RESEARCH ARTICLE

Fiscal decentralization, government innovation preference, and haze pollution

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Abstract

Local governments are the dominant players in haze pollution control; furthermore, financial power reconstruction affects the effectiveness of haze control. Government innovation preference achieves win-win results for environmental protection and economic development by increasing innovation support. Therefore, a moderating variable for government innovation preference was added to the fiscal decentralization effect on haze pollution, and their interactive effect on haze pollution was studied. This study was conducted in 30 provincial regions. Thus, the severity of regional haze pollution differs because of temporal heterogeneity and asynchronous development. Furthermore, we analyzed the impact on haze pollution from the perspectives of the temporal and spatial differences in different regions of China. The results indicate that (1) fiscal decentralization increases haze pollution, while government innovation preferences control it. (2) In a local evaluation model with a diversified background, fiscal decentralization restrains haze pollution, and pollution source complexity reduces government innovation preference's control pollution function. The interaction term revealed that government innovation preferences had a significant moderating effect. (3) Fiscal decentralization and government innovation preferences control the heterogeneity of haze pollution in different regions.

Keywords Fiscal decentralization · Government innovation preference · Haze pollution · Moderating effect · Temporal difference · Spatial difference

Introduction

Since the reform and opening up, China's economy has grown rapidly, with GDP exceeding 100 trillion yuan in 2020. Economic growth initiated a simultaneous increase in energy consumption, which caused poor air quality problems (Shahzad et al. 2021). According to *the China Ecological Environment Status Bulletin*[1], in 2020, more than 40% of cities with PM2.5 and PM10 haze pollutants have not yet passed pollution emission standards. Haze pollution causes serious damage to the human body, causing symptoms such as nasal discharge and coughing (Zeng et al. 2019) and respiratory and cardiovascular diseases (Qu et al. 2021). The negative social impacts of haze pollution cannot be ignored. Hao et al. (2019) showed that haze pollution increased public service costs. Moreover, the resulting resident health expenditure accounted for 2% of the urban GDP. Haze pollution problems directly affect public health and are related to long-term sustainability and healthy societal development. Faced with haze threats, the public is gradually becoming more concerned about government regulatory actions and expects local governments to provide timely management of pollution problems (Brimblecombe and Zong 2019). Local governments have high governance

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[1] *China Ecological Environment Status Bulletin* https://www.mee.gov.cn

motivation (Liu et al. 2019) and low regulatory costs (Tong et al. 2019) advantages. However, financial resource shortages reduce governance effectiveness; thus, haze pollution remains a major catastrophic weather (Eaton and Kostka 2018; Sun et al. 2021). To control haze pollution, the 19th Central Conference of China proposed building a local government-led environmental governance system and increasing the fiscal decentralization degree continuously to improve the local plight of insufficient financial resource. Previous studies have shown that fiscal decentralization is a central incentive policy tool and can effectively allocate financial resources. Fiscal decentralization provides sufficient financial resources for local governments to improve their environmental quality (Kuai et al. 2019). Therefore, it is necessary to consider the positive impact of fiscal decentralization on haze pollution management.

Fiscal decentralization may lead to severe haze pollution, as it increases the allocation of financial resources to local governments. To pursue GDP growth unilaterally, local governments lobbied for environmental management funds and reduced environmental management inputs, which has led to difficulties in controlling haze pollution efficiently (Wang et al. 2020a). Additionally, for the sake of GDP growth targets, local leaders have increased infrastructure construction, and reduced environmental regulation intensity, causing more severe haze pollution (Cheng and Zhu 2021). Therefore, it is necessary to reexamine the negative impact of the local financial resource allocation authority on haze pollution management. Local leaders believe that environmental management hinders economic development, and fiscal resources restrict investment in the environmental protection region. However, Porter hypothesis suggests that environmental management promotes economic development by fostering innovation and improving production technology, offsetting environmental protection costs. Many scholars have shown that innovation is an important factor in promoting technological progress (Fan et al. 2020; Li and Wang 2019; He et al. 2022). Innovation can drive local economic development, reduce haze pollution, and achieve the goals of economic development and environmental protection (Dong et al. 2020; Wang and Li 2020; Han et al. 2022). Meanwhile, local governments' innovation activity preferences will increase the proportion of innovation spending and enhance regional innovation capacity (Anwar and Li 2021; Lu et al. 2022). In a fiscal decentralization context, local governments increase environmental protection expenditures and encourage environmental innovation project investments to promote green innovation power (Zhou et al. 2020). Previous studies suggest that fiscal decentralization gives local governments greater financial autonomy to spend more financial resources on haze pollution control. However, economic development pressures may aggravate haze pollution. Innovation is an important factor for technological progress. Technological advances improve productivity and reduce the negative impact of enterprise production activities on the environment. The government is an innovative leader. Government innovation preferences improve innovation ability, promote high-quality economic development, and achieve the goals of economic development and environmental protection. Therefore, it is necessary to focus on government innovation preferences regarding haze pollution's regulatory role.

This study considers fiscal decentralization as an entry point to investigate its impact on the degree of haze pollution. Additionally, this study provides government innovation preferences with a new observation dimension to discover fiscal decentralization and government innovation preference changes in the haze pollution relationship. The main contributions of this study are as follows. (1) The influence of fiscal decentralization and government innovation preference on haze pollution mechanisms are studied based on regional fiscal heterogeneity and development asynchrony conditions. (2) Examining the fiscal decentralization and regional heterogeneity effects of government innovation preferences through the GMM method, stepwise regression, and overall regression. (3) Variable substitution is tested for robustness to ensure that the empirical results are robust and reliable.

Literature review and theoretical hypothesis

Local governments are highly motivated to combat haze to gain public support for government policies. Gao et al. (2021) argue that fiscal decentralization increases local government incentives, and green businesses are more likely to receive government incentives. Local governments have reduced air pollution levels by setting mandatory pollutant emission standards and significantly strengthening green facilities. Local governments have greater financial autonomy in local public management affairs owing to fiscal decentralization. Governments can increase enterprises' economic benefits of green development through green subsidies to reduce pollutant emissions. Previous studies explored the relationship between fiscal decentralization and environmental protection. Chen and Liu (2020) argued that fiscal expenditure per capita and air pollution control effectiveness are positively correlated in the context of fiscal decentralization. Fiscal decentralization enlarges "Race to bottom" phenomenon; government among ecological protection race accelerates governance goal achievement. Innovation promotes high-quality local economic development. Government innovation preference achieves haze control goals through government support for innovation, R&D investment, and guiding enterprises for transformation and upgrading.

Fiscal decentralization increases innovation dynamism and controls haze pollution. Khan et al. (2021) argue that fiscal decentralization and eco-innovation can improve environmental quality. The balanced panel dataset results for seven empirical ECO countries show that fiscal decentralization and eco-innovation improve environmental quality. The effects of fiscal decentralization and eco-innovation on environmental quality are unidirectional. Ji et al. (2021) show that environmental quality problems can be solved through eco-innovation and fiscal decentralization. The panel regression results of high fiscal decentralization in seven countries show that fiscal decentralization and eco-innovation contribute to environmental quality improvement. Innovation can adjust the fiscal decentralization effect and control haze pollution effectively. Su et al. (2021) suggested that eco-innovation enhances the positive effect of fiscal decentralization on haze pollution control. Cheng et al. (2021) studied how political structures affect pollutant emission mechanisms and showed that fiscal decentralization and technological innovation are key factors in reducing pollutant emissions. Pollution emission levels are positively related to fiscal decentralization and technological innovation, both of which control pollutant emissions.

Fiscal decentralization highlights the position of local governments as haze pollution managers. Local governments have information that are advantageous for improving the regional air quality and lowering pollution regulation costs. The government is highly motivated to regulate the environment in response to public expectations. Therefore, local governments are the most capable managers of haze pollution control. Local governments' financial autonomy increases due to fiscal decentralization, which has a positive impact on haze pollution management. Fiscal decentralization provides local governments with more financial resources to support the green innovation of enterprises and cultivate a regional innovation atmosphere. Innovation capacity cultivation can bring about economic and social sustainability and high-quality development. Government innovation preferences strengthen the role of fiscal decentralization in controlling haze pollution and are an important factor for government support of regional innovation development. Government innovation preference guides the regional economy toward a resource-saving and environmentally friendly green development approach through industrial structure optimization and regional innovation system cultivation. Green development will achieve regional economic development and haze pollution control with win-win results. Therefore, this study proposes the following hypotheses:

H1$_a$: Fiscal decentralization can improve the control of haze pollution by local governments and positively inhibit haze pollutant emissions.
H1$_b$: Fiscal decentralization strengthens local governments' innovation preferences, which strengthens the role of fiscal decentralization in controlling haze pollution.

Additionally, it is argued that fiscal decentralization is not conducive to haze pollution control, as it weakens the effectiveness of central government supervision; furthermore, the local government's self-interest motives reduce the intensity of haze pollution control. Fiscal decentralization has led to the localized management of law enforcement agencies, allowing local governments to have more freedom in regulating haze pollution (Wang et al. 2020b). Gibson (2019) examined the Clean Air Act in the USA and showed that the state government only deals with excess regulation plants. Conversely, other plants were less regulated. Li et al. (2022) used a spatial regression approach to study the fiscal decentralization and haze pollution relationships of 270 cities in China between 2007 and 2016. The results show that fiscal decentralization is a key factor that aggravates haze pollution intensity, supporting the validity of the China pollution sanctuary hypothesis. You et al. (2019) argued that fiscal decentralization is an important inhibitor of corporate eco-innovation investment, corporate eco-innovation, and eco-planning innovation. Positive innovation spillover effect leads to innovation outcomes that do not easily result in regional economic development. The positive innovation spillover effect reduces local government innovation preference and investment, resulting in the double situations of internal innovation motivation and government innovation incentive.

The rationale for the suppressive effect of fiscal decentralization on haze pollution is that fiscal decentralization increases the financial autonomy of the local government. Local government leaders driven by the "GDP race" unilaterally pursue economic development at the expense of ecological environmental protection. Local leaders continue to follow the traditional industrial model of increasing production factor input and neglecting to control environmental pollution, resulting in more serious haze pollution. Therefore, fiscal decentralization leads to increasingly serious ecological problems caused by haze pollution. Innovation has long return cycles, high uncertainty, and positive spillover effects. If the local government pursues short-term economic goals, government innovation preferences will be inhibited. Government financial resources will mainly focus on expanding production scale, resulting in insufficient innovation investment. The degree of fiscal decentralization increases to allow local leaders to unilaterally pursue short-term economic growth goals, invest in

inefficient production industries, and increase their haze pollutant emissions. Reducing environmental regulations will make haze pollution more severe. In the short term, it is difficult to drive economic growth using innovation. Therefore, innovation was neglected by the local government, and the controlling role of haze pollution was restricted. The degree of haze pollution is aggravated by outdated methods of economic development. Economic growth comes at an environmental cost. Based on this, we propose the following hypothesis:

H2$_a$: Local governments are more inclined to choose short-term economic development goals in fiscal decentralization and have less of an incentive to combat haze pollution.

H2$_b$: Fiscal decentralization leads to local government investments to support production expansion and crowding-out innovation investments. Government innovation preference controls the decrease in haze pollution capacity.

There are environmental effects to fiscal decentralization and government innovation preference for haze pollution control. The impact of fiscal decentralization on the haze pollution function changes with the regional development stage, and the adjustment haze pollution due to government innovation preference has environmental heterogeneity. Que et al. (2018) argue that regional heterogeneity affects the effectiveness of fiscal decentralization in controlling haze pollution and market segmentation exacerbates the environmental pollution control effect. Yang et al. (2020) argued that fiscal decentralization positively affects air pollution control in the short term and has a negative and insignificant effect in the long term. Wang et al. (2020c) showed that technological progress is an important factor for reducing haze pollution levels. However, innovations that improve energy efficiency may lead to a rebound effect. Du and Sun (2021) showed that technology influences fiscal decentralization and controls carbon dioxide emission quality. Fiscal decentralization increases carbon dioxide emissions in regions of low-level energy and environmental technology development and reduces it in regions with high-level energy and environmental technology. Wang et al. (2021a) identified the development stage as a key influencing factor in achieving environmental protection goals and suggested enacting a differentiated environmental policy. Meng et al. (2021) showed that fiscal decentralization, environmental innovation, and environmental governance performance relationships exhibit regional heterogeneity. Fiscal decentralization reduces carbon dioxide emission in the low and middle quartiles alone. Environmental innovation reduces carbon dioxide emission only in the middle- and high-quantile regions. Economic and population growth have a significant effect on carbon dioxide emission growth in low-quartile regions.

Fiscal decentralization increases local financial revenue, provides sufficient financial support to control haze pollution, and significantly enhances government innovation preferences. The local government was motivated to support regional innovation systems, improve production efficiency, and promote progress in local production technology. However, fiscal decentralization and the effects of government innovation preferences on haze pollution control exhibit regional heterogeneity. The presence of rebound effects has led to technological progress, increased haze pollutant emissions in some areas, and even more serious haze pollution problems. Therefore, this study hypothesizes the following.

H3: Fiscal decentralization and the effect of government innovation preference on haze pollution exhibit regional heterogeneity. Fiscal decentralization in the eastern region of China reduces haze pollution and increases government innovation preferences. However, fiscal decentralization aggravates haze pollution and inhibits government innovation preferences in the western and central regions.

Research design

Model construction

Based on a literature review and theoretical hypotheses, to test the fiscal decentralization effect on haze pollution and the mediating role of government innovation preference, the haze pollution decision equation was constructed as follows:

$$WMit = \varphi_0 + \varphi_1 L.WM_{it} + \varphi_2 Fin_{it} + \varphi_3 GX_{it}$$
$$+ \varphi_4 Fin_{it} \times GX_{it} + \sum_{i=5}^{k} \varphi_5 X_{it} + \varepsilon_{it} \qquad (1)$$

WM denotes haze pollution, *Fin* denotes fiscal decentralization, and *Gx* denotes government innovation preferences. To test the moderating effect of government innovation preference, we set *Fin*x*Gx* as fiscal decentralization and government innovation preference interaction terms. Additionally, to solve the endogeneity problem arising from omitted variables, *the L.WM* lagged term was introduced as an instrumental variable. *X* denotes the control variables; *i* and *t* denote province and year, respectively; φ is the regression coefficient; and ε denotes the error term.

Variables

Explained variable

PM2.5, which is a culprit of haze pollution, is the main indicator of the degree of haze pollution. Therefore, PM2.5 was

used to measure regional haze pollution levels. The University of Washington Atmospheric Composition Analysis Group uses a two-stage statistical approach, capturing data from indirect satellite monitoring and ground-based detection, which can better estimate regional PM2.5 concentration. In the study by Ma et al. (2016), raster data from the University of Washington Atmospheric Composition Group were parsed using ArcGIS software. The population weighted values of the concentration of PM2.5 measured the haze pollution level. Geographically weighted values were tested for robustness. The population and geographically weighted PM2.5 concentration are both negative indicators. PM2.5 concentration has a positive relationship with the degree of regional haze pollution.

Core explanatory variable

(1). *Fiscal decentralization (fin)*. Common methods of measuring fiscal decentralization include the average share ratio, marginal retention, traditional fiscal revenue, and expenditure indicators. Fiscal decentralization degree is used as local fiscal expenditure/central fiscal expenditure ratio to measure, and local fiscal expenditure/regional total population ratio is used for robustness testing, calculated as (2 and 3). The degree of fiscal decentralization will increase the local government's ability to govern duties. However, fiscal decentralization also increases local governments' motivation of opportunistic behavior. Therefore, the impact of fiscal decentralization $Fin_{(1)}$ and $Fin_{(2)}$ indicator coefficients on the result cannot be determined.

$$Fin(1) = \frac{local\ fiscal\ \exp enditure}{central\ fiscal\ \exp enditure} \qquad (2)$$

$$Fin(2) = \frac{local\ fiscal\ \exp enditure}{regional\ total\ population} \qquad (3)$$

(2). *Government innovation preferences (GX)*. Government has a strong influence on regional innovation activities. The government regulates fiscal spending and guides enterprises in developing green technology to reduce haze pollutant emissions. Local governments enhance their regional innovation capacity by increasing subsidies for science and technology innovations. Government innovation preferences promote production technology improvements and suppress haze pollution. The government innovation preference index uses the number of patent applications granted. However, production technology improvements may expand enterprises' production scale and lead to more serious haze pollution. Therefore, the coefficient of the government innovation preference indicator cannot be predicted.

Control variable

(1) *Urbanization (UR)*. Urbanization refers to rural population transformation in the urban population process. The urbanization process realizes urban distribution rationalization, improves production efficiency, and reduces the negative impact of industrial development on the environment. Urbanization provides new opportunities for haze control (Zhou et al. 2022). Population urbanization is an important measure of the urbanization level, and the urban population/total population is used to assess the degree of urbanization. (2) *Human capital (EDU)*. Human capital level was used to measure the regional population education level. Human capital provides greater support for innovation. The workforce of highly educated individuals can respond better to government innovation preferences. We used the average years of education to reflect the human capital level. Human capital is a negative indicator. Average years of education has a positive relationship with the control of haze pollution. (3) *Foreign direct investment (FDI)*: Current research suggests "pollution sanctuary" effect significantly in China. An increase in openness will lead foreign companies to migrate to heavily polluted sectors in China, producing more serious pollution. Therefore, increased *FDI* causes more serious haze pollution. The *FDI* indicator transfers from USD to RMB units. (4) *Industrial added value (IAV)*. Industrial development has an inverse relationship with controlling haze pollution, and regional industrial development will increase haze pollutant emission pressure. Energy policy formulation needs to be based on enterprise characteristics (Wang et al. 2018), industrial development level will influence government environmental policy formulation, and industrial value added is chosen to reflect the impact of industrial development on haze pollution. (5) *General industrial solid waste disposal (SCD)*. Environmental regulations can alleviate resource misallocation and improve environmental governance efficiency (Wang et al. 2021b). The amount of industrial solid waste disposal reflects the influence of environmental regulations on the degree of green enterprise behavior. Generally, a high industrial solid waste disposal volume implies a significant environmental regulation effect on pollution control. Enterprises are more willing to actively treat industrial

pollutants. (6) *Transportation infrastructure (CAR).* Vehicle emissions are the main cause of haze pollution, and private-car ownership is a proxy variable for measuring transportation infrastructure. An increase in the number of private cars leads to severe haze pollution. The amount of private cars are derived from *the Chinese Statistical Yearbook*. Variables were logarithmized to ensure data smoothness and reduce the heteroscedasticity effect. Table 1 presents the descriptive statistics of the data.

Empirical study

Standard regression

To test the impact of fiscal decentralization and government innovation preferences on haze pollution, a stepwise regression was used for the empirical analysis. The Hausman test results reject the original hypothesis and indicate that the fixed effects model can better explain the regression model. Therefore, a fixed effects model was used. To solve the endogeneity problem of the current model and the omitted variables leading to model estimation errors, the dynamic GMM model was selected for regression analysis. The differential GMM model uses the lagged term as the instrumental variable, while the systematic GMM model can solve the weak instrumental variable problem. A possible error was estimated to test the lag effect on the causes. Thus, the research used systematic GMM model to test the weak instrumental variable and endogeneity problem. The standard regression AR(1) and AR(2) results show that the empirical model has only first-order but not second-order serial correlation. Sargan's (*p* value) shows that the instrumental variables are chosen reasonably, and Table 2 shows the econometric regression results.

Models (1)–(5) show that fiscal decentralization has a dampening effect on haze pollution control and fiscal decentralization policy implementation worsens haze pollution. As local governments reduce environmental supervision in pursuit of short-term economic growth. Regional differences in environmental regulations increase the likelihood of polluters' opportunistic behavior. Therefore, the transformation of pollution sources increases haze management complexity. In addition, regional fiscal capacity is influenced by local economic development and the development stages. Regional fiscal capacity difference is one reason for the investment heterogeneity in regional environmental governance. The differentiation of government environmental investment will lead polluting companies to flow to regions with lax regulation, and a lack of pollution elimination will further reduce their ability to recover polluted areas. The regression results show that government innovation preferences have a negative relationship with haze pollution. Investment in government innovation inhibits haze pollution by developing a regional green economy, promoting economic and environmental harmony, and reducing haze emissions. Thus, government innovation preferences can inhibit haze pollution.

Regression models (4)–(5) show that the interaction term coefficients of fiscal decentralization and innovation spending are significantly positive. Fiscal decentralization is an exogenous variable that is used to control haze pollution. Government innovation preferences and haze pollution present endogeneity issues. The GMM method can solve the endogeneity problem between the variables to some extent. The empirical results of Model (4) indicate that fiscal decentralization and the innovation preference interaction term have a suppressive effect on haze pollution control. The moderating variable of government innovation preference strengthens the fiscal decentralization effect on haze pollution. Government innovation preferences cause fiscal decentralization to produce more severe haze pollution. Model (5) includes a one-period lag,

Table 1 Data descriptive statistical analysis

Variable	Symbols	Mean	Std. dev.	Min.	Max.
PM2.5 (population weighted)	In WM (1)	47.63	17.05	15.40	112.70
PM2.5 (geographically weighted)	In WM (2)	37.47	15.98	8.00	85.50
Fiscal expenditure ratio(a)	Fin (1)	0.12	0.06	0.01	0.34
Fiscal expenditure ratio(b)	Fin (2)	5.00	3.01	1.08	14.83
Government innovation preference	GX	25,189.00	50,934.00	70.00	478,082.00
Urbanization	UR	0.49	0.15	0.19	0.89
Human capital	EDU	8.51	1.09	5.44	12.68
Foreign direct investment	FDI	372.90	448.00	0.30	2253.00
Industrial added value	IAV	5256.00	6146.00	50.87	37,651.00
Industrial solid waste disposal	SCD	1777.00	3084.00	0.21	25,601.00
Transportation infrastructure	CAR	235.80	313.90	2.14	1910.00

Table 2 Standard regression outcome and endogenous discussion

Explanatory variable	Explained variable				
	In WM (1)	In WM (1)	In WM (1)	In WM (1)	In WM (1)
	(1)	(2)	(3)	(4)	(5)
L. In WM (1)					0.933*** (45.30)
In Fin (1)	0.373*** (3.14)		0.364*** (2.93)	0.234* (1.74)	0.097** (2.12)
In GX		−0.094*** (−2.81)	−0.089** (−2.47)	−0.047 (−1.22)	−0.038*** (−2.97)
In Fin(1)×GX				0.035** (2.43)	−0.005 (−1.31)
In UR	−0.267* (−1.88)	−0.354*** (−3.37)	−0.286** (−2.49)	−0.258** (−2.62)	−0.033 (−1.39)
In EDU	−0.796*** (−2.81)	−0.572* (−2.01)	−0.727** (−2.37)	−0.767** (−2.59)	0.077 (1.08)
In FDI	0.045*** (3.57)	0.053*** (3.54)	0.046*** (3.42)	0.022 (1.27)	0.003 (0.64)
In IAV	−0.047 (−0.44)	0.107 (1.27)	−0.036 (−0.33)	−0.045 (−0.44)	0.048 (1.56)
In SPV	0.007 (0.55)	0.007 (0.82)	0.003 (0.32)	0.007 (0.71)	−0.003 (−0.95)
In CAR	−0.041 (−0.73)	0.061 (1.09)	0.035 (0.65)	0.033 (0.59)	−0.045*** (−4.15)
Constant	6.454*** (5.80)	4.129*** (6.97)	6.632*** (5.98)	6.935*** (7.50)	0.336 (1.25)
Hausman (*p* value)	0.000	0.000	0.000	0.000	
Observation	570	570	570	570	510
R^2	0.139	0.117	0.163	0.189	
AR(1)					0.000
AR(2)					0.262
Sargan					0.995

Robust *t*-statistics in parentheses:*** $p<0.01$, ** $p<0.05$, * $p<0.1$

which indicates that haze pollution control task accumulation increases ecological and environmental control pressures, resulting in a superimposed effect. Therefore, haze pollution problems should be solved promptly to avoid increased difficulties in haze pollution control.

The control variable study showed that urbanization, human capital, FDI, and private transportation have significant effects on haze pollution. Urbanization reduces the degree of regional haze pollution by improving industrial synergy and promoting green production technology development. Human capital improves regional population quality and promotes regional innovation in research and applications. Therefore, human capital positively affects haze pollution control. Public transportation infrastructure plays an inhibiting role in haze pollution. Private transportation controls haze pollution by reducing urban overcrowding. Conversely, FDI leads to more severe haze pollution. Enterprise's FDI leads to the entry of polluting enterprises and increases the degree of pollution. An empirical study also proves the existence of pollution sanctuaries; local government pollution management under low standards attracts more pollution.

Robustness test

The robustness of the variable coefficient is important for testing the rationality of the model design. Therefore, some variables are replaced to perform a standard regression robustness test. The concentration of the population weighted PM2.5 was replaced with a geographically weighted PM2.5. Fiscal decentralization calculation method (*b*) replaces the fiscal decentralization calculation method (*a*). To ensure smoothness, the variables were logarithmized (Table 3). The robustness test correlation

Table 3 Standard regression robustness test outcome

Explanatory variable	Explained variable				
	In WM (2)	In WM (2)	In WM (2)	In WM (2)	In WM (2)
	(1)	(2)	(3)	(4)	(5)
L. In WM (2)					0.895*** (29.50)
In Fin (2)	0.344*** (2.87)		0.338** (2.75)	0.115 (0.51)	0.005 (0.05)
In GX		−0.081** (−2.21)	−0.078* (−2.04)	−0.162* (−1.95)	−0.049 (−1.54)
In Fin (2) × GX				0.036 (1.23)	0.004 (0.29)
In UR	−0.390** (−2.45)	−0.353*** (−3.24)	−0.404*** (−2.97)	−0.317** (−2.11)	−0.055 (−1.43)
In EDU	−0.675** (−2.32)	−0.531* (−1.92)	−0.617* (−2.01)	−0.699** (−2.29)	−0.074 (−0.27)
In FDI	0.041*** (3.06)	0.053*** (3.03)	0.042*** (2.95)	0.035** (2.34)	0.018 (0.87)
In IAV	−0.034 (−0.32)	0.103 (1.13)	−0.025 (−0.23)	−0.013 (−0.12)	0.134*** (3.29)
In SPV	0.006 (0.43)	0.006 (0.61)	0.003 (0.23)	0.001 (0.07)	0.009 (0.71)
In CAR	−0.048 (−0.88)	0.043 (0.75)	0.018 (0.36)	0.015 (0.30)	−0.082** (−2.13)
Constant	4.417*** (5.31)	3.783*** (5.99)	4.611*** (5.66)	5.421*** (5.35)	0.014 (0.03)
Hausman (p value)	0.006	0.002	0.003	0.000	
Observation	570	570	570	570	510
R^2	0.126	0.098	0.141	0.147	
AR(1)					0.000
AR(2)					0.798
Sargan					0.141

Robust t-statistics in parentheses:*** $p<0.01$, ** $p<0.05$, * $p<0.1$

regression coefficient was consistent with the standard regression. The robustness test proves that the current econometric model can better explain fiscal decentralization and the effect of government innovation preference on the haze pollution mechanism. Therefore, the standard regression is robust.

Further discussion

Time heterogeneity test

Ecological protection performance has been an important element of political achievement assessments since 2013. Therefore, studying the effects of fiscal decentralization and government innovation preferences on the haze pollution relationship, based on time differences, helps to investigate the effect of the central appraisal method on the effectiveness of haze pollution control. The annual data were divided into different periods from 2000 to 2012 then 2013–2018. Table 4 presents the time heterogeneity regression results.

The study showed a positive correlation between current haze pollution and the lag period for both 2000–2012 and 2013–2018. Accumulation of haze pollution tasks will negatively impact the future control of haze pollution. The model of pollution and subsequent treatment will lead to serious environmental problems.

Fiscal decentralization and haze pollution showed a positive relationship between the years 2000 and 2012; fiscal decentralization aggravating haze pollution. From 2013 to 2018, fiscal decentralization showed a negative relationship; fiscal decentralization reduced the degree of haze pollution. Political achievement assessment diversification has prompted local governments to be more proactive in controlling haze pollution. Therefore, fiscal decentralization had a suppressive effect on haze pollution in 2013-2018.

Table 4 Time heterogeneity result

Explanatory variable	Explained variable in In WM (1)	
	2000–2012 year	2013–2018 year
L. In WM (1)	0.468***	0.639***
	(5.84)	(6.66)
L2. In WM (1)	0.475***	0.306***
	(6.10)	(4.04)
In Fin (1)	0.239***	−0.232***
	(5.48)	(−2.93)
L. In GX	−0.046*	0.065
	(−1.97)	(1.57)
In Fin (1) x In GX	−0.022***	0.032***
	(−2.85)	(2.86)
In UR	−0.015	−0.048*
	(−0.50)	(−1.78)
In EDU	−0.089	0.067
	(−0.77)	(0.59)
In FDI	−0.016	0.001
	(−1.60)	(0.03)
In IAV	−0.003	0.007
	(−0.14)	(0.21)
In SPV	−0.004	0.019*
	(−0.52)	(1.83)
In CAR	0.007	−0.062*
	(0.35)	(−2.03)
constant	1.036***	−0.394
	(3.30)	(−1.42)
AR (1)	0.008	0.018
AR (2)	0.155	0.126
Sargan (*p* value)	0.797	0.262
Observation	150	120

Robust *t*-statistics in parentheses:*** *p*<0.01, ** *p*<0.05, * *p*<0.1

Government innovation preferences and haze pollution showed a negative correlation between 2000 and 2012. Government innovation preferences reduce haze pollution. The correlation between government innovation preferences and haze pollution was not significant from 2013 to 2018. From 2000 to 2012, China's economic development adopted the crude economic development model of expanding production scale and increasing production factors. Haze pollutant sources are mainly concentrated in the expanded industrial production scale. Therefore, governments have innovative preferences to transform regional development patterns, reduce ineffective production factor input, and effectively reduce haze pollution. After 2013, population urbanization and the modern service industry increased the number of haze pollutant sources and the difficulty of controlling haze pollution. Meanwhile, government innovation preference in the haze pollution temporal heterogeneity test proves the existence of a rebound effect. Government innovation preferences promote scientific and technological progress, while energy efficiency reduces energy consumption costs.

However, producers aim to achieve profit maximization goals, expand the production scale continuously, increase haze pollutant emissions, and offset technological advances that inhibit haze pollution.

The interaction term influences the haze pollution analysis results according to fiscal decentralization and government innovation preferences. The interaction term negatively moderates the fiscal decentralization effect on haze pollution between 2000 and 2012. As government innovation preferences weaken fiscal decentralization and positively contribute to haze pollution. The interaction term positively moderates the fiscal decentralization effect on haze pollution between 2013 and 2018, as government innovation preferences strengthen the negative inhibitory effect of fiscal decentralization on haze pollution. Therefore, the interaction term research reveals a significant moderating effect of government innovation preferences. In 2010–2012, government innovation preferences inhibited the negative effects of fiscal decentralization and reduced the role of fiscal decentralization in increasing haze pollution. In 2013–2018, government innovation preferences enlarged the positive effects of fiscal decentralization, strengthening the role of fiscal decentralization in inhibiting haze pollution.

Regional heterogeneity test

China has had a remarkable effect on industrial fragmentation. In particular, industrial transfer from the southeastern coastal region to the central and western regions occurred after 2010. Industrial transfers promote economic restructuring and ensure high-quality regional economic development. However, industrial transfers also increased the regional industrial characteristic differences. Therefore, fiscal decentralization and government innovation preferences have different impacts on haze pollution. The regional heterogeneity test can be used to study their effects on haze pollution under regional heterogeneity conditions. China's 30 provinces were divided into eastern, central, and western regions for separate analysis. Table 5 presents the results of the regional heterogeneity tests.

The effect of fiscal decentralization on haze pollution control is not significant in the eastern region. The eastern region has strong financial strength. Financial constraints do not limit the achievement of haze pollution control. The eastern region has a reasonable industrial structure and high-tech enterprises that drive regional economic development. Government innovation preferences support innovation development, while governments and markets form positive circular interactions. Therefore, the inhibitory effect of government innovation preferences on haze was significantly negative. Government innovation preference effect on haze pollution is significantly negative. This phenomenon reflects that innovation is the main driving force for controlling haze

Table 5 Regional heterogeneity test result

Explanatory variable	Eastern			Central			Western		
	lnWM (1)	lnWM (1)	lnWM (1)	lnWM (1)	lnWM (1)	lnWM (1)	lnWM (1)	lnWM (1)	lnWM (1)
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
ln Fin(1)	0.044		0.083	0.886***		0.865***	0.756***		0.773***
	(0.33)		(0.42)	(3.95)		(3.72)	(5.77)		(6.92)
ln GX		−0.163**	−0.165**		−0.079	−0.055		0.041	0.072**
		(−3.03)	(−2.93)		(−1.61)	(−1.08)		(1.44)	(2.75)
ln UR	0.068	−0.029	−0.012	−0.864**	−1.005**	−0.810**	−0.057	−0.894	−0.150
	(0.86)	(−0.26)	(−0.11)	(−2.72)	(−2.37)	(−2.53)	(−0.11)	(−1.67)	(−0.27)
ln EDU	−0.043	0.494**	0.478**	0.115	0.398	0.136	−1.394**	−0.878	−1.300**
	(−0.12)	(2.41)	(2.28)	(0.33)	(0.94)	(0.38)	(−3.01)	(−1.56)	(−2.69)
ln FDI	0.078	0.077**	0.069*	0.049	0.075*	0.053	0.035	0.046	0.037
	(1.81)	(2.25)	(1.83)	(1.64)	(2.02)	(1.50)	(1.44)	(1.84)	(1.50)
ln IAV	0.148	0.250**	0.222*	−0.243	0.087	−0.243	−0.114	0.166	−0.117
	(1.17)	(2.51)	(1.91)	(−1.55)	(0.55)	(−1.57)	(−1.06)	(1.74)	(−1.12)
ln SPV	−0.006	−0.009	−0.011	0.021	0.011	0.017	0.014	0.010	0.015
	(−0.34)	(−0.74)	(−0.86)	(1.16)	(0.94)	(1.03)	(0.84)	(0.50)	(0.83)
ln CAR	−0.108	−0.028	−0.031	−0.043	0.096	0.004	−0.165	−0.024	−0.228*
	(−1.59)	(−0.58)	(−0.62)	(−0.40)	(0.75)	(0.05)	(−1.38)	(−0.19)	(−2.15)
Constant	2.897*	1.909***	2.462	6.610***	1.210	6.827***	9.871***	3.123**	9.347***
	(2.03)	(3.43)	(1.73)	(5.00)	(1.18)	(5.50)	(7.59)	(2.37)	(6.44)
Model	FE	FE	FE	FE	FE	FE	FE	FE	FE
Observation	209	209	209	190	190	190	171	171	171
R^2	0.086	0.189	0.192	0.329	0.199	0.336	0.411	0.251	0.419

The eastern regions include Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; The central regions include Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, and Guangxi; The western regions include Sichuan, Guizhou, Yunnan, Chongqing, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang

Robust t-statistics in parentheses:*** $p<0.01$, ** $p<0.05$, * $p<0.1$

pollution. Government support for innovation will promote local industrial transformation and upgrading, increase clean energy application, and reduce haze pollution. Government finance effectively guides innovation, and the regional innovative development approach continues to reduce haze pollution.

Fiscal decentralization exacerbated haze pollution in the central region; however, the effect of government innovation preference on haze pollution was not significant. The central region is rich in resources, has a good industrial base, and has abundant human resources; however, haze pollution is prevalent due to heavy industry-dominated industrial structures. Fiscal constraints in the central region are the main reason for the lack of environmental investment. Fiscal decentralization reduces the regulatory strength of the central government. Consequently, local governments have relaxed environmental regulations to achieve rapid economic growth, resulting in a significant positive effect of fiscal decentralization on haze pollution. Urbanization in the central region reduces the impact of human activities on the natural environment, thus, reducing haze pollution significantly.

Fiscal decentralization significantly aggravated haze pollution in the western region. Government innovation preferences also aggravated haze pollution. The western region suffers from a low fiscal foundation, and fiscal decentralization aggravates the problem of insufficient financial resources. Therefore, fiscal decentralization has a significant positive correlation with haze pollution. Innovation increases production efficiency and aggravates haze pollution. The education quality of the population in the western region has significantly improved. High-quality human resources have increased in the western region to absorb and transform technology from the eastern region. Therefore, the effect of human capital on haze was significantly negative.

Conclusion and suggestions

Based on the 2000–2018 panel data from 30 Chinese provinces, fixed-effects panel regression and dynamic system GMM models were used to study the effect of fiscal decentralization and innovation preferences on haze pollution.

First, a standard regression is established to study the effects of fiscal decentralization and government innovation preferences on haze pollution, and robustness tests are conducted. Second, the temporal and spatial differentiation effects are further discussed. Based on the empirical results, the main findings are as follows:

(1) Fiscal decentralization negatively impacts haze pollution management, whereas local government fiscal autonomy suppresses haze pollution management. Government innovation preference has a positive impact on haze pollution, and governments encourage innovation to effectively promote the formation of new development models and to control haze pollutant emissions at the source.

(2) Fiscal decentralization facilitated haze pollution in 2000–2012, and government innovation preferences inhibited haze pollution. From 2013 to 2018, fiscal decentralization inhibited haze pollution, and the effect of government innovation preference on haze pollution was insignificant. Accumulation of haze pollution control tasks will, therefore, increase the difficulty of recovery. The research results indicate that diversified local government assessment mechanisms will encourage local governments to actively perform ecological protection responsibility and realize harmonious economic and ecological development. Haze pollutant source diversity decreases the effectiveness of government innovation input and increases the difficulty of controlling haze pollution.

(3) Fiscal decentralization and the effect of government innovation preference on haze pollution have regional heterogeneity. Government innovation preference in the eastern region is an important force for promoting local industrial structure transformation and haze pollution reduction. Conversely, in the central and western regions, fiscal decentralization has a negative effect on haze pollution control owing to local economic development pressure. Thus, the government innovation preference mediating effect is weakened. Government innovation preferences make it difficult to control haze pollution in the central and western regions of China.

Haze pollution management is the key to implementing new green development concepts. Haze pollution control is related to public health, and high-quality economic and social development. Therefore, it is necessary to study the effects of fiscal decentralization and government innovation preferences on haze pollution governance mechanisms to achieve win-win results for economic and ecology-balanced development. Based on the research results, this study presents the following recommendations.

(1) The Chinese central government should improve its local political achievement assessment system and establish a diversified appraisal system. Fiscal decentralization is an external factor in haze management, and governance role realization requires the central government to establish a comprehensive evaluation system that effectively performs local government environmental protection functions. The performance appraisal system of the local government plays a role in regulating their behavior. Central government should incorporate environmental protection performance into local performance appraisal system and promote local government to fulfill the responsibility of haze pollution prevention, control and remediation. Political achievement assessment pressure drives local managers to actively fulfill ecological protection responsibilities, emphasize financial incentives and regulatory constraint functions, and promote balanced regional, ecological, and economic development.

(2) Financial decentralization combined with central environmental supervision to control haze pollution. China's centralized inspection of the central government environment formed an effective supervision of local government action and weakened the negative impact of fiscal decentralization on haze pollution. Local governments should improve government policies that support a green economy and establish green incentives and subsidy policies. Moreover, the central government should strengthen environmental monitoring and clarify the ecological and environmental responsibilities of local governments. Ecological and environmental achievements are linked to local leader rewards, punishments, appointments, and appraisals, motivating fiscal decentralization to become a force for haze pollution in local government governance.

(3) Financial resources support regional innovation, create new momentum for regional development, and pursue high-quality regional economic development. Haze pollution control requires competent governments to cooperate in effective markets. The government strengthens top-level system design, builds environmental regulations and financial incentive mechanisms, and mobilizes enterprise enthusiasm to reduce haze pollutant emissions. Meanwhile, local governments should focus on innovation roles, fostering a regional innovation atmosphere, and encouraging enterprises to develop pollution detection, pollutant recovery, and comprehensive energy utilization technologies to reduce economic development damage to ecology and achieve win-win results for the economy and ecology.

This study considers haze pollution environmental problems as the main line of research, focusing on exploring

government financial power changes and attitudes toward the effects of innovation on haze pollution. A new observational dimension of government innovation preferences is added to study the fiscal decentralization effect on haze pollution and investigate the moderating effect of government innovation preferences and fiscal decentralization on haze pollution. Therefore, the study results provide a useful reference for studying the government actions that influence haze pollution mechanisms.

However, this study had some limitations. First, the study only investigates fiscal decentralization and the effect of government innovation preference on haze pollution in the Chinese institutional context; therefore, it lacks more empirical studies in a cultural institutional context. Therefore, empirical studies in more cultural contexts can be a direction for future research. Second, the study did not provide an empirical analysis on the effects of policy on the degree of haze pollution, before and after fiscal decentralization and policy implementation, which will also serve as a future research direction.

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Declarations

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