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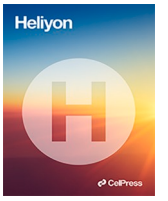

Research article

Decoding the impact of fiscal decentralization on urban pollution intensity in China: A spatial econometric analysis

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ABSTRACT

Utilizing city-level data from China, the paper employs a spatial econometric analysis to investigate the impact of fiscal decentralization on urban pollution. Empirical evidence indicates: (1) In the context of the emphasis of ecological civilization construction in China, an increase of fiscal autonomy for local governments is conducive to mitigating urban pollution intensity. Specifically, fiscal decentralization in one city not only promotes a reduction in local pollution intensity but alleviates environmental pollution problems in adjacent cities through spatial spillover effects. (2) Industrial structure upgrading and green technology progress become crucial measures for local governments to realize pollution reduction targets through fiscal expenditure. (3) Heterogeneity analysis reveals that the positive significance of decentralization is most prominent in the eastern China, while local governments with fiscal autonomy in central region tend to transfer pollution to neighboring cities. (4) There is a threshold characteristic for fiscal decentralization to promote a reduction in urban pollution intensity, and its marginal effect becomes more significant accompanied by continuous introduction of sophisticated foreign direct investment. Finally, the paper summarizes the potential significance of fiscal decentralization among Chinese local governments against the background of "Chinese-style decentralization" and proposes corresponding policy recommendations.

1. Introduction

The rapid industrialization of China's economy [1] since its reform and opening has unavoidably put a significant strain on ecological quality and environmental protection [2]. As a matter of fact, Chinese local governments have exhibited remarkable proficiency in mitigating environmental pollution. Chinese central government formulated a quantitative pollution control policy and assigned emission reduction tasks to the provinces during the 11th Five-Year Plan, including emission lowering targets towards sulfur dioxide and chemical oxygen demand [3]. To ensure the successful implementation of this policy, the Ministry of Environmental Protection (MEP) initiated a pollution reduction performance assessment and linked environmental performance to the promotion of officials, with those who failed to fulfill emission reduction tasks at risk of being removed from office [4]. As expected, the implementation of the policy has yielded great results, and China's pollution decrease targets have been met ahead of schedule. However, the "2022 China Ecological Environment Bulletin" states that China's ecological and environmental quality has generally improved, but the situation of environmental protection is still severe [5]. Against the background of the repeated emphasis on building an ecological civilization, the issue of synergistic development of economic construction and ecological environmental protection has

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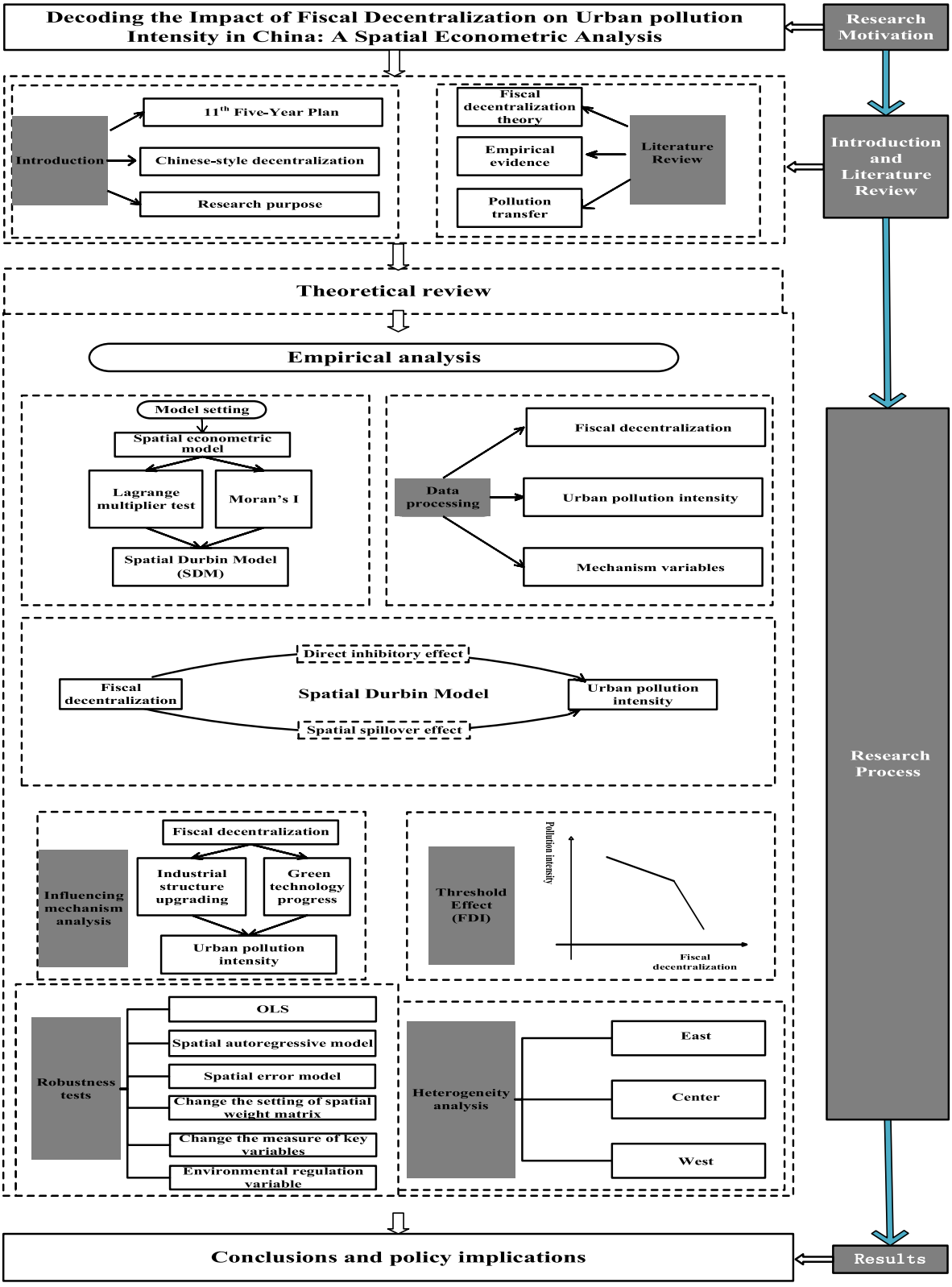

Fig. 1. Theoretical framework.

been particularly critical, and how to do a good job of coordinating and allocating the powers as well as responsibilities of Chinese central government and local governments deserves attention and further research [6].

China's environmental issues are largely resulted from an extensive economic development mode, while this development mode stems from government behaviors against the background of "Chinese-style decentralization", which centralizes power in the political system and decentralizes power in the economic system [7]. Since the implementation of tax share reform, local governments in China have been granted more autonomy in terms of fiscal expenditures, resource allocation and utilization, so in the context of decentralization, local governments are evolving separately and engaging in intense competition in economic activities, and how will this trend affect the regional ecological environment?

Some of the literature suggests that decentralization may result in a "race to the bottom", whereby local governments ease environmental regulations to expand the economy, ultimately leading to environmental degradation [8] under a performance assessment system that relies on economic growth [9]. Moreover, environmental quality serves as a kind of public good with significant externalities. Consequently, local governments tend to disregard the impacts of their actions on the environmental quality of neighboring areas. However, in recent years, the policy orientation of China's development has taken on the "ecological civilization" dimension, and environmental quality has been widely included in the performance appraisal system so that local governments are faced with dual incentives of economic development and ecological quality [10]. To foster the economy simultaneously, will local governments strive for excellence in environmental quality?

Given all this, relying on panel data from 246 cities and employing spatial econometric models, we attempt to explore the potential influence of fiscal decentralization on urban pollution intensity and elucidate the underlying logic. The potential contributions of the paper might incorporate the accompanying aspects. First, we construct a comparable composite pollution intensity indicator, which is more convincing than the single pollution indicator used in previous studies. Second, we analyse the direct and spatial spillover effects of fiscal decentralization by using spatial econometric models and provide reasonable explanations that offer novel perspectives for clarifying the strategic game relationship among local governments. Third, this paper analyses the mechanisms by which fiscal decentralization affects urban pollution intensity. This analysis is logically more complete than the literature [11,12] and can better inform policy formulation. Fourth, we attempt to illustrate the influence of fiscal decentralization on urban pollution according to the viewpoint of fiscal autonomy for local governments, rather than the viewpoint of environmental regulation. The theoretical framework is shown in Fig.1.

2. Literature review and research hypotheses

2.1. Fiscal decentralization and environmental pollution

Regarding the relationship between decentralization and public goods, Tiebout [13] made a seminal contribution to the fiscal decentralization theory: both the theory of "voting by foot" and the "decentralization theorem" suggest that in the case of free movement, residents will migrate to areas where they are satisfied and decentralization is able to improve the proficiency of public products allocation and lead to greater social welfare. However, "the local government model" makes strict assumptions that are difficult to satisfy in reality. The model of interjurisdictional competition shows that inter-regional competition is efficient if local governments seek to maximize the welfare of residents within their jurisdictions [14]. In a scenario of complete information, the central government can maximize social welfare by providing outputs according to local demand [15]. However, due to the existence of information asymmetry, local governments are better informed about the preferences of residents and costs of providing public goods than the central government. Therefore, decentralization can improve the productivity of resource distribution and increment social welfare. The nexus between environmental quality and fiscal decentralization has garnered widespread academic attention, yet a consensus remains elusive. Traditional fiscal decentralization theory assumes that competition among local governments will not negatively impact the environment and argues that local governments will not take the "race to the bottom" approach. Instead, they will adopt the "race to the top" or "not in my backyard" strategy [16], which means that local government officials, as "rational men", will increase the environmental protection standard to ameliorate local environmental quality and attempt to transfer pollution to other areas [17]. When the fiscal situation improved, decentralization can help control the level of pollution in the states and prevent the deterioration of air quality [18]. Using provincial panel data and an input–output model, Tan and Zhang [19] discovered an increase of fiscal decentralization contributes to controlling and mitigating ecological pollution. Wang et al. [11] also argued that fiscal decentralization in China has actually worked to diminish urban haze pollution. For all above facts, we formulate Hypothesis 1a.

Hypothesis 1a. Fiscal decentralization contributes to reducing environmental pollution.

However, it has been argued that decentralization can have an adverse impact on ecological quality. Qian and Weingast [20] modified the first generation of decentralization theory by arguing that government officials do not act according to certain rules and need appropriate constraints and incentives, especially given the background of "Chinese-style decentralization", which manifests itself as "economically decentralized and politically centralized". Several studies [21,22] have discussed the linkage between officials' promotions and their performance in terms of economic growth and the possibility of officials acting shortsightedly to develop local economies, which may lead to a wide range of social issues, such as inequalities, environmental degradation, and disruption of the market order. In the subsequent theoretical literature, Digkstra and Fredriksson [23] further argued that decentralization would lead local governments to successively lower environmental standards, triggering "race to the bottom" phenomenon, thus leading to environmental degradation. Likewise, Zhang et al. [7] examined the connection between fiscal decentralization and carbon emissions through employing provincial panel data in China and concluded that there is a positive correlation between the two. Hence their

research does not support the view that fiscal decentralization is favorable for reducing regional carbon emissions. Luo and Wang [24] investigated the effects of fiscal decentralization and environmental regulation on regional eco-efficiency by employing a spatial Durbin model with provincial-level panel data in China and concluded fiscal decentralization results in a decrease for regional eco-efficiency when government officials are subjected to promotion incentives. However, as the degree of environmental regulation increases, this effect gradually shifts from negative to positive. Similarly, using provincial-level data from China, Guo et al. [25] concluded fiscal autonomy exacerbates ecological pollution. Yu et al. [12] examined 281 Chinese prefecture-level cities and the evidence showed the beneficial impact of an ordered land structure on haze pollution reduction diminishes with increasing fiscal decentralization. Hence, this paper proposes Hypothesis 1b.

Hypothesis 1b. Fiscal decentralization exacerbates environmental pollution.

Study about the relation between fiscal decentralization and regional environmental pollution shown that researchers differ greatly in terms of indicators selection and construction, models, and research perspectives and are unable to reach a consensus conclusion. Therefore, we re-explore the local impact and spatial spillover impact for fiscal decentralization on urban environmental quality simultaneously to assess whether the incentive for "ecological civilization construction" in the new era is effective.

2.2. Influence mechanism

2.2.1. Industrial structure upgrading

A Granger causality test has shown that industrial structure upgrading is an essential driving force in promoting regional economic growth [26]. Therefore, this paper believes that it is feasible for local governments to facilitate industrial structure upgrading under the dual incentives of economic development and ecological quality. Wang and Gao [27] investigated this effect by involving a difference-in-differences method, and their results showed that an increase of fiscal autonomy assists with the upgrading of regional industrial structure. Liu et al. [28] confirmed decentralization has a stimulative impact on promoting industrial structure upgrading, which implies local governments will promote regional industrial upgrading with sufficient fiscal resources.

Furthermore, the positive impacts of industrial structure upgrading and optimization for reducing environmental pollution have also been widely confirmed. Ma [29] held the view that at the national level, industrial structure upgrading helps to reduce environmental pollution, because industrial structure upgrading can promote industrial development from factor-driven to innovation-driven, and from crude, high-consumption, and extensive to intensive, green, and low-consumption. Based on indicators construction for industrial structure optimization, Ma and Cao [30] demonstrated the optimization of regional industrial structure can evidently decrease haze contamination for China. Additionally, this inhibitory impact of industrial structure optimization on ecological pollution may have a triple-threshold characteristic, which manifests as an initial increase and then a decrease [31]. Relying on this discussion, we propose the accompanying speculation.

Hypothesis 2. Fiscal decentralization can reduce environmental pollution through facilitating regional industrial structure upgrading.

2.2.2. Green technology progress

Similarly, the creation and enhancement for technology progress are pivotal to the realization of long-term economic growth and harmonious development [32–34]. For local governments, promoting green technology progress becomes an essential method to simultaneously accomplish the objectives of economic development and environmental governance. In the connected study on fiscal autonomy as well as technology progress, Chen and Li [35] measured green innovation efficiency using two-stage DEA network method in combination with provincial panel data and concluded fiscal decentralization exerts an evident favorable effect towards green technology innovation for China, while fiscal decentralization not only drives local green technology innovation [36] but positively affects technology innovation for nearby areas [37], implying local governments with more fiscal autonomy tend to promote green technology progress.

In addition, the gainful impacts of green technology progress on regional pollution reduction and green development have been widely demonstrated [38]. The collaborative innovation from "green technology institutions" exerts a beneficial impact on eco-efficiency and generates spatial spillover effects [39]. Based on the SBM model, Chen et al. [40] also showed that the sustainable development of innovation capacity and factors can ultimately be an increase in the urban eco-efficiency. Therefore, we present the next hypothesis.

Hypothesis 3. Fiscal decentralization can alleviate ecological contamination by promoting regional green technology progress.

2.3. Spatial spillover and pollution transfer

The majority of the literature adopts a macro perspective of intergovernmental competition when studying the spatial spillover effects of contamination for China. Environmental regulatory policies in neighboring regions can affect local air pollution [41]. Environmental decentralization, corruption, and foreign direct investment are all factors that affect air quality through spatial spillover effects [42,43]. Tan et al. [44] argued that intergovernmental competition within a region can affect air quality for neighboring areas. Through worsening air quality in geographically similar regions and improving air quality in regions with little difference in economic development conditions, this spatial transfer of pollution results from industrial transfer due to intergovernmental competition. Given that midwest regions of China are main recipients of pollution transfer with particularly severe pollution problems

[45], local governments may have incentives to transfer pollution to internal neighboring cities. However, there is little research examining intra-regional pollution transfer between cities from a fiscal decentralization perspective, which is supplemented in this paper. We propose Hypothesis 4.

Hypothesis 4. Fiscal decentralization may drive intra-regional pollution transfers.

3. Data and research methodology

3.1. Data processing and indicator construction

3.1.1. Explanatory variable

3.1.1.1. Fiscal decentralization (FisD). Fiscal decentralization is the explanatory variable of the study, which can be a reflection of fiscal autonomy for local governments in public expenditure. Referring to the literature [28], to eliminate the influence of population scope, this paper constructs the fiscal decentralization indicator as follows:

$$FisD_{it} = FisE_{it} /(FisE_{it} + FisE_{pt} + FisE_{nt}) \quad (1)$$

In equation (1), $FisE_{it}$ represents the fiscal expenditure per capita of city i in year t, $FisE_{pt}$ means fiscal expenditure per capita at the province level, $FisE_{nt}$ denotes the national fiscal expenditure per capita. A spatial distribution image of fiscal decentralization for each city in 2019 is shown in Fig. 2.

3.1.2. Explained variable

3.1.2.1. Urban pollution intensity (Pol). Urban pollution intensity is the explained variable in this paper. Distinguishing from per capita or total pollutant emissions, we refer to Zhu et al. [46] to set the composite urban pollution intensity indicator as follows:

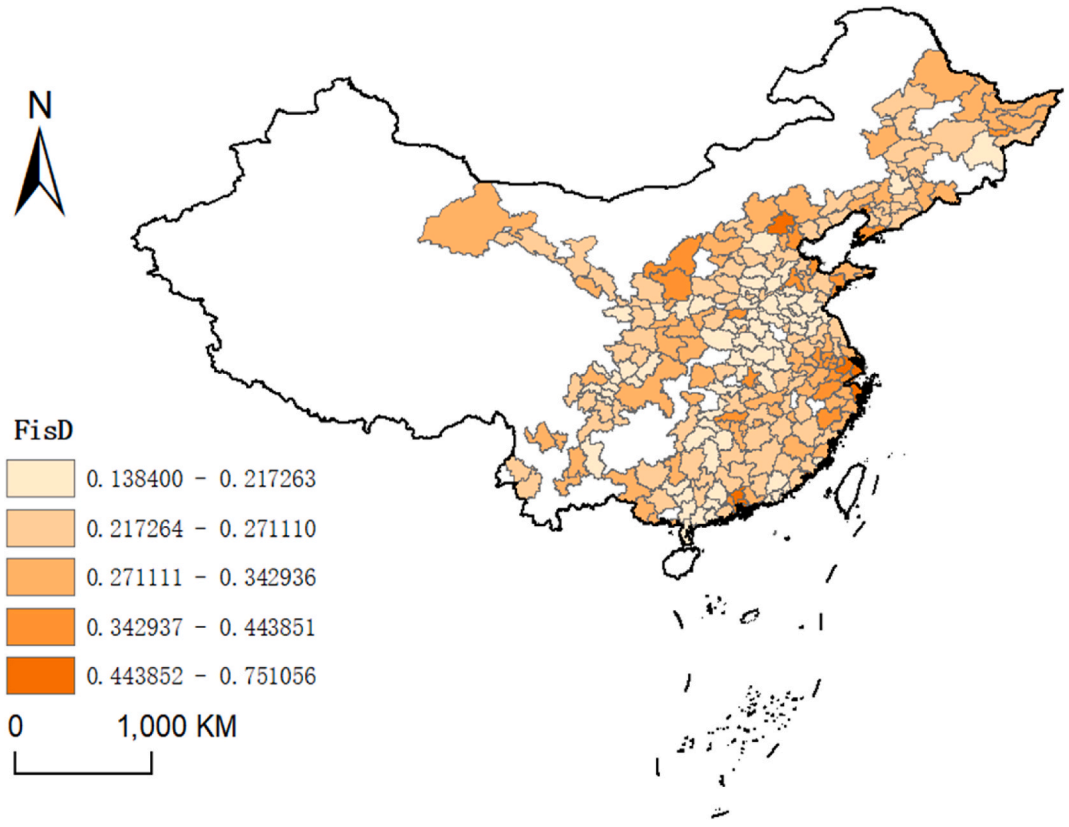

Fig. 2. Spatial distribution of fiscal decentralization in 2019.

$$Pol_{ist} = P_{ist} / \overline{P_{ist}} = \frac{p_{ist}/y_{it}}{\frac{1}{n}\sum_{i=1}^{n} p_{ist}/y_{it}}, s = 1,2,3,4,5 \quad (2)$$

In equation (2), P_{ist} is the discharge of pollutant s per unit of added value of secondary industry of city i in year t and Pol_{ist} reflects a relative discharge level of pollutant s in city i among all sample cities. This indicator, which takes the added value for secondary industry into account, is able to reflect the pollution intensity for the city and manifest whether the growth pattern of the region is reasonable and efficient. The pollution intensity of each pollutant is downgraded by principal component analysis (PCA) to obtain the comprehensive pollution intensity indicator and specific pollutants include CO_2 release, SO_2 discharge, wastewater discharge, fumes discharge and PM2.5 concentrations. A spatial distribution image of urban pollution intensity for each city in 2019 is shown in Fig. 3.

3.1.3. Mediating variable

3.1.3.1. Industrial structure upgrading (TS). We refer to Yuan and Zhu [47] to set up an indicator for industrial structure upgrading with following formula:

$$TS_{it} = \sum_{n=1}^{3} y_{itn} lp_{itn} = \sum_{n=1}^{3} (Y_{itn} / Y_{it})(Y_{itn} / L_{itn}), n = 1,2,3 \quad (3)$$

In equation (3), y_{itn} means the share of industry n of city i in year t, L_{itn} means the number of employees in industry n of city i in year t, lp_{itn} means the labor productivity of industry n of city i in year t.

3.1.3.2. Green technology progress (GTP). The degree of green technology progress is calculated by the quantity of patent applications for green inventions in each city.

3.1.4. Control variables

The industrial structure rationalization indicator (TL) can be calculated as follows in equation (4):

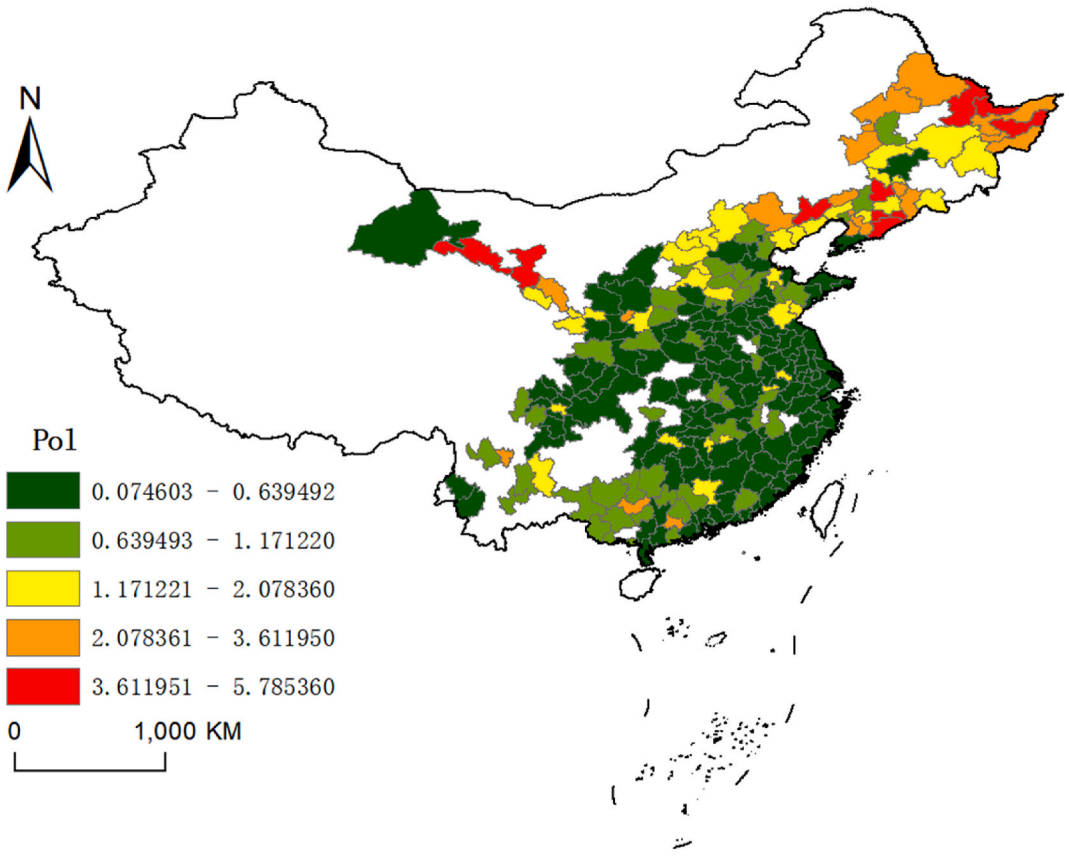

Fig. 3. Spatial distribution of urban pollution intensity in 2019.

$$TL_{it} = \sum_{n=1}^{3} y_{itn}\, ln(y_{itn} / l_{itn}), n = 1, 2, 3 \tag{4}$$

where y_{itn} means the share of industry n in city i in year t, and l_{itn} means the portion of employees in industry n to total employment in city i in year t. A larger TL indicator implies a greater deviation condition from the equilibrium state with a less rational industrial structure situation.

In addition, urbanization process and regional human capital level may have an impact on environmental governance [24]. Human capital level (*Edu*) is expressed by the proportion of the quantity of college graduates or higher to its total population in each city. The degree for urbanization (*UR*) is expressed in terms of the urbanization rate per city. To control for the potential effect of the level of openness on environmental performance [48,49], we also add the number of per capita import and export for resident population (*Open*) and foreign direct investment (*FDI*), measured by the proportion of the amount of foreign capital actually used for each city to its GDP, to the control variable set. Taking into account the positive influence for the development of digital economy (*DigE*) on pollutant emission reduction [33], we refer to Zhao et al. [50] to acquire a development indicator for the digital economy. We select six indicators, including the number of Internet users per 100 people, the proportion of people engaged in computer services and software, the volume of telecommunication services per capita, the number of mobile phone subscribers per 100 people, the volume of postal services per capita, and a digital financial inclusion index. The variation coefficient method is utilized to downscale these indicators, subsequently enabling the construction of a comprehensive index for digital economy development.

All data selected for this research are from the China Statistical Yearbook, China City Statistical Yearbook and Chinese Research Data Services Platform. Descriptive statistics for variables used are presented in Table 1.

3.2. Spatial model setting

3.2.1. Spatial correlation test

Prior to spatial modeling, it's appropriate to perform spatial correlation tests on the key variables. For the section, *Moran's I* index is chosen to verify spatial relation for fiscal decentralization and urban pollution intensity respectively, and the spatial adjacency matrix is employed for the benchmark matrix. When *Moran's I* is significantly higher than 0, it indicates that the variable shows a positive spatial correlation; when significantly lower than 0, it implies the variable reflects a negative spatial correlation. The specific calculation formula is shown in equation (5):

$$Moran's\ I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(Y_i - \overline{Y})(Y_j - \overline{Y})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{5}$$

The results of spatial correlation test of fiscal decentralization and urban pollution intensity are demonstrated in Table 2. The global *Moran's I* values of urban pollution intensity and fiscal decentralization are both positive and satisfy the test successfully. Therefore, there is a strong positive spatial correlation ("high-high" and "low-low" characteristics of spatial distribution) for urban pollution intensity as well as fiscal decentralization among cities from 2011 to 2019.

3.2.2. Lagrange multiplier (LM) test

In this paper, we continue to carry out a Lagrange multiplier test to adopt a fitting spatial econometric model, and the test outcomes are displayed in Table 3.

The evidence shows that the Lagrange multiplier index for the spatial lag model and spatial error model is significant at the 1 % level, the Robust Lagrange multiplier index is evident at least at the 1 % level, and the spatial Durbin model does not degenerate into the spatial lag model (SLM) or the spatial error model (SEM). Consequently, we set up a spatial Durbin model (SDM) to concentrate on the correlation between fiscal decentralization and urban pollution intensity.

3.2.3. Spatial durbin model setting

In contrast to regular econometric models, the spatial spillover effects of the core variables can be captured through spatial models.

Table 1
Statistical description.

Variable	Obs	Mean	Std. Dev.	Min	Max
Pol	2214	1.076	0.922	0.075	6.558
FisD	2214	0.269	0.089	0.085	0.815
TS	2214	0.123	0.073	0.009	0.714
lnGTP	2214	4.432	1.750	0.000	10.183
TL	2214	0.284	0.200	0.000	2.195
Open	2214	1.437	3.134	0.001	31.317
DigE	2214	0.204	0.126	0.017	0.862
FDI	2214	0.017	0.017	0.000	0.116
Edu	2214	1.721	1.994	0.005	12.764
UR	2214	0.546	0.140	0.226	1.000

Table 2
The correlation test.

YEAR	*Pol*		*FisD*	
	Moran's I	Z	*Moran's I*	Z
2011	0.351***	8.116	0.362***	8.400
2012	0.365***	8.414	0.379***	8.757
2013	0.466***	10.723	0.354***	8.173
2014	0.510***	11.769	0.354***	8.191
2015	0.479***	11.054	0.347***	8.069
2016	0.495***	11.473	0.354***	8.225
2017	0.507***	11.782	0.364***	8.447
2018	0.471***	10.966	0.354***	8.226
2019	0.547***	12.655	0.361***	8.368

Note: ***p < 0.01, **p < 0.05, *p < 0.1.

Table 3
Lagrange multiplier test (LM test).

LM Test	Statistic	P-value
Spatial error:		
Moran's I	26.415	0.000
Lagrange multiplier	683.902	0.000
Robust Lagrange multiplier	54.911	0.000
Spatial lag:		
Lagrange multiplier	852.655	0.000
Robust Lagrange multiplier	223.663	0.000

With the help of spatial Durbin model, this paper explores the "local-neighbor" effects of fiscal decentralization on urban pollution intensity from the perspective of competition and cooperation for local governments. After conducting a Hausman test and the fixed effects type test, the study determines that a two-way fixed spatial Durbin model is chosen for benchmark regression, which is set as follows:

$$Pol_{it} = \alpha_0 + \rho W_{ij} Pol_{it} + \alpha_1 W_{ij} FisD_{it} + \alpha_2 W_{ij} X_{it} + \alpha_3 FisD_{it} + \alpha_4 X_{it} + u_t + \lambda_i + \varepsilon_{it} \quad (6)$$

In equation (6), W_{ij} denotes the spatial weight matrix, which is set as the spatial adjacency matrix in benchmark regression. Adjacency matrix allows for the division of local governments from an administrative perspective, which can help reflect the impact of behaviors for local governments and satisfy our research targets, and ρ represents the spatial autoregressive coefficient for urban pollution intensity and reflects spatial correlation of pollution intensity. $\alpha_1 - \alpha_2$ represent spatial spillover effects from fiscal decentralization as well as the control variables towards pollution intensity, respectively, while $\alpha_3 - \alpha_4$ represent their direct effects. u_t means the time fixed effect, and λ_i denotes the city fixed effect. Due to the limited explanatory power of the coefficients in spatial Durbin model, which cannot directly reflect their effect sizes [51], this paper further decomposes the total effects of the variables into direct (local) and indirect effects (spatial spillover effects) via a partial differential method in benchmark regression.

Table 4
Results of the effects of fiscal decentralization on urban pollution intensity.

Pol	Coef.	p-value	Coef.	p-value	Coef.	p-value
	Main		Direct		Indirect	
FisD	−2.009*** (0.473)	0.000	−2.095*** (0.480)	0.000	−2.575*** (0.997)	0.010
TL	0.259*** (0.093)	0.005	0.261*** (0.089)	0.003	0.136 (0.194)	0.484
Open	−0.015 (0.015)	0.292	−0.014 (0.014)	0.302	−0.012 (0.037)	0.750
DigE	−0.790*** (0.199)	0.000	−0.862*** (0.192)	0.000	−1.709*** (0.414)	0.000
FDI	0.488 (1.165)	0.675	−0.141 (1.097)	0.898	−15.809*** (2.068)	0.000
Edu	0.071*** (0.026)	0.007	0.063** (0.026)	0.017	−0.233*** (0.056)	0.000
UR	−0.169 (0.256)	0.510	−0.210 (0.262)	0.426	−0.981** (0.479)	0.041
Spatial rho	0.199*** (0.027)	0.000				
sigma2_e	0.133*** (0.004)	0.000				
City FE	YES		YES		YES	
Year FE	YES		YES		YES	

Note:Standard errors in parentheses ***p < 0.01, **p < 0.05, *p < 0.1 Number of obs 2214.

4. Empirical analysis

4.1. Benchmark regression: fiscal decentralization and urban pollution intensity

For benchmark regression, we empirically investigate the correlation between fiscal autonomy and urban pollution intensity adopting the spatial Durbin model. We report the regression coefficients, the local effect and the spatial spillover effect for each explanatory variable in Table 4.

The analysis towards benchmark empirical results reveals the following:

(1) Overall, fiscal decentralization exerts a remarkable negative impact on urban pollution intensity (−2.009) and these results confirm Hypothesis 1a, which suggests that fiscal autonomy motivates local governments to implement corresponding measures to reduce the intensity of pollutant discharges.
(2) After decomposing the total impacts for fiscal decentralization into local effects and spatial spillover effects, we notice the coefficient of its local effect is −2.095, while the spatial spillover effect reaches −2.575 and both of them are significant. All results show fiscal decentralization not only induces local governments to take measures to reduce local environmental pollution but also leads to a reduction for pollution intensity in adjacent cities.
(3) Moran's I shows an evident spatial correlation with urban pollution intensity between neighboring cities in China. Here, the spatial autoregressive coefficient ρ is 0.199, which confirms this phenomenon again, indicating that urban pollution intensity itself exhibits a positive spatial spillover effect and that elevated pollution status in one area can also exacerbate environmental pollution in neighboring areas.
(4) Among the variables, the direct effect of FDI is not significant, but its spatial spillover effect can lead to the transformation of production modes and reduce regional pollution intensity in neighboring areas. The digital economy demonstrates a prominent negative impact on urban pollution intensity of local as well as adjacent areas, indicating that provoking the progress of digital economy becomes an imperative approach to reduce environmental pollution. Increasing the level of human capital can solve environmental pollution in neighboring areas, but it exacerbates local pollution intensity, suggesting that there is a distortion in the allocation of human capital in Chinese cities.

4.2. Mechanism analysis - the intermediary effect

According to the above analysis, we know that improving fiscal autonomy of local governments helps reduce local pollution intensity and can lead to a reduction in environmental pollution in neighboring regions. In what way does the local government achieve the purpose of reducing pollutant emissions? This paper uses a two-step analysis to test the intermediary effects for industrial structure upgrading as well as green technology progress for fiscal decentralization affecting urban pollution intensity, and the specific models in equations (7) and (8) are as follows:

$$M_{it} = \alpha_0 + \rho W_{ij} M_{it} + \alpha_1 W_{ij} FisD_{it} + \alpha_2 W_{ij} X_{it} + \alpha_3 FisD_{it} + \alpha_4 X_{it} + u_t + \lambda_i + \varepsilon_{it} \quad (7)$$

$$Pol_{it} = \alpha_0 + \rho W_{ij} Pol_{it} + \alpha_1 W_{ij} FisD_{it} + \alpha_2 W_{ij} M_{it} + \alpha_3 W_{ij} X_{it} + \alpha_4 FisD_{it} + \alpha_5 M_{it} + \alpha_6 X_{it} + u_t + \lambda_i + \varepsilon_{it} \quad (8)$$

where M_{it} is the mediating variable and represents industrial structure upgrading (*TS*) and green technology progress (*lnGTP*), respectively.

Table 5
Results of mechanism analysis.

Variable	(1) *TS*	(2) *Pol*	(3) *lnGTP*	(4) *Pol*
FisD	0.080** (0.034)	−1.942*** (0.473)	1.871*** (0.478)	−1.947*** (0.474)
TS		−0.816*** (0.299)		
lnGTP				−0.045** (0.021)
TL	0.054*** (0.007)	0.305*** (0.094)	−0.012 (0.094)	0.255*** (0.093)
Open	−0.003*** (0.001)	−0.013 (0.015)	0.011 (0.015)	−0.014 (0.015)
DigE	0.054*** (0.014)	−0.746*** (0.199)	−0.144 (0.201)	−0.779*** (0.199)
FDI	0.197** (0.083)	0.615 (1.164)	1.021 (1.175)	0.541 (1.163)
Edu	−0.001 (0.002)	0.069*** (0.026)	−0.016 (0.027)	0.065** (0.026)
UR	0.041** (0.018)	−0.099 (0.256)	0.198 (0.259)	−0.152 (0.255)
Spatial rho	0.396*** (0.024)	0.189*** (0.027)	0.337*** (0.025)	0.186*** (0.027)
Sigma2_e	0.001*** (0.000)	0.13***(0.004)	0.137*** (0.004)	0.133*** (0.004)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Note:Standard errors in parentheses.
*p < 0.1 Number of obs 2214.
*** p < 0.01.
** p < 0.05.

Industry type can determine the proportion of resource consumption and affect the quality of ecological environment. Industrial structure upgrading is capable of enhancing resource utilization efficiency and alleviating pollutant emissions problems [52]. Therefore, this research attempts to testify whether fiscal decentralization affects urban pollution intensity through industrial structure upgrading. Column (1) of Table 5 demonstrates the influence of fiscal decentralization on industrial structure upgrading with a positive coefficient of 0.080, implying fiscal decentralization can actually promote upgrading for urban industrial structure. Column (2) further verifies industrial structure upgrading is fit for mitigating pollution severity and optimizing regional development patterns.

Technological progress can optimize production processes and energy use, eliminate highly polluting equipment, promote technological innovation for green production, and enhance regional eco-efficiency [39]. The influence coefficient for fiscal decentralization in column (3) is 1.871, which is significant, implying fiscal decentralization can promote green technology progress. The results for intermediary mechanism analysis in column (4) manifest that green technology progress exerts a noteworthy negative effect on urban pollution intensity, confirming the role for green technology progress in reducing regional pollution intensity does exist.

These outcomes are basically in line with expectations because against the background of "Chinese-style decentralization" and considering that local government officials have more discretionary power in fiscal expenditures and resource allocation, accelerating the optimization and upgrading of local industrial structure and the progress for green technology are imperative for achieving economic growth as well as environmental governance. Furthermore, the spatial autoregressive coefficients of industrial structure upgrading as well as green technology advancement are both obviously positive at the 1 % level, indicating industrial structure optimization as well as green technology progress in one city will drive the development of neighboring regions, which also offers a theoretical basis for fiscal decentralization to reduce environmental pollution through the spillover effect. The results provide support for Hypothesis 2 and 3.

4.3. Heterogeneity analysis - empirical results at the regional level

The degree of economic and technological development for various regions of China varies greatly. In this section, the sample is partitioned into three regions—the eastern, central and western areas—to examine the heterogeneity of the influence for fiscal decentralization on urban pollution intensity. After the LM test, this paper selects appropriate spatial econometric models to perform econometric analysis for the three major regions.

Table 6 manifests the coefficient of fiscal decentralization on urban pollution intensity reaches as high as −5.230 in the eastern region, which is significant at the 1 % level. This coefficient in the central region is −2.179, while the impact in the western region is not obvious, which may be due to the fact that for western region, it is more critical to revitalize and increase dynamics for the economy, and the use of public fiscal expenditures has not yet benefited the level of environmental protection. For the western region of China, industrial structure rationalization exerts an obvious influence for the reduction of ecological pollution; therefore, actively boosting the continuous optimization of industrial structure may be the best way to give consideration to environmental protection and economic expansion. Considering an obvious "pollution decrease effect" of fiscal decentralization in the eastern region as well as "beggar-thy-neighbor" phenomenon in the central region, our paper further decomposes the effect of fiscal decentralization on pollution intensity for the eastern and central regions into direct and indirect effects.

As demonstrated in Table 7, in the eastern region, the coefficient for decentralization on local pollution intensity reaches −5.235, which is significant at the 1 % level, and its impact is much greater than −2.095 in the national sample, which indicates the governments in the eastern region are capable of rationally utilizing and allocating public fiscal expenditures to realize the purpose of controlling pollution problems [53]. However, in the central region, which receives pollution transfer from other regions, fiscal decentralization can reduce local pollution intensity but it will lead to a significant increase in pollution intensity of adjacent areas, proving that local governments in the central region adopt the "beggar-thy-neighbor" and "not in my backyard" strategies and realize the transfer of pollution to adjacent areas through public expenditures. For the local governments in central region, accelerating the

Table 6
Results of heterogeneity analysis.

Pol	(1)*East*	(2)*Center*	(3)*West*
FisD	−5.230*** (0.861)	−2.179*** (0.731)	−0.717 (0.850)
TL	0.439** (0.201)	0.035 (0.137)	0.320** (0.152)
Open	−0.032* (0.018)	0.004 (0.032)	0.070 (0.047)
DigE	−1.225*** (0.274)	−0.691* (0.406)	−0.341 (0.448)
FDI	−2.836** (1.372)	1.314 (2.305)	1.256 (1.321)
Edu	0.045 (0.048)	0.178*** (0.044)	−0.028 (0.046)
UR	0.301 (0.360)	−2.562*** (0.438)	1.815*** (0.594)
Spatial rho	0.166*** (0.042)	0.247*** (0.041)	0.035 (0.054)
Sigma2_e	0.135*** (0.006)	0.126*** (0.006)	0.109*** (0.007)
City FE	YES	YES	YES
Year FE	YES	YES	YES
Number of obs	873	837	504

Note:Standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

Table 7
The direct and indirect effect of fiscal decentralization in the eastern and central regions.

Pol	Eastern region		Central region	
	Direct	Indirect	Direct	Indirect
FisD	−5.235*** (0.885)	−0.981*** (0.270)	−1.783** (0.747)	7.210*** (1.559)
TL	0.434** (0.195)	0.082* (0.044)	0.062 (0.132)	0.647** (0.296)
Open	−0.030* (0.018)	−0.006 (0.004)	−0.004 (0.031)	−0.233*** (0.090)
DigE	−1.240*** (0.266)	−0.235*** (0.083)	−0.733* (0.395)	−0.664 (0.930)
FDI	−2.859** (1.326)	−0.529* (0.273)	0.721 (2.158)	−11.358** (4.722)
Edu	0.048 (0.048)	0.009 (0.010)	0.146*** (0.044)	−0.648*** (0.099)
UR	0.301 (0.374)	0.058 (0.076)	−2.786*** (0.460)	−4.311*** (0.907)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Note:Standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

process for industrial structure transformation as well as green technology progress is vital.

Moreover, the spillover effect of fiscal decentralization in eastern region is −0.981, which is significant at the 1 % level, illustrating an improvement for the extent of local fiscal decentralization actually mitigates the pollution intensity for neighboring regions and the "beggar-thy-neighbor" phenomenon will not occur. This shows that in the eastern region, where the economic foundation appears solid and the infrastructure is complete and adequate, the synergy between economic benefits and environmental management among local governments has reached a relatively high level, truly reflecting the concept of "collaboration, participation, and shared benefits". With more fiscal autonomy, the eastern region may transfer pollution to the midwest region of the country through industrial transfer without increasing its own pollution level, while the central region, which is also the "destination" of pollution transfer in China, tends to re-transfer pollution to its internal neighboring cities. This also means that the phenomenon described in Hypothesis 4 is confirmed in the central region of China.

4.4. The threshold effect analysis

Liu et al. [54] noted fiscal decentralization may have a nonlinear effect on ecological contamination: the effect of fiscal decentralization varies with the level of FDI, so this paper attempts to validate this phenomenon. Before constructing the threshold model, it is reasonable to verify the threshold variables to confirm the existence of the threshold effect.

As demonstrated in Table 8, FDI passes the double threshold test, accompanied by two threshold values of 0.0017 and 0.0092, both of which are significant at least at the 10 % level, proving that when FDI is at different levels, the pollution reduction impact of fiscal decentralization is also distinguishing.

To ensure the presence for the threshold effect, the image of likelihood ratio function is shown in Fig. 4. We can see that the images of the two thresholds intersect with the horizontal line, passing the significance test.

Considering the existence of double-threshold effect for FDI, this paper sets the threshold regression model in equation (9):

$$Pol_{it} = \sigma_0 + \beta_1 FisD_{it} I(FDI \le \gamma_1) + \beta_2 FisD_{it} I(\gamma_1 < FDI \le \gamma_2) + \beta_3 FisD_{it} I(FDI > \gamma_2) + \sum_{i \ge 1} \theta_i Controls_{it} + u_t + \lambda_i + \varepsilon_{it} \quad (9)$$

where *Pol* represents urban pollution intensity; *FisD* represents fiscal decentralization; *FDI*, the threshold variable for this model, represents foreign direct investment; γ_1 and γ_2 represent the first and second thresholds, respectively; β_1 denotes the influence for fiscal decentralization on urban pollution intensity when $FDI \le \gamma_1$; and β_2 represents the influence when $\gamma_1 < FDI \le \gamma_2$ and β_3 is the impact when $FDI > \gamma_2$. We report the regression consequences for this panel threshold model in Table 9:

According to the regression results, when FDI value is less than the first threshold, the coefficient for fiscal decentralization on urban pollution intensity is −1.747, which is significant at the 10 % level; when FDI is between the two thresholds, the coefficient becomes −2.499; and after FDI exceeds the second threshold, this impact reaches −2.974. First, it is not difficult to discover that with the introduction of FDI, the "pollution reduction" effect for fiscal decentralization also increases. Contrary to the pollution haven hypothesis [55], local governments do not sacrifice environmental quality to attract low-quality foreign investment, resulting in environmental pollution problems. With more fiscal autonomy, the capabilities of local governments in China in utilizing and

Table 8
Threshold effect test.

Threshold variable	Threshold value	F-Value	P-Value	Critical value		
				10 %	5 %	1 %
FDI	0.0017	30.01	0.0067	18.1130	21.2236	29.4922
	0.0092	16.22	0.1000	16.0325	18.7525	26.5326

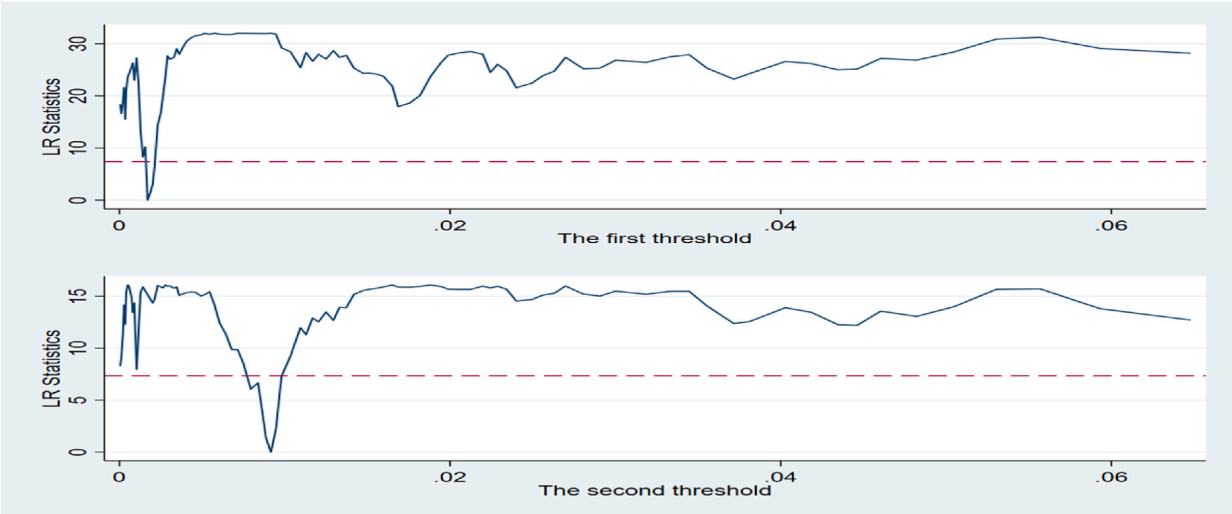

Fig. 4. Likelihood ratio function plot (LR test).

Table 9
Threshold effect regression results.

Pol	Coef.	Robust Std.Err.	t	P>|t|
FisD (*FDI* ≤ 0.0017)	−1.747*	0.899	−1.94	0.053
FisD (0.0017 < FDI ≤ 0.0092)	−2.499***	0.853	−2.93	0.004
FisD (*FDI* > 0.0092)	−2.974**	0.897	−3.31	0.001
TL	0.364*	0.190	1.91	0.057
Open	−0.028	0.021	−1.37	0.172
DigE	−0.933***	0.276	−3.38	0.001
FDI	−3.810*	2.156	−1.77	0.078
Edu	0.041	0.066	0.62	0.539
UR	0.189	0.551	0.34	0.732
_cons	1.782***	0.291	6.13	0.000

Note.
*** p < 0.01.
** p < 0.05.
* p < 0.1.

Table 10
Robustness tests (I).

Pol	(1)	(2)	(3)	(4)
FisD	−1.923*** (0.456)	−2.497*** (0.460)	−2.513*** (0.477)	−2.891*** (0.503)
TL	0.211** (0.090)	0.304*** (0.092)	0.312*** (0.094)	0.351*** (0.101)
Open	−0.009 (0.014)	−0.022 (0.015)	−0.022 (0.015)	−0.025 (0.016)
DigE	−0.668*** (0.195)	−0.879*** (0.199)	−0.804*** (0.203)	−1.013*** (0.218)
FDI	−0.520 (1.064)	−4.091*** (1.023)	−3.399*** (1.133)	−6.302*** (1.099)
Edu	0.046* (0.026)	0.055** (0.027)	0.068** (0.027)	0.034 (0.029)
UR	0.115 (0.255)	0.028 (0.250)	0.113 (0.258)	0.052 (0.275)
Spatial rho/lambda	0.716*** (0.073)	0.262*** (0.025)	0.257*** (0.027)	
Sigma2_e	0.126*** (0.004)	0.138*** (0.004)	0.140*** (0.004)	
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Note:Standard errors in parentheses.
*** p < 0.01.
** p < 0.05.
* p < 0.1 Number of obs 2214.

managing foreign capital continue to improve. Second, the empirical evidence of the study supports the technical effect for FDI [56], meaning the introduction of foreign capital promotes interactions among enterprises, governments and institutions in host countries and the improvement of enterprise technology, which indeed contributes to reducing pollution and protecting the environment [29].

Accordingly, local governments should adequately bring in high-quality and high-level foreign investment, pay attention to the examination as well as full utilization of the advantages of foreign technologies, facilitate the synergistic development of economy construction and ecological civilization, thereby embarking on the road to green and sustainable development [57].

4.5. Robustness tests

To guarantee the consequences of our research are credible and valid, we conducted the following robustness tests:

The selection of the spatial matrix is changed. In this section, we adopt the spatial geographical distance matrix in place of the spatial adjacency matrix employed in benchmark regression, and its results are introduced in column (1). After setting the geographic distance matrix, the impact for fiscal decentralization on urban pollution intensity is −1.923, which is significant and consistent with the benchmark regression results.

The regression model setting is changed. To avoid model setting errors, we replace the spatial Durbin model employed in benchmark regression with the spatial lag model (SLM), spatial error model (SEM) and OLS method to re-validate the previous results. As demonstrated in columns (2), (3) and (4) of Table 10, the impacts of fiscal decentralization on urban pollution intensity for the three models are −2.497, −2.513 and −2.891, respectively. The finding proves that the effect of fiscal decentralization on promoting the reduction of urban pollution intensity is still evident after we change the regression model.

The core explained and explanatory variables are replaced. In accordance with the literature [19], the data for the discharges of sulfur dioxide, wastewater and fumes of each city is selected, and the entropy weight method is adopted to acquire a comprehensive pollution indicator for robustness test. After we change the explained variable, the coefficient for fiscal decentralization on urban pollution intensity becomes −0.130 in column (1) of Table 11 and still significant at the 1 % level, which indicates the regression results in our research are reliable and valid. Furthermore, we remeasure the fiscal decentralization indicator with fiscal revenue rather than fiscal expenditure and the results in column (2) are coincident with benchmark analysis.

An environmental regulation variable is added to the model. Considering that environmental regulation or environmental policy [58] may affect urban pollution intensity [24], the research refers to the work of Zhang and Chen [59] and adopts the proportion for the number of environmental protection words to the total number of words in government work reports for each city to reflect the degree of attention attached to environmental protection by local governments and this variable is utilized as a proxy for the environmental regulation (ER). To avoid the bias from environmental regulation measurement, five indicators including industrial sulfur dioxide removal rate, industrial soot removal rate, general industrial solid waste comprehensive utilization rate, harmless treatment rate of domestic garbage, and centralized treatment rate of sewage treatment plant are synthesized into another environmental regulation index using entropy weight method, and the larger its value, the greater the strength of environmental regulation. After adding the environmental regulation variable, the impact of fiscal decentralization becomes −2.092 and −2.042 in column (3) and (4), proving the empirical regression evidence of this paper is robust again. Notably, the two environmental regulation tools have not fully played their expected roles, demonstrating the environmental regulation of Chinese local governments has no obvious effect and needs to be further implemented.

5. Discussion

5.1. Research findings

By applying spatial econometric models, this paper concludes fiscal decentralization exerts a negative effect on pollution intensity in the local and neighboring areas. In keeping with the opinions of several studies [11,19], these results suggest that in a developing country like China, under the premise of increasing attention given to environmental protection and ecological civilization, local governments have the capacity to implement the targets of ecological governance while developing the economy, and they not only “compete for economic growth” but also “compete for environmental quality” in resource allocation. Fiscal decentralization means that local governments will have more fiscal resources, decision-making power, and greater incentives to take the initiative to protect the environment. This incentive will help local governments to be more proactive in responding to environmental problems and to improve the efficiency and effectiveness of environmental protection.

The findings of mechanism analysis inform the future focus and directions for local governments. Industrial structure upgrading and green technology progress play intermediary roles in the process of fiscal decentralization promoting a reduction in urban pollution intensity in China. Resource sharing, technology exchange and learning, benign competition among local governments provide a theoretical basis for the spatial spillover effects of fiscal decentralization. Through heterogeneity analysis, we know that fiscal decentralization exerts spatial spillover effects in reducing environmental pollution in eastern region, which means the synergistic pollution management has been realized, thereby providing valuable insights for local governments in the central and western regions to emulate.

5.2. Limitations and future research directions

In terms of research limitations and future research directions, it should be noted firstly that our findings may not be applicable to

Table 11
Robustness tests (II).

Pol	(1)	(2)	(3)	(4)
FisD	−0.130*** (0.049)	−3.128*** (0.359)	−2.092*** (0.478)	−2.042*** (0.474)
ER			8.565 (7.593)	0.655* (0.361)
TL	0.023* (0.010)	0.217** (0.092)	0.292*** (0.094)	0.260*** (0.093)
Open	0.003* (0.002)	−0.015 (0.014)	−0.017 (0.015)	−0.015 (0.015)
DigE	0.012 (0.020)	−0.658*** (0.197)	−0.764*** (0.201)	−0.795*** (0.199)
FDI	−0.120 (0.120)	0.823 (1.147)	−0.204 (0.681)	0.529 (1.165)
Edu	−0.002 (0.003)	0.081*** (0.026)	0.060** (0.027)	0.071*** (0.026)
UR	0.060** (0.026)	0.083 (0.254)	−0.072 (0.256)	−0.187 (0.256)
Spatial rho/lambda	0.115*** (0.029)	0.172*** (0.027)	0.226*** (0.026)	0.198*** (0.026)
Sigma2_e	0.001*** (0.000)	0.130*** (0.004)	0.136*** (0.004)	0.133*** (0.004)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Note:Standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$ Number of obs 2214.

other countries due to the specificity of Chinese-style decentralization. In the future, we aim to expand our research scope by obtaining a larger number of samples and derive more universally applicable conclusions. Secondly, despite performing robustness tests, potential limitations in data and modeling may still introduce biases in our conclusions. A more representative and informative assessment framework of fiscal decentralization as well as urban pollution intensity could be focused and completed. Thirdly, the two environmental regulation tools employed in this study do not fully realize their intended purpose of environmental protection. Therefore, our future research aims to identify more effective environmental regulation tools that can better promote sustainable environmental development. Fourthly, to enhance the depth and quality of such literature, available and marked mechanism variables need to be discovered in the future.

6. Conclusions and policy implications

6.1. Conclusions

The study empirically analyses the significant correlation between fiscal decentralization and urban pollution intensity through utilizing spatial econometric models and reaches following conclusions. First, in the national sample, in the context of the dual incentives of “economic situation” and “ecological performance” faced by local governments since the 18th National Congress, an increase in fiscal decentralization in a city can have dual impacts: it can influence the local pollution intensity and generate a negative spillover effect on neighboring cities’ pollution intensity. Second, industrial structure transformation and green technology progress are significant paths by which local governments can boost the decrease of urban pollution intensity, as well as feasible ways to balance economic benefits and environmental conservation. Third, the heterogeneity analysis demonstrates that the effects of fiscal decentralization on reducing urban pollution intensity are more significant in the economically developed eastern coastal district, which suggests that local governments in eastern region have achieved a high degree of synergistic development between economic growth and environmental conservation, while local governments in central region have adopted a “beggar-thy-neighbor” strategy to transfer pollution to internal neighboring cities. Finally, a higher level of FDI indicates a greater negative effect for fiscal autonomy on the intensity of regional contamination. Local governments can achieve the dual goals of promoting scientific and technological progress and reducing environmental pollution by attracting high-quality foreign investment.

6.2. Policy implications and recommendations

On account of all the previous analysis, this paper offers the accompanying policy proposals. First, in terms of performance evaluation, the connection between the central government and local governments should be rationally harmonized, a multi-objective incentive mechanism should be actively introduced, a scientific environmental evaluation system should be established, and local governments should be encouraged to take into account ecological governance while pursuing economic development. Second, local governments ought to be entrusted with greater fiscal responsibilities for pollution management, as they are closer to the pollution sources and have a comprehensive understanding of local environmental issues. By allocating more fiscal resources, they can implement targeted pollution control measures that are tailored to the specific needs and characteristics of the regions. Third, all cities are supposed to actively promote the upgrading of industrial structure and green technology progress to fully exploit the “pollution reduction effect”, which is an imperative method to accomplish long-term balanced development. Fourth, the introduction for high-level foreign investment should be vigorously pursued to cross the FDI threshold, stimulate the technological effect of foreign investment, and promote positive and healthy interaction between foreign and domestic enterprises. Finally, spatial effects deserve attention in the process of pollution control, as pollution frequently spreads across regions and boundaries. Fiscal decentralization

strategies should aim to strengthen spatial coordination and cooperation among local governments, which can be accomplished through the foundation of regional environmental protection agencies and platforms that foster information sharing, joint pollution control efforts, and the harmonization of fiscal resources among neighboring regions.

Data availability statement

The data will be made available on reasonable request.

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Ethics statement

Not applicable.

CRediT authorship contribution statement

Liang-Jun Wang: Supervision, Methodology, Investigation, Funding acquisition, Formal analysis. **Zi-Han Lin:** Writing – original draft, Supervision, Investigation. **Pei-Ling Yang:** Validation, Resources, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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