnsc.39.10.1261

Batty, M. (2008). The size, scale, and shape of cities. *Science* 319, 769–771. doi:10.1126/science.1151419

Burger, M. J., van der Knaap, B., and Wall, R. S. (2014). Polycentricity and the multiplexity of urban networks. *Eur. Plan. Stud.* 22, 816–840. 32. doi:10.1080/09654313.2013.771619

Chen, B., and Lin, Y. (2013). Development strategy, urbanization and the rural-urban income disparity in China. *Soc. Sci. China.* 4, 81–102. 206.

Chen, Z., and Lu, M. (2014). How big should the first city be? -- the impact of country size, globalization and urbanization. *Acad. Mon.* 46 (05), 5–16. doi:10.19862/j.cnki.xsyk.2014.05.001

Cheng, Y., and Zhai, Y. (2015). The inequality effect of social integration in urbanization. *Soc. Sci. China.* 6, 78–95.

Cooper, W., Seiford, L., and Tone, K. (2007). *Data envelopment analysis: A comprehensive text with models, applications, references and DEA-solver software.* Kluwer Academic Publishers.

Cui, W., and He, C. (2018). The effect of urbanization on rural poverty reduction: Theoretical mechanism and empirical test. *Econ. Sci.* (04), 89–102. doi:10.12088/PKU.jjkx.2018.04.07

Ding, C., Liang, Z., and Chang, L. (2015). Urban size distribution and regional economic growth —— Evidence from China. *World Econ.* 5, 91–117.

Edmund, N. U. (2022). Lucy davou philip, firat emir. Performance and sustainability of environment under entrepreneurial activities, urbanization and renewable energy policies: A dual study of Malaysian climate goal. *Renew. Energy* 189, 734–743. doi:10.1016/j.renene.2022.03.024

Edmund, N. U., and Lucy, D. P. (2022). *Policy insight from renewable energy, foreign direct investment (FDI) and urbanization towards climate goal: Insight from Indonesia.*

Edmund, N. U. (2020). Mediation of foreign direct investment and agriculture towards ecological footprint: A shift from single perspective to a more inclusive perspective for India. *Environ. Sci. Pollut. Res.* 27 (21), 26817–26834. doi:10.1007/s11356-020-09024-4

Edmund, N. U. (2021). "Pakistan ecological footprint and major driving forces, could foreign direct investment and agriculture be among?" in *Asia-pacific journal of regional science*, 109–122.

George, E., and Epameinondas, A. (2013). The effect of government expenditure on the environment: An empirical investigation. *Ecol. Econ.* 91, 48–56. doi:10.1016/j.ecolecon.2013.04.002

Giovanni, O. P., Kannan, G., Antonio, B., Loisi, R. V., De Boni, A., and Roma, R. (2016). Local action groups and rural sustainable development: A spatial multiple criteria approach for efficient territorial planning. *Land Use Policy* 59, 12–26. doi:10.1016/j.landusepol.2016.08.002

Guo, X., Zhang, J., and Wu, L. (2019). City size, productivity advantage and resource allocation. *Manage. World* 35 (04), 77–89. doi:10.19744/j.cnki.11-1235/f.2019.0051

Han, L., and Liu, C. (2018). Evaluation and regional comparison of China's rural development process under the background of rural revitalization. *Rural. Econ.* 12, 44–48.

Hao, Y., Zhang, Q., Zhong, M., and Li, B. (2015). Is there convergence in per capita SO2 emissions in China? An empirical study using city-level panel data. *J. Clean. Prod.* 108, 944–954. doi:10.1016/j.jclepro.2015.06.054

Hu, Z., Miao, C., Hua, M., and Liu, L. (2018). Spatio-temporal pattern and influencing factors of location choice of foreign investment in China. *Hum. Geogr.* 33 (05), 88–96. doi:10.13959/j.issn.1003-2398.2018.05.011

Hua, J., and Sun, B. (2015). Economic Performance measurement of polycentric spatial structure in Metropolitan areas of China. *Urban Probl.* (09), 68–73. doi:10.13239/j.bjsshkxy.cswt.150910

Huang, Y., Gao, B., and Wei, S. (2016). Spatial structure and evolution of urban agglomerations in China. *Economist* 09, 50–58. doi:10.16158/j.cnki.51-1312/f.2016.09.006

Huang, Y., Li, L., and Yu, Y. (2018). Do urban agglomerations outperform non-agglomerations? A new perspective on exploring the eco-efficiency of Yangtze River economic belt in China. *J. Clean. Prod.* 202, 1056–1067. doi:10.1016/j.jclepro.2018.08.202

Huang, J., Scott, R., Zhu, X., Sheng, Y., and Zhao, S. (2020). Agricultural and rural development in China during the past four decades: An introduction. *Aust. J. Agric. Resour. Econ.* 64 (1), 12352. doi:10.1111/1467-8489.12352

Huang, Z. (2018). On the strategy of rural revitalization in China. *Chin. Rural. Econ.* 4, 2–12.

Jiang, Y., Fan, J., and Song, Z. (2008). The new strategies of urbanization in China. *Reform. strategy* 176, 32–34. doi:10.16331/j.cnki.issn1002-736x.2008.04.008

Kan, F. (2014). Empirical analysis of FDI on agricultural growth in China. *Agric. Econ.* (10), 3–6. doi:10.3969/j.issn.1001-6139.2014.10.001

Ke, S., and Zhao, Y. (2014). Industrial structure, city size and urban productivity in China. *Econ. Res. J.* 49 (04), 76–88+115.

Lan, J., Kakinaka, M., and Huang, X. (2012). Foreign direct investment, human capital and environmental pollution in China. *Environ. Resour. Econ.* 51 (2), 255–275. doi:10.1007/s10640-011-9498-2

Lan, F., Da, H., Wen, H., and Wang, Y. (2019). Spatial structure evolution of urban agglomerations and its driving factors in mainland China: From the monocentric to the polycentric dimension. *Sustainability* 11 (3), 610. doi:10.3390/su11030610

Li, H., and Shao, M. (2017). City size, skill difference and wage income of workers. *Manag. World* (08), 36–51. doi:10.19744/j.cnki.11-1235/f.2017.08.006

Li, L., and Zhou, Y. (2006). Can technology improve energy efficiency?——based on the empirical test of China's industrial sector. *Manage. World* 10, 82–89. doi:10.19744/j.cnki.11-1235/f.2006.10.010

Li, S., and Zhang, Z. (2015). The impact of city size on urban-rural income gap——analysis based on prefectural-level city panel data. *Urban issues.* (06), 14–20. doi:10.13239/j.bjsshkxy.cswt.150603

Li, Y., and Liu, X. (2018). How did urban polycentricity and dispersion affect economic productivity? A case study of 306 Chinese cities. *Landsc. Urban Plan.* 173, 51–59. doi:10.1016/j.landurbplan.2018.01.007

Li, Y., Jia, L., Wu, W., Yan, J., and Liu, Y. (2018). Urbanization for rural sustainability - rethinking China's urbanization strategy. *J. Clean. Prod.* 178, 580–586. doi:10.1016/j.jclepro.2017.12.273

Li, W., Sun, B., Liu, Q., and Zhang, T. (2018). Characteristics and influencing factors of urban spatial structure in China. *Sci. Geogr. Sin.* 38 (05), 672–680. doi:10.13249/j.cnki.sgs.2018.05.004

Li, Y., Westlund, H., and Liu, Y. (2019). Why some rural areas decline while some others not: An overview of rural evolution in the world. *J. Rural Stud.* 68, 135–143. doi:10.1016/j.jrurstud.2019.03.003

Li, Y., Yan, J., and Song, C. (2019). Rural revitalization and sustainable development: An analysis of international typical cases and its enlightenment. *Geogr. Res.* 38 (03), 595–604. doi:10.11821/dlyj020180879

Li, J., Liu, Y., Yang, Y., and Jiang, N. (2019). Multi-dimensional impact of urbanization on agriculture and rural areas: An empirical study based on inter-provincial panel data. *Hum. Geogr.* 34 (3), 137–145. doi:10.13959/j.issn.1003-2398.2019.03.018

Liang, W., and Lu, M. (2016). Cities in the post-industrial era: Microeconomic evidence of the impact of city size on human capital externalities in service industries. *Econ. Res. J.* 51 (12), 90–103.

Liu, H. (2013). Study on the evaluation of rural sustainable development capacity in Western China -- Based on entropy weight principal component method. *J. Northwest A&F Univ.* 13 (01), 68–73+98. doi:10.13968/j.cnki.1009-9107.2013.01.022

Liu, X. (2014). Spatial efficiency and regional balance: A test of agglomeration effect at provincial level in China. *World Econ.* 37 (01), 55–80.

Liu, S. (2018). Spatial structure and FDI spillover in multi-center Cities. *J. Yunnan Univ. Finance Econ.* 34 (07), 47–56. doi:10.16537/j.cnki.jynufe.000333

Liu, Y., Teng, Y., and Li, H. J. (2010). Does the inflow of FDI necessarily widen the income gap between urban and rural areas? *J. World Econ. Res.* (08), 63–68+89. doi:10.13516/j.cnki.wes.2010.08.011

Liu, X., Li, S., and Qin, M. (2017). Urban spatial structure and regional economic efficiency -- Also on the Mode selection of China's Urbanization Development Path. *Manage. World*, 51–64. doi:10.19744/j.cnki.11-1235/f.2017.01.006

Liu, H., Shen, G., and Ru, G. (2020). Dynamic mechanism and international experience of enhancing rural industrial development in megacities. *Rural. Econ.* (01), 128–136.

Lu, M., and Chen, Z. (2004). Urbanization, urban-biased economic policies and urban-rural inequality. *Econ. Res. J.* 6, 50–58. doi:10.2753/CES1097-1475390304

Lu, M., and Feng, H. (2014). Agglomeration and emission reduction: Empirical study on the influence of urban size gap on industrial pollution intensity. *J. World Econ.* 37, 86–114.

Lu, M., and Wan, G. (2014). Urbanization and urban systems in the people's republic of China: Research findings and policy recommendations. *J. Econ. Surv.* 28 (4), 671–685. doi:10.1111/joes.12078

Lu, M., Xiang, K., and Chen, Z. (2011). Chinese urbanization and urban system adjustment: Based on literature review. *J. World Econ.* 34, 3–25.

Lu, M., Li, P., and Zhong, H. (2019). A new era of development and balance: Spatial political economy in the 70 Years of new China. *Manage. World* 35 (10), 11–23+63+219.

Mao, F., Wang, Q., and Pan, J. (2019). Urban system and provincial development in China: An empirical study from the perspective of Structuralism. *J. Guizhou Univ. Finance Econ.* (04), 1–12. doi:10.3969/j.issn.1003-6636.2019.04.001

Meijers, E. J., and Burger, M. J. (2010). Spatial structure and productivity in US metropolitan areas. *Environ. Plan. A* 42, 1383–1402. doi:10.1068/a42151

Meijers, E. (2008). Measuring polycentricity and its promises. *Eur. Plan. Stud.* 16, 1313–1323. doi:10.1080/09654310802401805

Miquel, À. G., Ana, I., and Moreno, M. (2018). Income segregation in monocentric and polycentric cities: Does urban form really matter? *Regional Sci. Urban Econ.* 71, 62. doi:10.1016/j.regsciurbeco.2018.05.003

Pan, S., Zhu, D., and Xu, K. (2018). Are Chinese cities too big or too small? *Econ. Res. J.* 53 (09), 68–82.

Pang, J., Chen, X., Zhang, Z., and Li, H. (2016). Measuring eco-efficiency of agriculture in China. *Sustainability* 8 (4), 398. doi:10.3390/su8040398

Qin, G., Wei, X., Zhu, F., and Liu, A. (2016). Evaluation model and empirical analysis of rural regional sustainable development level: A case study of anhui province. *Ecol. Econ.* 32 (06), 123–128.

Ren, Y., Li, H., Shen, L., Zhang, Y., Chen, Y., and Wang, J. (2018). What is the efficiency of fast urbanization? A China study. *Sustainability* 10, 3180. doi:10.3390/su10093180

Satomi, K., David, S., and Nigel, D. (2007). Macro determinants of FDI inflows to Japan: An analysis of source country characteristics. *World Econ.* 30 (3), 446–469. doi:10.1111/j.1467-9701.2007.01001.x

Shao, S., Zhang, K., and Dou, J. (2019). Effects of economic agglomeration on energy saving and emission reduction: Theory and empirical evidence from China. *Manage. World* 35, 36–60. 226.

Sun, X., Guo, X., and Wang, Y. (2018). Industrial transfer, factor agglomeration and regional economic development. *Manag. World* 34 (05), 47–62+179-180. doi:10.19744/j.cnki.11-1235/f.2018.05.004

Tan, X., Ouyang, Q., An, Y., Mi, S., Jiang, L., and Zhou, G. (2019). Evolution and driving forces of rural functions in urban agglomeration: A case study of the chang-zhu-tan region. *J. Geogr. Sci.* 29 (8), 1381. doi:10.1007/s11442-019-1665-3

Tian, C. (2015). Whether the large cities hinder the coordinated development of provincial economy: An empirical analysis based on China's provincial panel data. *China Popul. Resour. Environ.* 25 (10), 87–94.

Udemba, E. N., and Keles, N. İ. (2021). Interactions among urbanization, industrialization and foreign direct investment (FDI) in determining the environment and sustainable development: New insight from Turkey. *Asia-Pacific J. Regional Sci.* 6, 1–22. doi:10.1007/s41685-021-00214-7

Wan, L., Sun, B., Zhao, J., and Zhang, T. (2018). Economic performance of spatial structure in Chinese prefecture regions: Evidence from night-time satellite imagery. *Habitat Int.* 76, 29–39. doi:10.1016/j.habitatint.2018.05.006

Wang, X. (2010). Economic analysis of China's urbanization path and city size. *Econ. Res. J.* 45 (10), 20–32.

Wang, J., and Li, S. (2015). Are the wages of migrant workers in big cities high? *Manag. World* (01), 51–62.

Wang, X., and Luo, Y. (2020). Has technological innovation capability addressed environmental pollution from the dual perspective of FDI quantity and quality? Evidence from China. *J. Clean. Prod.* 258, 120941. doi:10.1016/j.jclepro.2020.120941

Wang, Y., Ni, P., and Wang, G. (2019). Spatial structure and polycentric evolution of Urban agglomerations in China. *Jianghuai Forum* 03, 47–53. doi:10.16064/j.cnki.cn34-1003/g0.2019.03.038

Wei, H. (2015). Strategic thinking on promoting rural sustainable development. *Environ. Prot.* 43 (17), 16–19. doi:10.14026/j.cnki.0253-9705.2015.17.002

Xiao, J., and An, S. (2019). From unbalanced regional development to coordinated regional development -- 40 Years of regional development in China. *Reg. Econ. Rev.* (01), 13–24. doi:10.14017/j.cnki.2095-5766.2019.0002

Xiao, Q., and Chen, J. (2013). Research on sustainable agricultural development ability of Jiangxi province -- Based on entropy weight grey correlation analysis. *Jiangxi Soc. Sci.* 33 (04), 69–73. doi:10.3969/j.issn.1004-518X.2013.04.013

Xu, Q., Hu, C., and Liu, D. (2015). Population agglomeration gradient and industrial structure optimization and upgrading in urban agglomerations: A comparison between Yangtze River Delta region of China, Japan and South Korea. *China Popul. Sci.* (01), 29–37+126.

Yacouba, K., and Oluyemi, A. O. (2022). Analysis of spatio-temporal drivers and convergence characteristics of urban development in Africa. *Land Use Policy* 112, 105868. doi:10.1016/j.landusepol.2021.105868

Yu, J., Zhou, G., and Duan, Y. (2013). Research on the evolution trend of urban size distribution in China: Based on the national census data. *Popul. Econ.* (02), 44–52.

Yue, H., Lin, L., and Yu, Y. (2018). Does urban cluster promote the increase of urban eco-efficiency? Evidence from Chinese cities. *J. Clean. Prod.* 197, 957–971. doi:10.1016/j.jclepro.2018.06.251

Zhang, K., and Dou, J. (2015). Agglomeration and pollution: Empirical analysis based on the 287 cities of China. *J. Financ. Res.* 12, 32–45.

Zhang, X., Wu, Y., Skitmore, M., and Jiang, S. (2015). Sustainable infrastructure projects in balancing urban-rural development: Towards the goal of efficiency and equity. *J. Clean. Prod.* 107, 445–454. doi:10.1016/j.jclepro.2014.09.068

Zhang, L., Xu, Y., Yeh, C.-H., Liu, Y., and Zhou, D. (2016). City sustainability evaluation using multi-criteria decision making with objective weights of interdependent criteria. *J. Clean. Prod.* 131, 491–499. doi:10.1016/j.jclepro.2016.04.153

Zhao, J. (2018). The status of reasons for and solutions to the transfer of urban pollution to the rural areas. *People's Forum · Acad. Front.* 146, 88–91.

Zheng, L., and Wang, X. (2018). Does the inflow of foreign direct investment increase the inter-provincial income gap between urban and rural areas in China: An analysis based on spatial perspective. *Macroecon. Res.* (03), 62–80. doi:10.16304/j.cnki.11-3952/f.2018.03.007

Zheng, X. (2014). The contribution of urbanization to China's economic growth and its realization approaches. *Chin. Rural. Econ.* 6, 4–15.

Zhu, G., and Zhao, M. (2013). Sustainable development of urbanization and rural economy. *Rural. Econ.* 3, 113–115.