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The Role of Green Infrastructure in Urban Landscape Ecological Design for Urban Environmental Quality Enhancement

Chongwei Zhao[1,*]

[1] School of Art, Heilongjiang University, Haerbin, Heilongjiang, 150000, China

SUMMARY: *As urbanization continues to advance, scholarly attention to green infrastructure has expanded steadily; however, the way in which it contributes to better urban environmental quality remains insufficiently clarified. By combining the entropy-weight approach with regression analysis, this study employs panel data from 258 Chinese cities during 2008-2022 to examine empirically how the development of green infrastructure within urban landscape ecological design improves urban environmental conditions, while also identifying the moderating role and threshold characteristics of fiscal decentralization. The empirical evidence can be summarized in three aspects. First, green infrastructure construction exerts a significant positive effect on urban environmental quality, and this conclusion remains stable after a series of tests. Second, fiscal decentralization performs a moderating role, and a double-threshold characteristic is also observed in the relationship between green infrastructure and urban environmental improvement, with the estimated threshold interval being [0.35,0.64]. Finally, green infrastructure yields greater environmental benefits in the east and west and in big cities compared to central areas and small- and medium-sized cities. These results will be helpful to the governments in modifying fiscal decentralization in line with the prevailing local conditions, enhancing the growth of green infrastructure, and advancing environmental enhancement and green urbanization.*

KEYWORDS: *green infrastructure; urban environmental quality; fiscal decentralization; entropy method; regression model*

1 Introduction

In the 21st century, the rise of the third world countries, led by China, has brought a new round of high-speed growth for the global economy, but this economic prosperity is more a result of human beings' demand for nature. With the increasing power of science and technology, human beings have been taking natural resources and discharging wastes to nature, even exceeding the capacity of nature itself, its self-purifying power and regenerative power [1]. Although the world economy has made great achievements, the ecological and environmental problems have become more and more obvious, mainly manifested in the global greenhouse effect, which leads to global warming, and its negative consequences have already brought significant impacts on some regions [2]; natural resources, such as minerals, energy and so on, are becoming increasingly tense [3]; Environmental pollution, such as haze and sandstorms, has also brought bad effects to human life, and these have become constraints to the sustainable development of human society [4].

With the enhancement of public ecological awareness and the development of ecological

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*x2232626@163.com

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science and technology, ecological culture has become the mainstream culture of this era, ecological landscape design expresses the human desire to be close to nature, and the integration of symbiosis with nature's good intentions, it is a kind of recovery and salvation of unbalanced urban ecosystem [5, 6]. The ecological design of urban green-space landscapes can be used to effectively save urban resources, enhance the quality and degree of urban development, and best utilize the space environment of cities to meet the material, cultural and spiritual requirements of the residents and also to a large extent, protect their common interests. Green infrastructure is one of the main strategies of sustainable development and it is adopted on a large scale around the world besides being an important contributor to ecological landscape design in cities [7]. Green infrastructure offers significant assistance in building urban and rural ecological networks through optimizing the land-use structure and enhancing the ecosystem-service functions.

Earlier studies on green infrastructure mainly concentrated on fairness issues and traditional planning and design fields [8]. Over time, however, increasing attention has been given to its social value. Some scholars have examined the application of conventional planning and design theories to green-infrastructure scenarios, as well as equity in its planning and use [9]. For example, Hsu et al. quantitatively evaluated the accessibility of green infrastructure in Australia by using GIS, focusing on population density together with the spatial arrangement and distribution pattern of green infrastructure around urban communities. Their findings indicate that decision-making on green-infrastructure planning should be improved through targeted measures so as to reduce inequality in citizens’ access to environmental rights and benefits [10]. In research on ecological corridors, Peng et al. applied an ant-colony algorithm combined with kernel-density estimation to determine ecological-corridor boundaries and ecological-restoration nodes more precisely, thereby providing a new technical route and theoretical support for nature conservation and ecological restoration [11]. In addition, Tantipisanuh, N. et al. pointed out that, to mitigate habitat fragmentation and spatial isolation, landscape connectivity must be maintained through a green-infrastructure network linking natural core areas by means of ecological corridors [12]. Taking Langzhong City in Sichuan Province as a case, Feng et al. employed MSPA together with the minimum cumulative resistance model and a gravity model, identified 50 key ecological sources and 105 ecological corridors, and proposed network-construction and optimization paths for green infrastructure to support the improvement of the county’s ecological pattern, the construction of agricultural shelter forests, and the siting of ecological-restoration projects [13]. Accordingly, priority should be given to safeguarding critical ecological corridors and nodes so as to lower the dispersal cost of wild species and to improve land-resource management as well as the planning of regional ecological corridors from a more dynamic and systematic perspective.

Green infrastructure has gradually become a major concern in both urban and residential settings. With respect to its influence on the natural environment of cities, Liao and Kim examined the link between the scale of green infrastructure and urban air quality in Korea and found that larger green-infrastructure areas were negatively associated with several air pollutants, including nitrogen dioxide, carbon monoxide, particulate matter, and ozone [14]. Herreros Cantis further argued that green infrastructure serves as an important means of climate adaptation and mitigation because it can improve urban climate conditions by expanding green space, easing the urban heat-island effect, and improving air quality [15].Šrbać et al. demonstrated in their European research that green infrastructure implementation would be able to decrease soil erosion, enhance water quality, and increase the farmland biodiversity, so not only contributing to environmental protection, but also increasing farmer income and quality of life [16]. Yao et al. concluded that green and grey infrastructures can complement each other in urban water management and can provide great mitigation opportunities against flooding and diffuse water pollution in cities with multiple ecological, environmental, economic and social advantages. Under this premise, they suggested an optimization model of multi-objectives based on confirmed enhancements to the value of combined configurations that provides the basis of optimal urban spatial distribution [17].

For the impact of green infrastructure on urban habitats, Anderson et al. concluded through their study of green infrastructure that it plays an important role in enhancing social connectivity and skill development in communities and can increase food security, which is particularly significant for vulnerable populations [18]. McKinney et al. found that natural green infrastructure requires less maintenance and has been shown to provide mental health benefits, reduce crime, and promote social behaviors, making it a cost-effective solution in areas of urban decay [19]. Dzhambov and Dimitrova analyzed the connection between some objective indicators in the process of interaction between residents and green infrastructure and the degree of subjective perception of noise by establishing a mediating effect model, and found that the frequency of interaction between residents and green infrastructure and the way of interaction, etc., is one of the important factors in reducing their perception of noise [20]. Stangierska et al. analyzed data using multiple regression models to examine how green infrastructure elements affect outdoor physical activity and health levels, and found that residents' motivation to engage in outdoor activities may be more important than the green infrastructure itself for improving health [21]. Wang, X et al. examined the case of integrating green infrastructure in towns such as Bad Vorischofen, Germany, which showed significant health impacts through restorative ecological landscapes and sensory-rich natural healing parks that promote relaxation, cognition, and physical activity [22]. Akpinar studied the relationship between green infrastructure and the quantity of physical activity among residents using questionnaire data and concluded that higher amounts and sizes of community green infrastructure may significantly increase the level of daily physical activity [23]. According to Kim et al., green infrastructure serves as a significant conduit by which people in an urban setting can come into contact with nature, and this is a valuable part of the process of ensuring sustainable urban growth, environmental quality, and human health and wellbeing [24].

The optimization of green-infrastructure layout is central to enhancing its value, and this issue has therefore attracted continuous academic attention [25]. Chen et al. used cost-benefit analysis to explore optimal combinations of blue-green-grey infrastructure in functional spaces such as parks, plazas, and residential districts. Their results showed that both ecological and economic benefits improved significantly over time, and the study provided a theoretical basis for coordinating these three infrastructures so as to optimize the ecological and economic value of cities [26]. Ferreira et al. examined green-infrastructure network planning in Setúbal, Portugal, and proposed a multi-criteria approach integrating ecological and social factors into planning and decision-making, showing that green infrastructure covered about 91% of the study area [27]. Cilliers conducted a meta-analysis of studies on green infrastructure in South Africa and found that local planning practices display distinctive characteristics different from international theories, while also advocating the use of green infrastructure as a key instrument in urban planning to optimize land use [28]. Zhang et al. introduced cost-effectiveness as a constraint and optimized the scale, location, and connectivity of green infrastructure through the improved Non-dominated Sorting Genetic Algorithm-II (NSGA-II) and the Stormwater Management Model (SWMM). The proposed framework was shown to strengthen urban resilience to climate change by providing a specific cost-effective permeable-pavement layout design [29].

The paper starts with discussing the impact of green-infrastructure construction on urban environmental quality and then examines the moderating position of fiscal decentralization on the association between green-infrastructure development and urban environmental quality and eventually derives a panel-threshold model to assess under what level of fiscal decentralization does green infrastructure affect urban environmental quality at different levels, where fiscal decentralization is considered the threshold variable. Also, baseline regression outcomes are put through the robustness test and heterogeneity analysis. Two major contributions made by the study are as follows: Firstly, it offers new policy implications and empirical findings in relation to fiscal decentralization and betterment of urban environmental quality; Secondly, it looks into regional and population-size disparities in the functions of green infrastructure in improving urban environmental quality, which could assist governments in developing policy measures that are specific to the local context and encourage green urbanism.

2 Theoretical analysis and research hypothesis

2.1 Impact of green infrastructure on the quality of the urban environment

Green infrastructure is an integral component of urban development that has a positive impact on environmental quality in terms of ecology, climatology, hydrology, society and economy. The ability of parks, wetlands, and other types of green infrastructure to absorb carbon dioxide using photosynthetic processes in plants, enhance air quality, mitigate the urban heat-island effect, control regional climate, conserve wildlife, conserve soil and water, and purify water supplies will enhance living standards but also create aesthetic value. Based on this observation, the following hypothesis is advanced:

Green infrastructure can be used to improve the environmental quality of cities.

2.2 Moderating and threshold effects of fiscal decentralization

The institutional constraints should also be taken into account. When under pressure concerning the assessment and incentive systems, local governments may choose revenue-focused investment approaches and cut spending on green infrastructure, environmental quality, and any other like public goods that consequently influences the contribution of green infrastructure to urban environmental improvement. Furthermore, various levels of fiscal decentralization might cause local governments to make different policy decisions, hence producing different results in the role played by green infrastructure to enhance urban environmental quality. Hence, the hypotheses below are suggested:

Heading 2: Fiscal decentralization has a moderating role in green infrastructure impact on urban environmental quality.

Fiscal decentralization has a threshold effect on the role played by green infrastructure in improving urban environmental quality.

3 Study design

3.1 Sample Selection and Data Sources

The research involves the use of a panel dataset of 258 cities at the prefecture level and higher in China within the frame of time between 2008 and 2022. Data on green infrastructure, urban environmental quality, fiscal decentralization, and control variables are primarily based on China Urban Statistical Yearbook, China Statistical Yearbook, China Urban Construction Statistical Yearbook and the CSMAR database. The sample includes cities that have significant missing data, and those that have only minimal missing data are interpolated.

3.2 Variable Selection and Indicator Measurement

3.2.1 Selection of variables

(1) Explained variable: urban environmental quality (Env).

City environmental quality can be assessed through two fundamental aspects that are energy usage and emission of pollutants. Industrial carbon dioxide emissions, industrial wastewater, and industrial dust are the main components that define the pollution dimension. Energy-consumption dimension is mainly reflected by the portion of primary electricity consumption of all energy consumption as well as energy intensity per unit of GDP.

(2) Explanatory variable: establishment of urban green infrastructure (Gf).

Urban green infrastructure is perceived as a green network that is a key element in the development of urban and community contexts. Its primary forms are woodlands, grasslands, croplands, wetlands, and water bodies in highly urbanized regions. As proposed by Yan Qing, this paper calculates the level of development of urban green infrastructure based on the ratio between the vertical projection area of all urban green planting and the sum area of the built-up urban zone, i.e., the green coverage rate of the built-up urban area.

(3) Control variables.

To estimate more accurately how green infrastructure affects urban environmental quality, the following variables are introduced as controls:

1) Population size (Pop): It is measured as a logarithm of the urban household population.

2) Per capita GDP (Pgdp): measured based on the logarithm of per capita GDP.

3) Industrial development stage (Ind): measured by the value added of the secondary industry as a percent of GDP.

4) Level of financial development (Fin): the amount of the loan balance of financial institutions divided by GDP at the end of the year.

5) Urbanization level (Urb): it is determined as a share of urban resident population out of total population.

6) Foreign investment level (Fdi): the actual foreign investment used by the city divided by city GDP in the same year.

(4) Moderating and threshold variable: fiscal decentralization (Fisc).

The proportion of provincial government expenditure to total provincial fiscal expenditure is used to measure fiscal decentralization. Greater levels of fiscal decentralization suggest that local governments have greater powers to tax and a wider range of spending responsibilities, allowing them to choose the level and composition of the fiscal expenditure more autonomously. Therefore, grassroots governments are also more capable of offering financial assistance and providing public services tailored to the needs of the locality, which can be advantageous concerning the development of green infrastructure as well as the enhancement of urban environment.

3.2.2 Measurement of explanatory variables

The entropy-weight method is used to allocate various weights to each indicator when assessing urban environmental quality in the present research and the final score is computed based on these weights. The entropy-weight method is less subjective than most other methods as it reduces the contribution of human judgement. It depends on the quantity of information present in the observed data to determine indicator weights and compute the information entropy of each index. Since the traditional entropy value method is not comparable from year to year when measuring the comprehensive index of urban environmental quality, it is only applicable to time series or cross-section data, which leads to the lack of comparability between cities on a yearly basis. Therefore, this paper considers adding time variables, changing the method of standardized processing data, and deriving a set of weights for the overall data to increase the comparability between years and years, cities and cities, as shown in the following steps:

(1) Assume that there are r years, n cities to be evaluated, and m evaluation indicators to form the original indicator data matrix:

$$X_\theta = \left(X_{ij}\right)_{n\times m}, \theta = 1,\ldots,r; i = 1,2,\ldots,n; j = 1,2,\ldots,m \tag{1}$$

(2) Non-negativity of indicators:

$$X'_{\theta ij} = \frac{X_{\theta ij} - \min\left(X_{11j}, X_{12j},\ldots,X_{21j},\ldots,X_{mj}\right)}{\max\left(X_{11j}, X_{12j},\ldots,X_{21j},\ldots,X_{mj}\right) - \min\left(X_{11j}, X_{12j},\ldots,X_{21j},\ldots,X_{mj}\right)} + 1 \tag{2}$$

For the convenience of the next calculation, the variable after the non-negativization process is still recorded as X_{ij}.

(3) Calculate the weight of the j th city under the i th indicator for that indicator:

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \tag{3}$$

(4) Calculate the entropy value of the j th indicator:

$$e_j = -k \times \sum_{i=1}^{n} P_{ij} \log\left(P_{ij}\right), k = \frac{1}{\ln m} \tag{4}$$

(5) Calculate the coefficient of variation for the j th indicator:

$$g_j = 1 - e_j \tag{5}$$

(6) Find the weights and calculate the composite environmental quality index for each city:

$$W_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \tag{6}$$

$$S_j = \sum_{j=1}^{m} W_j * P_{ij} \tag{7}$$

3.3 Model construction

3.3.1 Benchmark regression model

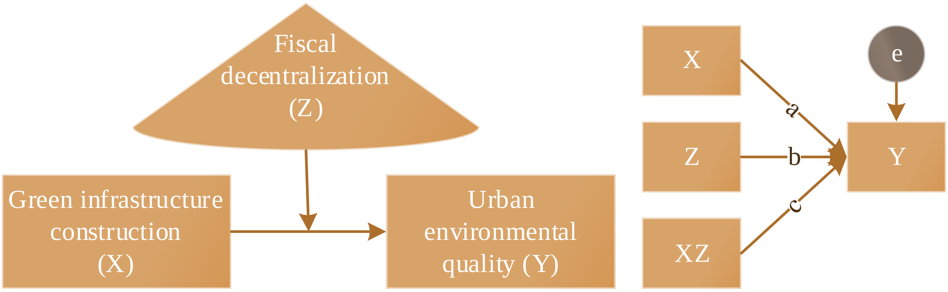
Based on the previous analysis of the relationship between green infrastructure construction and urban environmental quality, this paper constructs the following benchmark regression model:

$$Env_{i,t} = \alpha_0 + \alpha_1 Gf_{i,t} + \alpha_2 Controls_{i,t} + \sum Year + \sum Individual + \varepsilon_{i,t} \tag{8}$$

where i denotes the province, t denotes the year, Gf represents urban green-infrastructure development, Env stands for urban environmental quality, and $Controls$ refers to the set of control variables. $\sum Year$ captures time fixed effects, $\sum Individual$ denotes individual fixed effects, and $\varepsilon_{i,t}$ is the random disturbance term. A significantly positive α_1 indicates that green-infrastructure development promotes urban environmental quality, whereas a significantly negative coefficient would imply that green-infrastructure construction suppresses environmental improvement.

3.3.2 Modelling the Moderating Effects of Fiscal Decentralization

Continuing with the previous analysis, fiscal decentralization can change the effect of green-infrastructure development on urban environmental quality, and the particular moderating mechanism is shown in Figure 1.



(a) Concept map (b) Route maps

Figure 1: Moderating effect model

In this figure, both variable X and variable Z are treated as fixed-distance variables, and the moderating effect can be examined by the following regression equation:

$$Y = i + aX + bZ + cXZ + e \tag{9}$$

where the explanatory variable Y is a function of the explanatory variable X and the moderating variable Z.

In order to verify the moderating effect of fiscal decentralization in green infrastructure construction to improve urban environmental quality, this paper establishes the following moderating effect model:

$$Env_{i,t} = \beta_0 + \beta_1 Gf_{i,t} + \beta_2 Fisc_{i,t} + \beta_3 c\_Gf_{i,t} \times c\_Fisc_{i,t} + \beta_4 Controls_{i,t} + \sum Year + \sum Individual + \varepsilon_{i,t} \tag{10}$$

where $Fisc_{i,t}$ denotes the level of fiscal decentralization.

Let $c\_Gf = Gf - \overline{Gf}, c\_Fisc = Fisc - \overline{Fisc}$ and $c\_Gf = Gf - \overline{Gf}, c\_Fisc = Fisc - \overline{Fisc}$, where $\overline{Gf}$ and $\overline{Fisc}$ are the sample means of Gf and FiscFiscFisc, respectively. β_1 captures the effect of a one-unit increase in green-infrastructure development on urban environmental quality when fiscal decentralization is fixed at its mean level. The interaction term $c\_Gf_{i,t} \times c\_Fisc_{i,t}$ measures the joint effect of green infrastructure and fiscal decentralization after centralization adjustment. If both β_1 and β_3 are statistically significant, fiscal decentralization can be regarded as having a significant moderating role in the relationship between green-infrastructure construction and urban environmental quality. When β_1 and β_3 have the same sign, fiscal decentralization strengthens the contribution of green infrastructure to urban environmental quality; when their signs differ, fiscal decentralization weakens that contribution.

3.3.3 Modeling the threshold effect of fiscal decentralization

The fiscal decentralization has additional consequences than just controlling the connection between the development of green infrastructure and the environmental quality of the city. It can also create an incremental or non-linear effect on the environmental benefits offered by green infrastructure as it varies in intensity. Or in other terms, the relationship may not be fixed at different levels of fiscal decentralization but could have threshold properties. To explore this possibility, the following panel threshold specification is adopted in this study:

$$\begin{aligned} Env_{it} &= \gamma_0 + \gamma_1 Gf_{i,t-1} I\left(Fisc_{it} \leqslant \delta_1\right) + \gamma_2 Gf_{i,t-1} I\left(\delta_1 \leqslant \right. \\ &\left. Fisc_{it} \leqslant \delta_2\right) + \gamma_3 Gf_{i,t-1} I\left(Fisc_{it} > \delta_2\right) + \sum \gamma_k Controls_{i,t-1}^{k} + \\ &\sum Year + \sum Individual + \varepsilon_{i,t} \end{aligned} \tag{11}$$

In this equation, fiscal decentralization $\left(Fisc_{it}\right)$ serves as the threshold variable, δ_1 denotes the first cutoff point, and δ_2 refers to the second cutoff point. I represents the dummy indicator function, while the $Controls$ variables are defined in the same way as in the preceding model.

4 Empirical results and analysis

4.1 Descriptive statistics

The descriptive statistics results are shown in Table 1. In the 3,870 observations of 258 city samples over the period of 2008-2022, the average value of urban environmental quality (Env) has been recorded as 4.143, which means that the overall environmental quality of Chinese cities is still relatively low. The lowest and highest values are 0.304 and 20.176, respectively, which indicates that there is significant disparity in environmental quality over the years as well as among different cities. Some cities have relatively developed environmental consciousness and comparatively good environmental conditions while others remain weak and need additional improvements. Urban green-infrastructure construction (Gf) standard deviation is 0.071, with a minimum of 0.161 and a maximum of 0.493 indicating that the cross-city differences in levels of green-infrastructure development are significant. Fiscal decentralization (Fisc) has a minimum of 0.142 and a maximum of 0.936, similar to that it shows wide variation in the level of fiscal decentralization across China.

Table 1: Descriptive statistics of variables

Variable	Observed value	Mean	Standard deviation	Minimum value	Maximum value
Env	3870	4.143	3.764	0.304	20.176
Gf	3870	0.332	0.071	0.161	0.493
Fisc	3870	0.516	0.173	0.142	0.936
Pop	3870	5.854	0.629	4.322	7.211
Pgdp	3870	10.573	0.713	8.771	12.103
Ind	3870	0.493	0.113	0.164	0.707
Fin	3870	0.935	0.558	0.293	3.166
Urb	3870	0.524	0.174	0.204	0.936
Fdi	3870	0.027	0.016	0.000	0.086

4.2 Correlation analysis

The correlation coefficients for the entire group of variables are presented in Table 2. In the table, ***, ** and * represent significance levels of 1 percent, 5 percent and 10 percent respectively, and such findings serve as the foundation of the following empirical analyses. The estimates indicate the positive relationship between green infrastructure and urban environmental quality and indicate that this link is statistically significant at 1 percent level, which provides initial evidence in favor of H1. Conversely, fiscal decentralization has a negative correlation with urban environmental quality and also achieves significance at the 1 percent level. Simultaneously, the interaction term between fiscal decentralization and green infrastructure can be used to preliminarily deduce the moderating role played by fiscal decentralization. Additionally, a multicollinearity test as indicated in Table 3 shows that VIFs of all explanatory variables are far less than 10, implying that multicollinearity is not significantly influencing the model estimation.

Table 2: Variable correlation analysis

Variable	*Env*	*Gf*	*Fisc*	*Pop*	*Pgdp*	*Ind*	*Fin*	*Urb*	*Fdi*
Env	1								
Gf	0.324 ***	1							
Fisc	-0.062 ***	-0.217 ***	1						
Pop	0.253 ***	0.094 ***	0.085 ***	1					
Pgdp	0.182 ***	0.193 ***	0.024	0.245 ***	1				
Ind	-0.113 ***	0.051 **	-0.026	-0.091 ***	-0.053 ***	1			
Fin	0.461 ***	0.424 ***	0.072 ***	0.414 ***	0.228 ***	-0.084 ***	1		
Urb	0.235 ***	0.231 ***	-0.143 ***	0.241 ***	0.085 ***	-0.183 ***	0.137 ***	1	
Fdi	-0.242 ***	-0.138 ***	-0.009	-0.287 ***	-0.101 ***	0.108 ***	-0.372 ***	-0.136 ***	1

Table 3: Multicollinearity diagnosis results

Variable	*Gf*	*Fisc*	*Pop*	*Pgdp*	*Ind*	*Fin*	*Urb*	*Fdi*
VIF	1.52	1.23	1.48	1.42	1.14	1.18	1.76	1.28
1/VIF	0.66	0.81	0.68	0.70	0.88	0.85	0.57	0.78

4.3 Main and Moderating Effects Analysis

Based on the Hausman test findings, the p-values of both the baseline regression and the moderation specification are 0.00, which means that the fixed-effects model should be used in the empirical analysis. The estimates of the benchmark and moderation are shown in Table 4. Column (1): the estimation is without adding control variables, where green infrastructure has a clear positive and statistically significant effect on the quality of the urban environment. When controls are added to column (2) the green infrastructure coefficient remains positive and becomes significant at 1 percent, thus confirming the hypothesis H1.

One also needs to note that over the past few years, China has put more focus on high-quality urbanization and environmentally friendly development. Since prefecture-level cities are critical players in the implementation of green transformation, they should actively implement actions aimed at improving the environmental situation in their regions. The increase of green infrastructure may directly increase urban vegetation coverage and integrate the ecological role of green space into urban development. With such an approach, the cities are well placed to get the economic benefits as well as environmental gains and also add even more value to the overall quality of the urban environment.

Table 4: Regression results of the main effect and moderating effect

Variable	*Env*	*Env*	*Env*	*Env*
	(1)	(2)	(3)	(4)
Gf	0.0612*** (14.8194)	0.0137*** (2.9356)	0.0485*** (7.8543)	0.0049 (0.8394)
Fisc	-	-	-0.5924* (-2.0491)	-0.4826* (-1.7854)
Gf×Fisc	-	-	0.1412*** (2.8637)	0.1118** (2.2814)
Pop	-	0.0456*** (2.8734)	-	0.0524*** (2.8319)
Pgdp	-	0.0462*** (3.4567)	-	0.0423*** (3.4857)
Ind	-	-0.0345* (-1.8522)	-	-0.0342* (-1.8593)
Fin	-	0.0624*** (18.2157)	-	0.0617*** (17.5329)
Urb	-	-0.0165 (-1.6328)	-	-0.0178* (-1.7943)
Fdi	-	-0.0138*** (-4.2507)	-	-0.0131*** (-4.0813)
Year fixation effect	YES	YES	YES	YES
Individual fixed effect	YES	YES	YES	YES
N	3870	3870	3870	3870
F value	67.5948	79.5392	65.9473	76.2437
R^2	0.3542	0.4671	0.3678	0.4695
Adjusted R^2	0.3504	0.4601	0.3603	0.4634

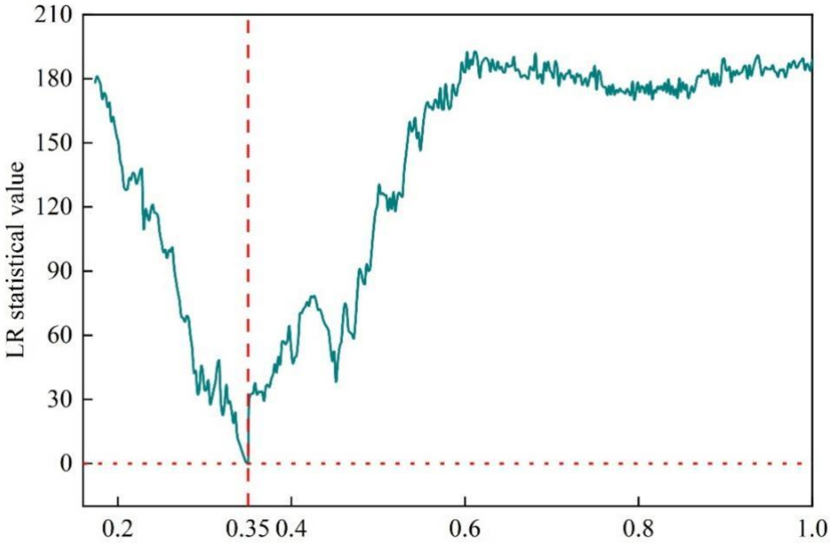
4.4 Analysis of threshold effects

The previous analysis indicates that the impact of green infrastructure construction on the quality of the urban environment depends on the level of fiscal decentralization. In order to test whether this impact varies across different fiscal decentralization ranges, i.e. if it has a threshold effect, this paper uses a panel threshold model to investigate further.

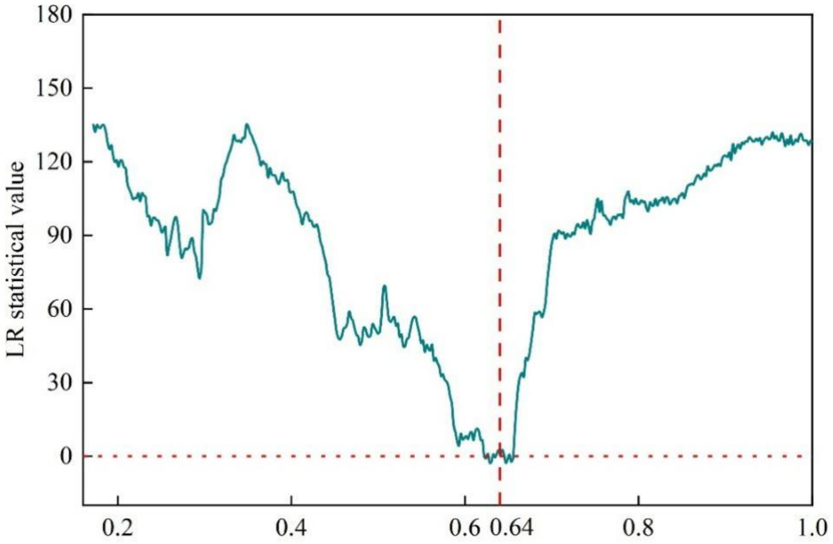
This section identifies fiscal decentralization (Fisc) as the threshold variable and performs the threshold test using urban environmental quality (Env) as the dependent variable. Using 400 bootstrap replications, the F statistics and related p-values of the threshold estimates are calculated and the estimation outcomes are presented in Table 5. The threshold estimates with their confidence intervals are shown in Figure 2, where panels (a) - (b) show the single-threshold and double-threshold cases respectively. The findings show that the association between fiscal decentralization and urban environmental quality has a double-threshold structure whereby the estimated range of the second threshold is [0.35, 0.64], which supports H3.

Table 5: The test results of the threshold effect

Variable	Model	RSS	MSE	*F*	*P*	Critical value		
						10%	5%	1%
Env	On a single threshold	1058.5612	0.2754	243.8226	0.0000***	97.6234	106.2431	135.7306
	Double threshold	1027.6237	0.2676	140.2715	0.0000***	67.2943	72.0585	86.7240
	Triple threshold	1007.9423	0.2655	72.5803	0.8469	143.8217	155.9268	181.5329



(a) A single threshold



(b) Double threshold

Figure 2: Threshold values and confidence intervals

The outcome of threshold-regression is given in Table 6. When Fisc is less than or equal to 0.35, green infrastructure construction has a positive contribution to environmental improvement, but the absolute values of estimated coefficients decrease progressively between these intervals. Based on the threshold estimations, green infrastructure construction effects on urban environmental quality depend on fiscal decentralization, and further levels of fiscal decentralization diminish the contribution of green infrastructure to environmental quality. In such a situation, there should be the right amount of fiscal decentralization to ensure that green infrastructure construction remains a positive factor in enhancing the quality of urban environment.

Table 6: The model estimation results of the threshold variable

Variable	*Env*
Gf (*Fisc*≤0.35)	-0.3851*** (0.0342)
Gf (0.35<*Fisc*<0.64)	-0.0816*** (0.0064)
Gf (*Fisc*≥0.64)	-0.0197*** (0.0031)
Control variable	YES
F value	67.5948
Observations	3870
Number of id	258
R^2	0.5493

4.5 Endogeneity treatment and robustness tests

4.5.1 Endogenous treatment

The system GMM method and the instrumental-variable approach are used in this paper to minimize the effect of endogeneity in the empirical findings. The potential endogeneity of the underlying baseline regression is initially tackled with system GMM and the model is given in the following way:

$$\begin{aligned} Env_{i,t} = \alpha_0 + \alpha_1 Env_{i,t-1} + \alpha_2 Gf_{i,t} + \alpha_3 Controls_{i,t} + \sum Year \\ + \sum Individual + \varepsilon_{i,t} \end{aligned} \tag{12}$$

In order to meet the consistency conditions of estimation, System GMM supposes that the difference between the disturbance term is 1 st -order auto-correlated but without higher-order auto-correlation, and the instruments are strictly exogeneous. Consequently, it is necessary to perform two tests, namely, Arellano-Bond autocorrelation test and Hansen over-identification test.

Table 7 shows the endogeneity-corrected results and model 1 reports the estimates obtained with the System GMM approach. According to the diagnostics, the p-value of AR(1) less than 0.05 implies the presence of first order serial correlation of the differenced residuals, whereas the p-value of AR(2) is greater than 0.1, and therefore the null hypothesis cannot be rejected and there is no indication of second order serial correlation. At the same time, the Hansen test gives the p-value of 0.1821, and this indicates that the chosen instrumental variables are valid and that the assumptions necessary to apply System GMM are met. The predicted value of green infrastructure effect on the urban environmental quality is 0.0353 and is statistically significant at the 10 percent significance level. The result is in line with the baseline regression and also supports the fact that green infrastructure growth can enhance the urban environmental quality.

Table 7: Endogeneity management

Variable	*Env*	*Gf*	*Env*
	(1)	(2)	(3)
Gf	0.0353(0.019)		0.0421**(2.2416)
PG		0.0452***(7.2434)	
Control variable	YES	YES	YES
AR(1)	0.00127		
AR(2)	0.1563		
Hansen	0.1821		
Kleibergen-Paap rk LM		37.5281	
		[0.000]	
Kleibergen-Paap rk Wald F		38.2565	
		{19.93}	
Year fixation effect	YES	YES	YES
Individual fixed effect	YES	YES	YES
N	3870	3870	3870
R^2	0.5472	0.8064	0.8325

The paper also considers endogeneity through an instrumental-variable approach. Namely, the interaction term between the number of park facilities per capita in every city in 2000 and the green urban coverage rate at one year lag is applied as an instrument to the green infrastructure development index, which is referred to as PG. Two-stage least squares are reported in Table 7 of models (2) and (3). The Kleibergen-Paap rk LM statistic is highly significant at 0.001, and thus the null hypothesis of under-identification is rejected. The Kleibergen-Paap Wald F-statistic is 38.2565, which is above the critical value of 19.93 at the 10 percent significance level, and thus the instrumental variable may be considered acceptable and valid. On the first-step estimation, the coefficient of the instrument is positive in the case of green infrastructure construction, with a 1 percent significance level. Green infrastructure has a significantly positive effect on the quality of the urban environment, as shown in the second-stage outcomes. To rephrase it, although endogeneity is accounted for, the statement that green infrastructure enhances urban environmental quality remains true.

4.5.2 Robustness Tests

To verify whether the benchmark conclusions are reliable, this study performs a set of robustness checks, including changing the explanatory variables, replacing the core dependent variable, excluding part of the municipal sample, and controlling for the macro-policy context. The outcomes of these robustness exercises are reported in Table 8. In column (1), the dependent variable is replaced by the urban environmental pollution index (EP), which is likewise constructed with the entropy-weighting approach. The estimated coefficient of green infrastructure development on the industrial-city environmental pollution index is -0.0129 and remains significant at the 1 percent level, suggesting that the expansion of green infrastructure helps lower urban environmental pollution. Moreover, after substituting the explanatory variables originally adopted in the model, the re-estimated results still show that urban green infrastructure development exerts a clear positive influence on the enhancement of urban environmental quality, which further confirms the robustness of the main findings.

The report Model (2) gives an account of the regression outcomes after substituting the main explanatory variable with urban green coverage (GC) and taking the urban environmental quality (Env) as the dependent variable. The calculated coefficient of GC has a significant negative value at the 1 percent significance level, which is consistent with the baseline estimation findings.

To bring the research sample closer and to reduce the potential distortion of the regression estimation by the factor of administrative status and other similar factors, they exclude municipalities as participants. The estimates corresponding to them are presented within the model (3). Green infrastructure construction coefficient is still positive and significant at the 1 percent level, which also confirms the reliability of the benchmark regression findings in the present study.

To limit further the potential interference of the macro-policy environment in the econometric analysis, there are also province fixed effects and their interaction with year fixed effects included in the regression model. The estimated results of these fixed effects introduction are given in models (4) and (5). In either specification, the coefficient of the core explanatory variable, green infrastructure construction, remains highly significant (at 1%). It indicates that, regardless of the macro-policy environment, green infrastructure construction remains an effective contributor to the enhancement of the quality of urban environment, which confirms the strength of the baseline results.

Table 8: Robustness test results

Variable	*EP*	*Env*			
	(1)	(2)	(3)	(4)	(5)
Gf	-0.0129*** (2.7514)		0.0135*** (2.9356)	0.0137*** (2.9356)	0.0137*** (2.9356)
Pop	0.0843*** (2.1527)	0.0865*** (2.1319)	0.0456*** (2.8734)	0.0456*** (2.8734)	0.0387 (2.9514)
Pgdp	0.0578*** (3.0819)	0.0624*** (3.1738)	0.0462*** (3.4567)	0.0462*** (3.4567)	0.0442*** (3.2846)
Ind	-0.0428* (-2.9204)	-0.0532* (-3.0156)	-0.0345* (-1.8522)	-0.0345* (-1.8522)	-0.0327* (-1.7934)
Fin	0.0751*** (17.5263)	0.0773*** (18.4129)	0.0624*** (18.2157)	0.0624*** (18.2157)	0.0608 (17.9531)
Urb	-0.0231 (-1.8537)	-0.0315 (-1.7928)	-0.0165 (-1.6328)	-0.0165 (-1.6328)	-0.0149* (-1.5272)
Fdi	-0.0247*** (-3.8145)	-0.0281*** (-3.5237)	-0.0138*** (-4.2507)	-0.0138*** (-4.2507)	-0.0149 (-4.3824)
GC		0.0135*** (2.8306)			
_cons	-0.957*** (0.251)	-0.889*** (0.243)	-0.812*** (0.247)	-0.814*** (0.247)	-0.628*** (0.273)
Year fixation effect	YES	YES	YES	YES	YES
Individual fixed effect	YES	YES	YES	YES	YES
Provincial fixed effect	NO	NO	NO	YES	YES
Province×Year	NO	NO	NO	NO	YES
N	3870	3870	3870	3870	3810
R^2	0.4369	0.4671	0.4671	0.4671	0.5123

4.6 Heterogeneity analysis

4.6.1 Regression analysis of region-based heterogeneity

The main idea of this paper is that the 258 prefecture-level and higher cities can be reorganized into the eastern, central, and western regions based on their geographic position, and the regression analysis is done again to establish if green infrastructure construction impacts urban environmental quality differently depending on the region. In this case, it is aimed at offering a reference of region-based green-infrastructure development in response to local conditions.

The findings of the regional heterogeneity analysis are presented in Table 9. As per the regression estimates, the estimate of the coefficient of urban green infrastructure construction in the eastern region is 0.0245 and it is statistically significant at one percent. The calculated coefficient in the western region is 0.0137 which also satisfies the 1 percent significance test. These findings suggest that the construction of green infrastructure can be strongly positively related to the overall environmental quality of cities in the east as well as the west. By contrast, estimated coefficient of the central region is negative and does not achieve statistical significance, thus suggesting that the role of urban green infrastructure construction in environmental enhancement in that region is less pronounced

A number of reasons could account to these regional disparities. The eastern region enjoys a solid industrial background, improved supportive infrastructure and a more mature environment of green urbanization that are conducive to a good performance of green infrastructure as a carbon sink. Even though the western region is still behind the eastern region regarding the urban development, it has started to demonstrate some late-development benefits with the support of the national policy and resources tilt, whereas its natural ecosystem basis is not much deteriorated. On the other hand, the central region has poorer initial conditions. In this region, green infrastructure is at a relatively early stage of development, and the general level of construction is also relatively low, so the carbon-sink effect cannot be fully achieved and even can lead to more significant environmental issues during construction.

Table 9: Heterogeneity analysis results based on regions

Variable	East	Central	West
	(1)	(2)	(3)
Gf	0.0245*** (2.9356)	-0.0105*** (5.7142)	0.0137*** (4.0538)
Pop	0.1485*** (0.0573)	0.0425* (0.0191)	0.0286 (0.0354)
Pgdp	-0.1742* (0.2546)	0.3641*** (0.0862)	-0.0913 (0.0925)
Ind	0.0045* (0.0052)	0.0045 (0.0054)	0.0045 (0.0057)
Fin	0.0153 (0.0534)	-0.0138* (0.0091)	-0.0102 (0.0112)
Urb	0.1064 (0.0725)	-0.0728 (0.0643)	-0.0263 (0.0518)
Fdi	0.0734 (0.1315)	-0.6285*** (0.1397)	-0.5781* (0.3084)
_cons	0.1687 (0.5432)	-1.8273*** (0.3561)	0.7124 (0.4439)
Year fixation effect	YES	YES	YES
Individual fixed effect	YES	YES	YES
N	1605	1545	720
R^2	0.5237	0.3948	0.4524

4.6.2 Heterogeneity regression analysis based on city size

To test this hypothesis, the sample cities will be split into large, medium-sized and small cities to determine if the green infrastructure impact on the urban environmental quality is dependent on the size of the city populations.

The findings of the city-size heterogeneity analysis are given in Table 10. The estimates indicate that the coefficient of green infrastructures on the combined index of urban environmental quality in large cities was 0.0134 and statistically significant at 1%. To put it differently, each additional unit of green infrastructures development causes an increase of city environmental quality in large cities by 0.0134 units. Nevertheless, in medium-sized and small cities, the coefficient of green infrastructure is negative and does not pass the significance test.

Overall, these findings indicate that green infrastructure environmental impacts are different depending on city size; and only in big cities can green infrastructure achieve its full ecological potential. One explanation would be that big cities tend to have a higher rate of economic development, better infrastructure systems, and larger populations, which creates a higher demand on green infrastructure construction. This positive value of green infrastructure can then be increased even more with additional government assistance. In contrast, small and medium-sized cities do not have the same benefits when it comes to green infrastructure development. The development and construction phase of green infrastructure in these cities is still relatively low, and the smaller urban size of such cities is not beneficial to the effective implementation of carbon sinks, which subsequently undermines the effectiveness of green infrastructure in enhancing urban environmental conditions.

Table 10: Heterogeneity analysis results based on urban scale

Variable	Big cities	Medium-sized city	Small city
	(1)	(2)	(3)
Gf	0.0134*** (2.9356)	-0.0073 (2.9356)	-0.0042 (5.7251)
Pop	0.0853*** (0.0524)	0.0362 (0.0586)	0.0124 (0.0517)
Pgdp	0.4285*** (0.1241)	0.0423*** (0.0648)	-0.0325 (0.0852)
Ind	0.0037*** (0.0045)	0.0021* (0.0047)	0.0013 (0.0059)
Fin	-0.0065 (0.0145)	-0.0021 (0.0082)	-0.0067 (0.0083)
Urb	0.0372 (0.0526)	-0.1693 (0.05941)	0.0258 (0.05375)
Fdi	-0.4425*** (0.1622)	-0.1973** (0.1025)	-0.1864 (0.1438)
_cons	-2.538*** (0.5294)	-0.1941 (0.3561)	0.0812 (0.3954)
Year fixation effect	YES	YES	YES
Individual fixed effect	YES	YES	YES
N	1140	1410	1320
R^2	0.4953	0.4168	0.3927

5 Conclusion

The empirical investigation of how green infrastructure construction influences urban environmental quality is conducted with the help of panel data of 258 prefecture-level cities in China during the period between 2008-2022 and it also explores the role of fiscal decentralization as both a moderating variable and a threshold variable. The key findings are:

To start with, green infrastructure construction is also crucial to improving the environmental quality in cities, and fiscal decentralization can enhance this positive impact even more.

Firstly, fiscal decentralization has a dual-threshold property which has threshold values of [0.35, 0.64]. At a threshold variable of 0.35, green infrastructure construction is most effective in enhancing the urban environmental quality.

Moreover, the environmental-enhancing benefit of green infrastructure differs across regions and city sizes; however, the positive outcome is especially notable in the eastern and western cities and in big cities.

Following the aforementioned results, this paper offers the below policy recommendations.

To begin with, the government should accelerate the implementation of urban green infrastructure, formulate medium- and long-term construction targets, raise the urban green coverage rate and the proportion of green space in built-up areas, and expand the area of urban parks and wetlands so as to improve urban environmental quality and enhance urban livability.

Secondly, every city must develop its own policies based on its geographical position, natural resources, and other development attributes and thus adjust actions to the local environment. As an example, the government should enhance its financial input towards green infrastructure in eastern and western cities and big cities, create innovative financing mechanisms, establish a steady flow of finance into green-infrastructure projects, and unlock the potential of green infrastructure to cut emissions. On the other hand, in central cities and in small- and medium-sized cities, governments should boost the integrated capability of building green infrastructure in these cities to decrease pollution and carbon emission. At the same time, they need to increase their investments in clean energy research and development, direct urban companies to sustainable development, and hasten the shift in urban industry to green and low carbon economy.

Thirdly, the government ought to appropriately regulate the degree of fiscal decentralization, enhance the environmental measures implemented when constructing infrastructure, and continue to develop urban green infrastructure.

About the Author

Chongwei Zhao was born in Yichun, Heilongjiang, P.R. China, in 1998. He obtained a bachelor's degree from Heilongjiang University of Technology in China. I am currently studying at the School of art, Heilongjiang University.

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