Impact of Urban Innovation on Urban Green Development in China's Yangtze River Economic Belt: Perspectives of Scale and Network

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Research Article

Keywords: Sustainable urban development, Urban green development, Urban innovation, Spatial correlation network, Yangtze River Economic Belt

Posted Date: February 7th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1259343/v1>

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Abstract

Understanding whether and how urban innovation offers a sound solution to the dilemma of urban green development, is a crucial response to mitigate the detrimental effect on natural resources and environment for transitioning to sustainable urban development. To address the critical issue, we propose urban green development evaluation index system, and then examine how the urban innovation affect urban green development from the perspectives of government-scale, enterprise-scale and spatial correlation network, all of which are originally applied in the 108 cities of Yangtze River Economic Belt of China (YREB) during period 2006-2016. The evaluation results show that urban innovation promote urban green development, and both government-scale and enterprise-scale contribute to the effects. The constructed spatial correlation network of urban innovation illustrates the network structural form and reveals the network property, and further results tell that increasing network density and centrality would promote green development obviously. More specifically, the network density of urban innovation has been tied to the enhancement of urban green development, which is more significant in middle reaches than in lower and upper reaches of YREB. Similarly, optimizing the network's degree centrality and closeness centrality can help facilitate urban green development in whole YREB. Thus, the research findings would provide new insights into the essence and driving forces from various scale and hidden network when exploring and seeking urban green development path.

1. Introduction

In our epoch, the world has an accelerating urbanization rate and the dwellers in that more than 50% of the global population now lives in urban areas (Bloom et al., 2008), while China's gradual transition toward an urbanization-oriented development strategy leads to a spectacular socioeconomic growth and urbanization level over the past decades (Yang, 2013). As it continues along the path of rapid urbanization and industrialization, the technological innovation is the important power source to promote economic growth in China (Wang et al., 2019). In spite of its detrimental effect on natural resources, environment and social life to some degree, the technological innovation is instrumental in green development gains due to the improvement of green production and the reduction of environmental pressure continuously (Li et al., 2019; Cao et al., 2020).

The loss and degradation of natural recourse and ecological environment have raised widespread concern about the green development mode and the consequent impact to the economic activity and human well-being that they support (Tan and Lu, 2019; Ouyang et al., 2020). The green development conception has gradually gained wide currency globally. For instance, the United Nations Environment Program (UNEP) launched a "Green New Deal" and a "Green Economy" initiative through the promotion of green development in the short and medium term (Mundaca et al., 2016). Similarly, as one of China's paramount development conceptions, green development highlights the need to adhere to a national policy of resource conservation and environmental protection, and to adopt the green lifestyle and development mode. Thereby, investigating and assessing urban green development status is an essential prerequisite to improve urban or regional ecological environment (Fang et al., 2019; Weng et al., 2020; Wei et al., 2020).

With the continuous emergence of technology innovation and the concept of green development becoming more and more mature, researches on their theory and methods had been deepened. Currently, a growing body of literature has studied the interaction between urban innovation and urban green development, and various determinant analysis models have been used in the previous studies. The first strand of research focuses on the notion that urban innovation may exert a positive influence on urban green development. To be specific, innovation improves resource productivity (Pujari, 2010; Dai and Sun, 2021). Specifically, the productivity of enterprises in high-technology industries is higher than that in low-technology industries (Khanna and Sharma, 2021). Meanwhile, technological innovation can help mitigate the carbon emission risk (Liu and Zhang, 2021; Zhao et al., 2020), air pollution risk (Cui et al., 2011; Zhu et al., 2020) and other environmental risks (Chaudhry et al., 2021). It can also enhance the waste management (Li et al., 2019) and improve the resource recovery efficiency (Marchi, 2012). In addition, cities with high green development level harbors the agglomeration model of technology, capital and talents to some extent (Jin et al., 2019). Cities with low green development level should benefit from urban innovation due to higher development potential, lower technology threshold and more significant late-developing advantages (Hippel et al., 2006). The second strand of research concentrates on the negative impact of innovation on green development. For instance, the improvement of technological innovation may lead to excessive energy consumption and carbon emissions (Gunderson and Yun, 2017; Acemoglu et al.,

2012), and it is much worse for innovation due to deficient talent and capital (Jin et al, 2019). Afterwards, there may be an inverted U-shaped relationship between innovation and environmental pressure (Feng et al., 2016).

Existing studies have enlarged the research fields of urban green development, some results of which reveal that both the expansion of government-scale and enterprise-scale can enhance the driving effect from innovation on green development. The inconsistency between private cost and public cost often lead to market failure, according to the externality theory, which can be addressed from the government-scale (Glemarec and de Oliveira, 2012), such as distributing the emission rights (Guo et al, 2021; Tang et al, 2021), highlighting the role of emission tax (Villegas Palacio and Coria, 2010; Li et al, 2021), strengthening the environmental supervision (Cumming, 2007; Tang et al, 2021) and improving the green technology innovation level (Martinelli and Midttun, 2010). In the meantime, the expansion of enterprise-scale can bring the comparative advantage and talent advantage. In light of the talents advantage, for instance, the large-scale enterprises have access to more funds and preferential policies from the government (Beck et al., 2005). Subsequently, the expansion of enterprises-scale can help bring the economies of scale and economies of scope. Large-scale enterprises are more likely to implement the eco-friendly measures to improve the quality of green innovation (Wang et al, 2021), especially the state-owned enterprises. However, some studies also prove the adverse impact once expanding the scales of government and enterprise. Expanding the scale of government always increases the administrative units and rent-seeking activities, as well as the excessive bureaucracy and low administrative efficiency. Likewise, Expanding the scale of enterprise often reduce the innovation efficiency of enterprises (Mei and Shao, 2016). For example, the market full of large-scale enterprises or monopoly enterprises is more likely to be short of the competitive power to stimulate technology innovation. It is not only harmful to the sustainable technological innovation of enterprises in the market, but also destructive to the long-term health of regional market development.

Most extant studies pointed out that innovation has a positive impact on green development in virtue of technological progress (Lin and Nelson, 2017; Shao et al., 2016; Wang et al., 2019), environmental pollution mitigation (Chaudhry et al, 2021; Liu and Zhang, 2021) and economic improvement (Batabyal and Beladi, 2014; Snieska and Valodkiene, 2015). But from another aspect, innovation has been identified as the drivers to improve production capacity when contributing more serious natural resource consumption as well as environmental pollution (Wang et al., 2014; Zhao et al., 2010). Despite the more and more explorations of interaction between innovation and green development, on the whole, there are scarce theoretical and practical exploration from the coupling perspectives of government-scale, enterprise-scale and spatial correlation network.

How to achieve regional multi-scale green development is key to implement the practical needs of China's current ecological civilization practice and policies and to enrich the theoretical needs of global sustainable development. To be specific, understanding whether and how urban innovation should offer a sound solution to the dilemma of urban green development, is a crucial response to mitigate the detrimental effect on natural resources and environment for transitioning to sustainable urban development. It has important implications for exploring the current institutional obstacles and policy system of urban innovation, which should be conducive to achieve urban green development effectively. Under this circumstance, this study would join the debate and presents evidence from both perspectives of scales and network when discuss about the Yangtze River Economic Belt of China.

This paper will be structured as follows: Section 2 describes data, variables and empirical models. Section 3 shows results and analysis. Section 4 gives a description for the network correlation of urban innovation and Section 5 contains main achievements, policy implications and limitations.

2. Data And Methodology

2.1. Evaluation of urban green development level

The evaluation index system of urban green development level ought to contain main influencing variables, and some principles, such as comprehensiveness, representativeness, authority and feasibility, should be taken into consideration when constructing the index system. Thereby, the index system of urban green development level in this study is characterized and identified by its economic growth, industrial structure upgrading, residents' living standards improvement and ecological

environment management from an integrated view. Further, the modified entropy method is used to deal with index weight, and it contribute to assess the comprehensive urban green development level. Specific steps can be found in many studies (Wang et al., 2014; Tan and Lu, 2015; Tan et al., 2017), which can help maintain all information of the original samples and can help prevent the elimination of diversity of the raw data. In summary, following the sequence of ‘bottom to top’, each indicator is multiplied by the standardized value of each indicator with its corresponding weight, and subsequently the values of each dimension during the study period are determined to represent urban green development general trend of each city in YREB.

Table 1
Established index system of urban green development level.

Dimension	Index	Weight	Attribute
Economic growth	Per capita GDP (yuan / per capita)	0.0577	Positive
	Investment in fixed assets per worker (yuan/per capita)	0.0580	Positive
	Financial income per worker (ten thousand yuan/per capita)	0.0521	Positive
Industrial structure upgrading	Proportion of tertiary industry in GDP (%)	0.0661	Positive
	Proportion of employees in the tertiary industry (%)	0.0658	Positive
	Labor productivity of tertiary industry (ten thousand yuan/per capita)	0.0464	Positive
Residents' living standards improvement	Disposable income of urban residents (yuan)	0.0492	Positive
	Total retail sales of consumer goods per worker (yuan / per capita)	0.0570	Positive
	Urban per capita maintenance and construction capital expenditure (yuan / per capita)	0.0303	Positive
	Proportion of urban basic medical insurance (%)	0.0406	Positive
	Public transport vehicles per ten thousand people in the city	0.0496	Positive
	Urban per capita public green space area (km ₂ / per capita)	0.0499	Positive
Ecological environment management	Industrial SO ₂ removal rate (%)	0.0621	Positive
	Dust removal rate of industrial smoke (%)	0.0655	Positive
	Harmless treatment rate of domestic waste (%)	0.0642	Positive
	Urban sewage treatment rate (%)	0.0641	Positive
	Per capita discharge of industrial wastewater (ton / per capita)	0.0559	Negative
	Ratio of industrial solid wastes disposed and utilized (%)	0.0654	Positive

2.2. Urban innovation and the other variables

The independent variable (urban innovation) is measured by the number of patent applications per capita when considering the local urban employees. The share of public expenditure in GDP stands for government-scale (threshold variable) and the log transform of total profits of industrial enterprises above designated size stands for enterprise-scale (threshold variable).

Urban green development should be affected by urban innovation, as well as by other explanatory variables. Some control variables are selected as follows. Foreign direct investment (FDI) can bring more advanced and cleaner production technology,

and further improve the ecological environmental quality of host country, while the foreign enterprises may transfer the high-polluting industries to underdeveloped regions with low environmental standards. Environmental regulation (ER) policy can directly restrain the high pollution emission behavior of enterprises and promote the technology innovation. The government should refrain from promoting the urban green development (UGD) at the expense of a high unemployment rate (UNE). Generally speaking, with the improvement of urbanization rate (Urban), the production factors such as talents and capital are gathered in cities for improving the urban innovation level. However, the accelerating urbanization process should be harmful in the green development mode. Technology and education investment (TE) is an important driving factor for the urban green development, providing the funds and talents for urban innovation.

2.3. Study area and data description

As a typical region moving forward on green development demonstration belt, the Yangtze River Economic Belt (YREB) spans three regions of east, middle and west of China, and it is an important economic and population agglomeration area in China. Thereby, it is important strategic significance for transitioning to the green development model of the Yangtze River Economic Belt. In spite of seeking the common goal of the whole economic belt, there is regional heterogeneity of urban green development tendency due to different resource endowments, geographical positions, infrastructures, policy slants and so on. In particular, urban innovation is a key element for promoting urban green development. On account of the above, this paper evaluates and explores the interaction between innovation and green development from both the perspectives of scale and network.

The required data come from China Statistical Yearbook, China Industrial Statistical Yearbook, China Environmental Statistical Yearbook, China Science and Technology Statistical Yearbook, and Statistical Yearbook of Provinces and cities. Some data pretreatments should be covered. For instance, all current variables are processed and converted to the real value according to the value of 2006. Besides, taking the logarithm can help eliminate the heteroscedasticity of non-proportional and non-standardized variables, and the linear interpolation techniques will be used once there is some missing data. Consequently, Table 2 and Table 3 show the details and descriptive statistics of main variables in this study. It should be noted that the variance expansion factor (VIF) test shows that all the selected variables do not have serious multicollinearity ($VIF < 10$).

Table 2
Details of main variables.

Variable	Surrogate letters	Name	Measurement methods
Dependent variable	UGD	Urban green development	Index system calculation * 100
Independent variable	UINN	Urban innovation	Patent applications per capita (piece / ten thousand yuan people)
Control variable	FDI	Foreign direct investment	Proportion of foreign direct investment in GDP (%)
	UNE	Unemployment rate	Urban registered unemployment rate (%)
	ER	Environmental regulation	SO ₂ removal rate (%)
	TE	Technology and Education Investment	Proportion of expenditure on science, technology and education in total financial expenditure (%)
	Urban	Urbanization rate	Proportion of permanent residents in the total population at the end of the year (%)
Threshold variable	GS	Government-scale	The proportion of public expenditure in GDP
	ES	Enterprise-scale	Logarithmic transformation of total profits of industrial enterprises above designated size

Table 3
Descriptive statistical characteristics of variables.

Variable symbol	Mean	Sd	Min	Max
UGD	100.03	47.839	39.549	327.770
UINN	8.572	18.376	0	198.052
FDI	2.276	1.958	0	11.674
UNE	6.630	4.783	0	29.66
ER	4.686	2.915	-19.741	9.945
TE	1.607	1.529	0	16.273
Urban	5.874	0.977	2.639	8.923
GS	0.177	0.094	0.035	1.485
ES	4.326	1.424	-2.659	7.977

2.4. Regression models

The setting of the basic panel model is used to test and verify the overall impact of urban innovation (UINN) on urban green development (UGD). In addition to the urban innovation, there are some other factors to promote urban green development, such as foreign direct investment (FDI), environmental regulation (ER), unemployment rate (UNE), urbanization rate (Urban) and the Technology and Education Investment (TE). As a result, the benchmark model of urban innovation and urban green development can be established as follows.

$$UGD_{it} = \beta_0 + \beta_1 UINN_{it} + \beta_2 FDI_{it} + \beta_3 ER_{it} + \beta_4 UNE_{it} + \beta_5 Urban_{it} + \beta_6 TE_{it} + \delta_i + \varepsilon_{it}$$

(1)

Where, i stands for the individual city, t represents the year, β_0 is the coefficient of the constant term, $\beta_1 \sim \beta_6$ are the coefficients of independent and control variables, δ_i denotes the individual effect, and ε_{it} is the error term.

The basic panel model needs to address the endogenous problem between urban innovation and urban green development due to the deviation in coefficient estimation. Then, the solution is as follows. The fixed-effects model eliminates heterogeneity between individuals and minimizes the endogenous biases caused by the absence of variables. Here, we use a two-step System GMM for robust estimation. The GMM model of the system is presented as equation (2).

$$UGD_{it} = \beta_0 + \beta_1 UINN_{it} + \beta_2 FDI_{it} + \beta_3 ER_{it} + \beta_4 UNE_{it} + \beta_5 Urban_{it} + \beta_6 TE_{it} + \beta_7 UGD_{it-1} + \delta_i + \varepsilon_{it}$$

(2)

UGD_{it-1} is the first-order lag term of urban green development level, β_7 is the coefficient of the lag term, and the other variables are the same as above.

In order to identify the moderating effect of government-scale and enterprise-scale, we use the threshold models to test how government-scale and enterprise-scale act on the influence process from urban innovation on urban green development. The models are set as follows.

$$UGD_{it} = \beta_0 + \beta'_1 UINN_{it}(GS_{it} \leq \eta_1) + \beta'_2 UINN_{it}(GS_{it} \geq \eta_1) + \delta_i + \varepsilon_{it} \quad (3)$$

η_1 is the threshold value to be estimated from government-scale. This is the expression of single threshold model and so on.

$$UGD_{it} = \beta_0 + \beta'_1 UINN_{it}(ES_{it} \leq \eta_1) + \beta'_2 UINN_{it}(ES_{it} \geq \eta_1) + \delta_i + \varepsilon_{it} \quad (4)$$

η_2 is the threshold value to be estimated from enterprise-scale.

3. Results And Analysis

3.1. Urban green development general trend of the Yangtze River Economic Belt

The green development level showed a steady increasing tendency for the majority of cities during period 2006-2016, while it showed a decline for a small minority of cities due to the relatively frequent eco-environmental risk accidents. Fig. 1 intuitively reflected the change characteristics of urban green development level in the Yangtze River Economic Belt in 2006, 2011 and 2016. It can be seen that there is seldom any change for most cities in Jiangsu, Shanghai and Anhui, while there is noticeable change for other cities in YREB. In particular, some cities had a high level of green development in the early period, and then they have a gradual decline in the later period. Thereby, it is of great important to explore the green development and its drivers.

3.2. Overall impact of urban innovation on urban green development

As presented in Table 4, the fitting degree of regression equation and the accuracy of the model will be improved once increasing the control variables gradually. According to the regression results of column (7), the current value of urban green development level and its first-order lag value tell the motivating effect. In other words, the urban innovation may accelerate the improvement of urban green development level to a certain extent. The regression results when covering other control variables verify that the regression coefficients of foreign direct investment (FDI) and unemployment rate (UNE) are significantly negative, and that of environmental regulation (ER), urbanization rate (Urban) and Technology and Education Investment (TE) are significantly positive.

Table 4
Impact of urban innovation on urban green development in YREB.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable	UGD	UGD	UGD	UGD	UGD	UGD	SysGMM
UGD							0.505*** (0.168)
UINN	1.257*** (0.187)	1.155*** (0.205)	1.040*** (0.180)	1.027*** (0.178)	0.959*** (0.166)	0.791*** (0.158)	0.843** (0.386)
FDI		-3.037*** (1.101)	-2.743*** (0.929)	-2.783*** (0.932)	-2.975*** (0.904)	-2.854*** (0.774)	-1.407 (0.997)
ER			3.170*** (0.766)	3.096*** (0.759)	2.893*** (0.722)	2.462*** (0.678)	1.540** (0.672)
UNE				-0.451 (0.347)	-0.412 (0.313)	-0.337 (0.258)	-0.538 (0.361)
Urban					6.104*** (0.844)	6.008*** (0.767)	1.205 (1.182)
TE						5.499*** (1.776)	3.680 (2.607)
C	89.25*** (1.605)	97.04*** (3.873)	82.50*** (4.292)	86.04*** (4.889)	51.91*** (5.604)	46.32*** (5.252)	29.56*** (8.502)
Observations	1,188	1,188	1,188	1,188	1,188	1,188	1,080
R ²	0.395	0.408	0.482	0.489	0.515	0.552	
N	108	108	108	108	108	108	108
Note: *Significant at 0.1, **Significant at 0.5, ***Significant at 0.01.							

In general, the urban innovation plays a positive and significant role in urban green development for the three urban agglomerations in the middle, lower and upper reaches of YREB from Table 5. The urban innovation in the middle reaches give the most obvious motivating effect to urban green development. To be specific, the upper reaches struggle to bring sufficient technical capital and talent investment for urban innovation, as well as the limited progress of green development level. Meanwhile, the lower reaches have a slight decline of urban innovation, leading to the impenetrable technological threshold. And there is not obvious motivating effect between urban innovation and urban green development for the lower reaches. To sum up, the urban innovation level has been tied to the enhancement of urban green development level, which is more significant in middle reaches than in lower and upper reaches of YREB.

Table 5
Overall impact of urban innovation on urban green development in YREB.

	(8)	(9)	(10)
	Lower reaches of YREB	Middle reaches of YREB	Upper reaches of YREB
Variable	UGD	UGD	UGD
UINN	1.769*** (0.338)	7.373*** (0.710)	4.387*** (0.590)
FDI	-4.639*** (0.790)	-3.562** (1.533)	1.806 (1.541)
ER	2.115 (1.539)	2.462*** (0.609)	1.394** (0.662)
UNE	-0.197 (0.189)	-1.124** (0.549)	-0.450 (0.446)
Urban	6.258*** (1.068)	4.514*** (0.999)	4.711*** (1.296)
TE	6.449*** (2.225)	1.539 (0.947)	6.678*** (2.083)
C	65.42*** (10.30)	61.21*** (9.482)	36.80*** (8.042)
R ²	0.613	0.624	0.474
N	41	36	31
Note: *Significant at 0.1, **Significant at 0.5, ***Significant at 0.01.			

3.3. From government-scale

From the perspective of government-scale, there is a clear threshold effect between urban innovation and urban green development. The results of double-threshold model tell that there are two estimated thresholds when considering the impact of urban innovation on urban green development from government-scale, and the double threshold values are 0.094 and 0.162. According to the values, 108 cities in YREB were classified as being small-government-scale ($GS \leq 0.094$), medium-government-scale ($0.094 < GS < 0.162$) and large-government-scale ($GS \geq 0.162$).

Table 6
Threshold effect test.

Variable		Estimate value of the threshold	F value	P value
GS	Single threshold	0.162	102.178***	0.007
	Double threshold	0.094, 0.162	18.112*	0.06
	Triple threshold	0.133	9.212	0.28
ES	Single threshold	5.351	36.173***	0.030
	Double threshold	2.642, 5.362	7.342*	0.100
	Triple threshold	6.609	5.747	0.265
Note: *Significant at 0.1, **Significant at 0.5, ***Significant at 0.01.				

As shown in Table 7, the urban innovation plays a crucial role in promoting the urban green development level despite from various government-scales. From urban innovation to urban green development, the influence coefficient is significant in the category of large-government-scale. For example, from the angle of increasing government financial investment, cities with large government-scale often provide more financial subsidies to stimulate the innovation power of enterprises and scientific researchers, all of which will help improve the overall innovation level of the city.

Table 7
Impact of urban innovation on urban green development under the threshold of government-scale.

	(1)	(2)	(3)	(4)	(5)	(6)
	GS $\leq$ 0.094		0.094 < GS < 0.162		GS $\geq$ 0.162	
Variable	UGD	UGD	UGD	UGD	UGD	UGD
UINN	0.929***	0.518***	1.832***	1.234***	3.699***	3.062***
	(0.121)	(0.123)	(0.380)	(0.292)	(0.547)	(0.590)
FDI		-5.258*		-2.982***		-1.907
		(2.641)		(0.883)		(2.465)
ER		4.220***		2.713***		0.498
		(1.447)		(0.874)		(0.383)
UNE		-2.309		-0.513		-0.819***
		(1.467)		(0.570)		(0.207)
Urban		3.152***		5.768***		2.143***
		(1.136)		(1.121)		(0.695)
TE		1.977		3.519*		1.603
		(1.671)		(2.050)		(2.205)
C	108.8***	103.3***	86.56***	47.92***	0.41***	65.22***
	(2.468)	(16.05)	(2.984)	(8.091)	(1.418)	(5.707)
Observations	195	195	692	692	301	301
R ²	0.670	0.802	0.314	0.451	0.281	0.383
N	48	48	98	98	50	50
Note: *Significant at 0.1, **Significant at 0.5, ***Significant at 0.01.						

3.4. From enterprise-scale

From the perspective of enterprise-scale, the results tell that there is also a threshold effect between urban innovation and urban green development. The results of double-threshold model tell that there are two estimated thresholds when considering the impact of urban innovation on urban green development from enterprise-scale and the double threshold values are 2.642 and 5.362. According to the values, 108 cities in YREB were classified as being small-enterprise-scale ($ES \leq 2.642$), medium-enterprise-scale ($2.642 < ES < 5.362$) and large-enterprise-scale ($ES \geq 5.362$).

Table 8 shows the regression results after covering the threshold of enterprise-scale. The threshold effect of enterprise-scale is similar to that of government-scale. The coefficients of urban innovation are significant in the cities with various enterprise scales, suggesting that innovation-driven urban green development is effective in the cities with various enterprise scales. In particular, the influence coefficient is more significant in large-enterprise-scale than that in small and medium-enterprise-scale. Thereby, urban innovation should involve in urban green development in YREB, which is more obvious in cities with large-enterprise-scale.

Table 8
Impact of urban innovation on urban green development under the threshold of enterprise scale.

	(7)	(8)	(9)	(10)	(11)	(12)
	ES ≤ 2.642		2.642 < ES < 5.362		ES ≥ 5.362	
Variable	UGD	UGD	UGD	UGD	UGD	UGD
UINN	0.494***	0.348***	0.565***	0.428***	0.884***	0.647***
	(0.0737)	(0.0772)	(0.0958)	(0.0826)	(0.239)	(0.204)
FDI		0.227		-2.664***		-3.839***
		(1.034)		(0.747)		(1.435)
ER		12.66***		5.997***		6.767***
		(2.264)		(1.512)		(2.309)
UNE		-1.705***		-38.29***		-26.40*
		(0.275)		(12.44)		(13.60)
Urban		2.273		1.753**		4.233***
		(5.398)		(0.688)		(1.373)
TE		-0.0482		0.205***		0.346***
		(0.135)		(0.0607)		(0.117)
C	41.48***	37.58***	40.31***	31.18***	38.89***	18.33**
	(0.373)	(7.449)	(0.249)	(3.492)	(0.458)	(7.127)
Observations	136	136	774	774	278	278
R ²	0.451	0.658	0.220	0.432	0.135	0.425
N	52	52	104	104	88	88
Note: *Significant at 0.1, **Significant at 0.5, ***Significant at 0.01.						

4. From The Spatial Innovation Correlation Network

4.1. Topological characteristics of spatial innovation correlation network

The topological characteristics of spatial innovation correlation network is presented as Fig. 2. The network density and the relationship number are increasing during the study period in the network of Yangtze River Economic Belt. In terms of network density, the spatial innovation correlation network of YREB is closer and closer. However, it may include some adding redundant lines. For instance, some redundant lines should increase the transaction costs between various cities, leading to a negative impact on urban green development. Ultimately, it is critical to address how to improve the spatial correlation between cities inside YREB.

For the constructed network for 108 cities in YREB, the average value of degree centrality is 62.98. Inside YREB, 64 cities are higher than this average value (Table 9). The degree centrality was roughly in the order of middle, upper and lower reaches. To be specific, the majority of cities are concentrated in the lower reaches and a minority of cities are distributed in the upper and middle reaches. Each city is connected with other one in the spatial innovation correlation network to a greater extent.

The average value of closeness centrality is 6.603. Inside YREB, 57 cities are higher than the average value (Table 9). Specifically, the cities are concentrated in the provincial capital in the lower, upper and middle reaches. The higher closeness centrality in the lower reaches suggests that they should associate with other cities through the inherent connection of urban innovation elements at a faster rate. It seems clear that the closeness centrality in the upper reaches is lower than that in the lower and middle reaches, such as Guiyang and Kunming. In other words, when regarding Guiyang and Kunming as the core of urban network, the urban innovation level of the upper reaches is weak and the urban green development level is slow.

Table 9
The centrality characteristics of spatial innovation correlation network.

ID	Prefecture level city	Degree centrality	Sort	Closeness centrality	Sort	ID	Prefecture level city	Degree centrality	Sort	Closeness centrality	Sort
1	Shanghai	86.916	1	6.667	1	55	Shiyan	76.636	53	6.621	53
2	Nanjing	86.916	2	6.667	2	56	Yichang	85.047	39	6.658	39
3	Wuxi	86.916	3	6.667	3	57	Xiangfan	71.028	60	6.597	60
4	Xuzhou	84.112	42	6.654	42	58	Ezhou	60.748	65	6.552	65
5	Changzhou	86.916	4	6.667	4	59	Jingmen	71.963	58	6.601	58
6	Suzhou	86.916	5	6.667	5	60	Xiaogan	71.963	59	6.601	59
7	Nantong	86.916	6	6.667	6	61	Jingzhou	59.813	67	6.548	67
8	Lianyungang	84.112	43	6.654	43	62	Huanggang	49.533	83	6.505	83
9	Huaian	85.981	22	6.663	22	63	Xianning	69.159	62	6.589	62
10	Yencheng	85.981	23	6.663	23	64	Suizhou	0	101	0	101
11	Yangzhou	86.916	7	6.667	7	65	Changsha	85.981	33	6.663	33
12	Zhenjiang	86.916	8	6.667	8	66	Zhuzhou	85.047	40	6.658	40
13	Taizhou	86.916	9	6.667	9	67	Xiangtan	84.112	44	6.654	44
14	Suqian	85.047	37	6.658	37	68	Hengyang	60.748	66	6.552	66
15	Hangzhou	86.916	10	6.667	10	69	Shaoyang	46.729	84	6.493	84
16	Ningbo	86.916	11	6.667	11	70	Yueyang	58.879	71	6.544	71
17	Wenzhou	86.916	12	6.667	12	71	Changde	55.14	78	6.528	78
18	Jiaxing	86.916	13	6.667	13	72	Zhangjiajie	0	102	0	102
19	Huzhou	86.916	14	6.667	14	73	Yiyang	66.355	63	6.577	63
20	Shaoxing	86.916	15	6.667	15	74	Chenzhou	53.271	79	6.52	79
21	Jinhua	85.981	24	6.663	24	75	Yongzhou	46.729	85	6.493	85
22	Quzhou	85.981	25	6.663	25	76	Huaihua	41.121	89	6.469	89
23	Zhoushan	0	95	0	95	77	Loudi	56.075	77	6.532	77
24	Taizhou	86.916	16	6.667	16	78	Chongqing	0	103	0	103
25	Lishui	85.981	26	6.663	26	79	Chengdu	86.916	21	6.667	21
26	Hefei	86.916	17	6.667	17	80	Zigong	70.093	61	6.593	61
27	Wuhu	86.916	18	6.667	18	81	Luzhou	57.944	74	6.54	74
28	Bengbu	85.981	27	6.663	27	82	Panzhihua	85.981	34	6.663	34
29	Huainan	81.308	45	6.642	45	83	Deyang	79.439	50	6.634	50
30	Maanshan	86.916	19	6.667	19	84	Mianyang	85.047	41	6.658	41
31	Huaibei	85.047	38	6.658	38	85	Guangyuan	57.944	75	6.54	75
32	Tongling	0	96	0	96	86	Suining	59.813	68	6.548	68

ID	Prefecture level city	Degree centrality	Sort	Closeness centrality	Sort	ID	Prefecture level city	Degree centrality	Sort	Closeness centrality	Sort
33	Anqing	85.981	28	6.663	28	87	Neijiang	50.467	82	6.509	82
34	Huangshan	0	97	0	97	88	Leshan	59.813	69	6.548	69
35	Chuzhou	85.981	29	6.663	29	89	Nanchong	42.991	87	6.477	87
36	Fuyang	75.701	54	6.617	54	90	Meishan	53.271	80	6.52	80
37	Suzhou	58.879	70	6.544	70	91	Yibin	58.879	72	6.544	72
38	Lu'an	81.308	46	6.642	46	92	Guang'an	42.991	88	6.477	88
39	Mizhou	0	98	0	98	93	Dazhou	41.121	90	6.469	90
40	Chizhou	0	99	0	99	94	Ya'an	0	104	0	104
41	Xuancheng	85.981	30	6.663	30	95	Bazhong	33.645	93	6.438	93
42	Nanchang	85.981	31	6.663	31	96	Ziyang	57.009	76	6.536	76
43	Jingdezhen	79.439	47	6.634	47	97	Guiyang	85.981	35	6.663	35
44	Pingxiang	79.439	48	6.634	48	98	Liupanshui	46.729	86	6.493	86
45	Jiujiang	76.636	51	6.621	51	99	Zunyi	63.551	64	6.564	64
46	Xinyu	85.981	32	6.663	32	100	Anshun	0	105	0	105
47	Yingtian	0	100	0	100	101	Kunming	85.981	36	6.663	36
48	Ganzhou	73.832	55	6.609	55	102	Qujing	41.121	91	6.469	91
49	Ji'an	76.636	52	6.621	52	103	Yuxi	73.832	57	6.609	57
50	Yichun	57.944	73	6.54	73	104	Baoshan	0	106	0	106
51	Fuzhou	73.832	56	6.609	56	105	Zhaotong	19.626	94	6.38	94
52	Shangrao	50.467	81	6.509	81	106	Lijiang	0	107	0	107
53	Wuhan	86.916	20	6.667	20	107	Simao	38.318	92	6.457	92
54	Huangshi	79.439	49	6.634	49	108	Lincang	0	108	0	108

4.2. On the whole network structure

On the whole network structure, the urban green development and the network density at four scales are chosen as the explaining and explanatory variables in the OLS regression when in the natural logarithm transformation.

The whole spatial innovation correlation network structure gives a significant and positive effect to urban green development, which can be found in Table 10. The improvement of network density can effectively promote the urban green development level in YREB. Notable, the network density of YREB's urban innovation has a positive impact on the urban green development, which is more significant in middle reaches than in lower and upper reaches of YREB. Therefore, it is necessary to continuously strengthen the spatial connection between the lower reaches and the upper reaches by increasing some necessary lines and reducing some redundant lines from associated innovation institutional reforms.

Table 10
OLS regression results of the whole network structure.

	(1) YREB	(2) Lower reaches of YREB	(3) Middle reaches of YREB	(4) Upper reaches of YREB
Variable	UGD	UGD	UGD	UGD
Network density (YREB)	0.184*** (0.0172)			
Network density (Lower reaches)		0.944*** (0.126)		
Network density (Middle reaches)			1.377*** (0.138)	
Network density (Upper reaches)				0.950*** (0.173)
C	4.927*** (0.0295)	6.072*** (0.189)	6.848*** (0.220)	6.539*** (0.343)
Observations	11	11	11	11
R ²	0.927	0.862	0.917	0.769
Note: *Significant at 0.1, **Significant at 0.5, ***Significant at 0.01.				

4.3. On the individual network structure

This study takes the green development level of 108 cities in YREB as an explanatory variable to analyze the impact of individual innovation network structure on urban green development. The regression coefficient of degree centrality is 0.612, indicating that cities with high degree centrality have a stronger leading role rather than other cities inside the spatial innovation correlation network. Under the circumstance, government should pay more attention to these cities to promote the whole urban green development level of YREB. However, there are still plenty of cities with low degree centrality and low green development level that need to strengthen the innovation connection with the lower reaches. For example, the talents, technologies and funds in the lower reaches of YREB should be associated with the upper and middle reaches. What's more, government should be encouraged to reduce the unemployment rate, increase the urbanization rate and increase the science and education expenditure, and so on.

Table 11
Impact of degree centrality on urban green development.

	(1)	(2)	(3)	(4)	(5)	(6)
Variable	UGD	UGD	UGD	UGD	UGD	UGD
Degree centrality	0.612*** (0.0377)	0.567*** (0.0302)	0.514*** (0.0358)	0.508*** (0.0358)	0.488*** (0.0380)	0.411*** (0.0448)
FDI		-4.918*** (1.193)	-4.804*** (1.175)	-4.823*** (1.165)	-4.892*** (1.172)	-4.458*** (0.986)
ER			1.737*** (0.622)	1.716*** (0.619)	1.725*** (0.618)	1.506** (0.619)
UNE				-0.260* (0.150)	-0.259* (0.150)	-0.213* (0.124)
Urban					1.945** (0.798)	2.492*** (0.781)
TE						5.079*** (1.780)
C	79.65*** (1.256)	92.31*** (2.753)	85.68*** (3.637)	87.76*** (3.986)	77.12*** (6.385)	68.02*** (6.306)
R ²	0.476	0.515	0.535	0.537	0.539	0.570
N	108	108	108	108	108	108
Note: *Significant at 0.1, **Significant at 0.5, ***Significant at 0.01.						

The regression coefficient of closeness centrality is 8.119, presenting that in the spatial innovation correlation network. Cities with high closeness centrality have the comparative advantages with other cities. The cities may control and guide the flow direction of urban innovation elements in more targeted manner, which can strengthen the "spatial spillover" effect on other cities inside the spatial innovation correlation network. On the other hand, cities with low closeness centrality and low urban green development level have to be enhance the potential to obtain innovation profitability inside the network. To sum up, cities with high closeness centrality and high urban green development level should be encouraged to guide and transfer the specific innovation elements to motivate urban green development from the perspective of network.

Table 12
Impact of closeness centrality on urban green development.

	(7)	(8)	(9)	(10)	(11)	(12)
Variable	UGD	UGD	UGD	UGD	UGD	UGD
Closeness centrality	8.119***	7.357***	6.744***	6.701***	6.247***	5.413***
	(0.584)	(0.480)	(0.532)	(0.527)	(0.559)	(0.613)
FDI		-5.068***	-4.938***	-4.948***	-5.088***	-4.782***
		(1.228)	(1.198)	(1.193)	(1.217)	(1.049)
ER			1.797***	1.789***	1.717***	1.379**
			(0.560)	(0.564)	(0.553)	(0.565)
UNE				-0.145	-0.141	-0.115
				(0.0947)	(0.0908)	(0.0732)
Urban					4.017***	4.251***
					(0.975)	(0.920)
TE						4.395**
						(1.834)
C	68.65***	85.06***	78.79***	79.98***	58.34***	53.63***
	(2.873)	(3.750)	(4.168)	(4.499)	(6.860)	(6.236)
R ²	0.501	0.545	0.564	0.565	0.574	0.600
N	100	100	100	100	100	100
Note: *Significant at 0.1, **Significant at 0.5, ***Significant at 0.01.						

5. Discussion And Conclusions

5.1. Main achievements

As a typical region moving forward on green development demonstration belt, the Yangtze River Economic Belt is a valuable subject to explore whether and how urban innovation offers a sound solution to the dilemma of urban green development. Uncovering the influence path can help mitigate the detrimental effect on natural resources and ecological environment for the green demonstration belt. This study estimated the general trend of urban green development and the topological characteristic of spatial correlation network of innovation for YREB during period 2006-2016. It further investigated the specific impact of urban innovation on urban green development through uniting the government-scale, enterprise-scale and spatial correlation network. The research framework can provide the practical policy implications for the study area, as well as a theory framework for clarifying the interaction between urban innovation and green development.

Our research findings indicated that the urban innovation in YREB promote the urban green development. However, there is obvious heterogeneity in the interaction of innovation and green development for various cities. For instance, it is more apparent in the middle reaches than in the upper and lower reaches. Moreover, the government-scale and enterprise-scale are two important moderating factors between urban innovation and urban green development. The coefficients of urban innovation are all significant in the cities with various government scales and enterprise scales, which means the innovation-driven urban green development is effective in the cities with any scale.

The study further illustrated that the optimization of spatial correlation network of innovation can also promote the green development of all cities in YREB. Inside the spatial correlation network, the increase of network density can well improve the urban green development level. Moreover, the city's central position in the spatial innovation correlation network has also a significant role in promoting the urban green development inside YREB. In other words, if cities play a crucial role in the spatial innovation correlation network, these cities will have a large spillover effect on the surrounding areas, which is conducive to innovation-driven urban green development.

5.2. Policy implications and limitations

The central government of China has put forward the innovation-driven development policy, emphasizing that urban innovation can promote urban development continuously. A more flexible implementation of plenty of policies would promote technology innovation, further facilitate the green development and enhance the environmental performance, in spite of the negative effects from some specific environmental policies (Albrizio et al., 2017). As a matter of fact, government often launch some adaptive and appropriate programs to promote the technology innovation of enterprises, such as providing some subsidies of pollution mitigation, setting some targets of environmental supervision, granting the green credits and collecting the emission taxes, and so on.

From the view of regional disparity, furthermore, it will be critical to avoid a “one-size-fits all” policy approach, both across technologies and across cities. Government should expand the functional scope and strengthen the intervention when focusing on some cities with lower green development level and smaller scale. It is also suggested that government should initiate and launch some preferential policies and projects to drive the cities with small enterprise-scale. For example, some financial subsidies can help reduce the cost and risk of urban innovation (Huang et al, 2019). In terms of spatial correlation network, the network density of urban innovation has been tied to the enhancement of urban green development, which is more significant in middle reaches than in lower and upper reaches of YREB. Due to the motivated effect from network density and network centrality, the cities in middle reaches have reason to act for themselves through attracting adequate talents and strengthen the connections among the three reaches. In other words, it is profitable for deepening the network effect and talent flow effect of between cities, promoting the formation of coordination mechanism of green innovation among cities. One important issue, especially for some cities with low network density, centrality and green development, is integrating technical and industry expertise into government decision-making. Some cities and their industries articulate its performance needs, finds supporting funding, and funds academics to develop new or advanced technological technology to achieve the green development goals.

However, because of the restriction of data availability, it is hard to choose indicators that can cover all aspects of the compound urban green development index. We have the limitation that the study puts emphasis only on the past period and does not cover dynamic predictions, yet green development research would be better served by a long-term perspective. The urban green development is brought about by multiple intertwined factors, so we hope to make deeper explorations of the motivated determinants and reveal the interactions among different determinants. Indeed, inquiring into whether and how urban innovation offers a sound solution to the dilemma of urban green development is just the precondition of achieving a regional sustainability transition, and the journey towards real sustainability has just begun.

Declarations

Acknowledgments

We are grateful for support from the fund projects: National Natural Science Foundation of China (72074107&71603111), National statistical scientific research projects of China (2020LY062), and a Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions.

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Author contribution Z.N. conceptualized the idea. F. T., L. Y., and Z. L. wrote the first draft, and Z. N. reviewed the manuscript. All authors approved the manuscript.

Funding This research is supported by the National Natural Science Foundation of China (72074107&71603111), National statistical scientific research projects of China (2020LY062).

Competing interests The authors declare no competing interests.

Availability of data and materials Not applicable.

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Figures

Figure 1

Urban green development level of the Yangtze River Economic Belt in 2006, 2011, 2016.

Figure 2

Relationship number and network density of the spatial correlation network of urban innovation.