Can urban financial development help to protect the “Blue Sky”? An Empirical analysis on haze governance

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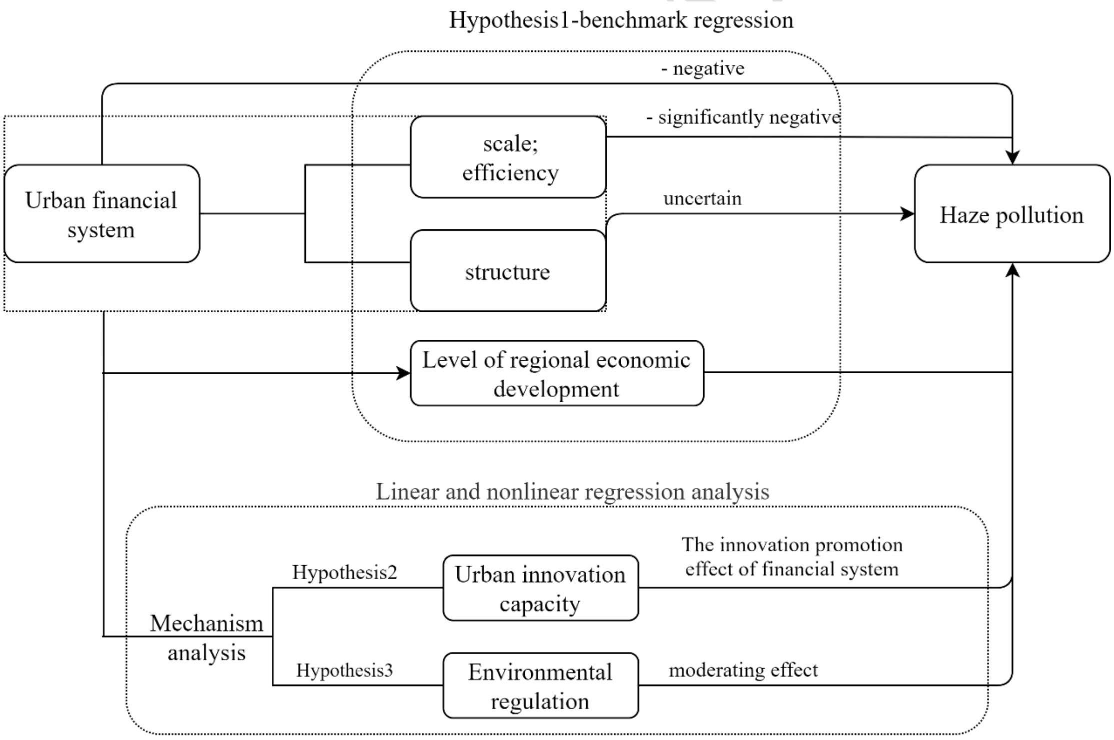
Graphical abstract



ABSTRACT

This study examines whether financial development contributes to haze pollution reduction. In a Partially Linear Functional-Coefficient (PLFC) model, we use a prefecture-level panel to analyse the influential mechanism of financial development on haze pollution by constructing the comprehensive index of urban financial development from three dimensions of financial scale, financial efficiency and financial structure. The results indicate that financial development significantly contributes to haze pollution reduction, both in terms of financial scale and financial efficiency. The role of financial structure is uncertain. Moreover, the impact of financial development on smog is nonlinear in regional changes. We also find that innovation and environmental regulation can significantly promote the impact of financial development on haze governance. These results suggest different channels through which financial development affect smog.

Keywords: Financial development***;*** Haze governance***;*** Innovation***;*** Environmental regulation

1.Introduction

Supporting high-quality development with a high-quality ecological environment has become one of the central themes of China's development in the new era. Among the key policy initiatives, the "Blue Sky Protection Campaign"—a flagship component of the country's broader battle against pollution—plays a pivotal role in advancing the vision of a "Beautiful China". In his address at the National Conference on Ecological and Environmental Protection in 2023, President Xi Jinping articulated the "Four Major Transformations" and the "Five Major Relationships" in ecological civilization, emphasizing that building a Beautiful China should be placed at the forefront of national modernization and rejuvenation efforts. This provides fundamental guidance for environmental governance, including air pollution control and smog mitigation.

The strategy has since been further institutionalized in practice. In 2024, the State Council issued the Action Plan for Continuous Improvement of Air Quality, which deepens the Blue Sky Protection Campaign through targeted measures such as promoting clean heating, advancing ultra-low emissions retrofitting in industry, and strengthening regional joint prevention and control mechanisms. According to the 2024 China Ecological and Environmental Status Bulletin, the average $PM_{2.5}$ concentration in cities at the prefecture level and above declined to 29.3 micrograms per cubic meter, while the proportion of days with good air quality rose to 87.2 percent—indicating a steady improvement in overall environmental quality.

However, it is worth noting that China's efforts to control smog still face substantial challenges, including uneven regional governance capacity and the need for deeper source-level pollution control. Key regions such as Beijing–Tianjin–Hebei and its surrounding areas continue to require intensive remediation efforts. Meanwhile, insufficient financial investment and the slow diffusion of green technologies have emerged as critical bottlenecks constraining the effectiveness of air pollution governance. Against this backdrop, the 2024 National Conference on Ecological and Environmental Protection called for improving the institutional framework for green and low-carbon development, emphasizing that high-level ecological protection should advance in tandem with high-quality economic growth. This policy direction highlights the role of finance as an enabling mechanism for smog mitigation.

As the core of modern economic systems, the financial sector plays a pivotal role in resource allocation. Yet, how this intermediation function can be translated into tangible environmental outcomes remains an open question. Specifically, whether instruments such as green credit and carbon finance can alleviate funding constraints, stimulate industrial green transformation, and ultimately enhance the efficiency of pollution control represents a critical issue at the intersection of financial development and environmental governance—and constitutes the central motivation of this study. Existing studies have shown that the effect of financial development on the environment has two sides: On the one hand, the scale effect, structural effect and technological effect of finance can expand the economic scale, improve the economic structure, and adopt more eco-friendly production methods by upgrading equipment and manufacturing processes to reduce pollution (Sadorsky,2010; Zhang, 2011; Brock et al., 2005). On the other hand, the improvement of financial level has broadened financing channels for high-polluting, high-energy-consuming and high-emission companies, which enabled them to attract more financial support (Boutabba, 2014; Ali et al., 2015; Zhang, 2011). The Environmental Kuznets Curve shows that the relationship between economic development and pollution is an inverted U-shaped curve at a certain stage. Therefore, with the phased changes in the way in which economic development and environmental governance are connected, does the impact of financial development on smog still have two sides? Is it true that the more developed the economy, the more significant the impact of financial development on the smog? How is this impact achieved? Previous research on these issues has not been sufficient. Many existing studies have explored the factors affecting haze pollution and the channels to reduce pollution from various perspectives such as urbanization, industrialization and foreign investment. In contrast, this paper has made the following contributions to related research. First, we use a prefecture-level panel of 276 cities in China from 2006 to 2018 to construct an index of financial development from the dimensions of financial scale, financial efficiency and financial structure to explore whether financial development can reduce haze pollution. Second, we use a

PLFC model to identify the nonlinear characteristics of this impact in different stages of economic development. Lastly, the role of innovation and environmental regulation in the effect of financial development on haze pollution has also been included in our empirical analysis, which provides new suggestive evidence for the improvement of both economic and environmental benefits.

This paper is organized as follows. In Section 2, we review previous literature and put forward research hypothesis. Section 3 follows with an empirical estimation strategy, including the description of the empirical model and the introduction of data and variables. Section 4 presents the main results and discuss the effects of financial development on haze governance from both linear and nonlinear aspects. Section 5 presents our conclusions and discusses the policy implication of this research.

2.Literature review and theoretical hypothesis

The literature on the financial development and environmental pollution has provided important insights for follow-up research. Lundgren (2003) explored the capitalization effect of financial development on environmental performance in the Swedish pulp industry and found that financial development may drive companies to increase investment in emission reduction equipment and encourage them to introduce eco-friendly technologies. Tamazian and Rao (2010) conducted a study on 24 countries in transition from 1993 to 2014. By using GMM methodology, they found that under a certain system, freer financial development can attract more foreign capital to support the development of new technologies, reduce the carbon intensity of the economy, and play an active role in environmental protection. In contrast, Sadorsky (2010) concluded that the improvement of the financial market has broadened financing channels for companies to expand their production capacity, which would increase energy consumption and pollution emissions. Some other studies have shown that the relationship between financial development and pollution may vary depending on the level of financial development. Yan et al. (2016) used an endogenous growth model to examine the impact of financial development on CO_2 intensity and find that the relationship between them shows an inverted U-shaped curve. High-level financial development can improve technology and reduce CO_2 intensity.

In fact, regions with more developed economies tend to have higher levels of financial development and stronger pollution reduction capabilities. Al-Mulali et al. (2015) grouped 129 countries by income to explore the impact of financial development on CO_2 emissions. The results showed that compared with low-income countries, high-income countries are more likely to use their financial advantages to introduce high-quality goods, services and technology so that they could significantly reduce CO_2 emissions in the long-term (Shahbaz et al., 2013; Jalil & Feridun, 2011). Similarly, Tamazian et al. (2009) concluded that countries with better financial markets tend to have a higher degree of financial liberalization. On the one hand, companies can obtain funds from the capital market and banks to reduce liquidity risks, increase R&D expenditures, support technological innovation, and enhance energy efficiency to reduce pollution emissions (Blanford, 2008). On the other hand, the opening and liberalization of financial markets can attract more foreign investment related to R&D to alleviate environmental degradation. There is a large gap in financial development between regions in China. With the support of national policies, the financial system in the eastern region has developed rapidly and credit resources are more sufficient. It is easier to obtain effective financial support for its R&D and innovation activities, which is conducive to reducing pollution. On the contrary, financial development in the middle and western regions is relatively backward, and financial support for R&D investment is not sufficient. Meanwhile, residents in the eastern region are more willing to pay higher prices for eco-friendly products and services because of their higher incomes and stronger environmental awareness. As a result, enterprises are encouraged to innovate in technology and use clean energy for production (Wang and Huang, 2015). Moreover, compared with the western region, both the financial support of government and the allocation of financial resources have promoted better environmental governance in the eastern region (He et al., 2019). Based on the existing literature, we believe that financial development contributes to haze governance. However, this impact may vary depending on the level of regional economic development. Therefore, we put forward the following hypothesis:

*Hypothesis*1: Urban financial development contributes to the reduction of haze pollution, and this effect is nonlinear with different levels of economic development.

Innovation plays an important role in the balance of economic and environmental benefits. Taking the construction of smart cities as an example, Shi et al. (2018) believed that urban innovation development strategies can improve the resource allocation and utilization efficiency of enterprises through innovations in technology, products, markets, resource allocation and organization, promote the transformation of enterprises and the upgrading of industrial structure, and reduce environmental pollution in cities. Xu et al. (2021) confirmed that the innovation of eco-friendly technologies may affect carbon emissions through transmission channels such as energy consumption structure, industrial structure, urbanizationt and foreign direct investment (Du and Li., 2019; Shao et al., 2013). In the theory of innovation, Schumpeter believed that the forms of innovation includes new products, mode of production, markets and organizations. It is true that the implementation of these innovative behaviors is inseparable from the core elements of innovation, namely R&D capital, human capital and technology (Griliches, 1979; Acemoglu, 2011).

Liu et al. (2020) examined the data of Chinese manufacturing industry and the results indicate that the distortion of the price of R&D capital significantly inhibited the innovation efficiency of enterprises. With the investment of educational resources, the increase in the supply of human capital has increased the number and quality of innovation patents in China. Generally speaking, the introduction of foreign capital may have a spillover effect of innovative technology on enterprises in the host country (Carluccio & Fally, 2013; Javorcik et al., 2018). The smaller the gap between the existing technology and the frontier technology is, the more obvious the spillover effect will be (Zhu et al., 2020). Previous studies have shown that financial development can affect key innovation factors of enterprises such as R&D capital investment, human capital investment, foreign capital introduction and technology absorptive capacity. Nevertheless, the impact of financial development on innovation factors may vary with the level of economic development, which can affect the effectiveness of pollution governance. In terms of R&D capital investment, the financial market in wealthy areas is usually more perfect, with rich financial resources and products. A well-developed financial market can provide diversified financing support for innovative enterprises, and promote their improvement of technology to reduce urban environmental pollution (Acemoglu, 2002). On the contrary, companies in poor areas with scarce financial resources usually lack for the motivation to innovate and improve technology because they are facing more financing constraints and fewer financing channels (Jerzmanowski & Tamura, 2019). As for human capital, financial development improve the level of it by expanding the scale of investment to achieve the goal of reducing environmental pollution from promoting the production of clean products, technologies and processes (Romer, 1990). The China Human Capital Report in 2018 shows that the distribution of human capital in China from 1985 to 2016 is unbalanced in space, showing a downward trend from east to west. In terms of foreign capital introduction and technology absorption, He (2014) believed that the technological spillover of FDI depends on the regional economic endowment, such as the level of economic development, financial market development, infrastructure and human capital. The spillover effects of FDI in regions with more developed economies and more perfect financial markets will be more significant (Alfaro et al., 2004). In summary, financial development can affect haze pollution by influencing the input of innovative elements. Meanwhile, this effect may be nonlinear because of different levels of innovative concentration, financial development and economic development in different regions. So we propose the following hypothesis:

Hypothesis2: Financial development can reduce haze pollution by improving the regional innovation capabilities. Meanwhile, the impact of financial development on haze pollution through innovation may be nonlinear because of different levels of economic development in different regions.

A series of evidences prove that environmental regulations play an important role in energy conservation and pollution reduction (Curtis and Lee, 2019; Wang et al., 2019). Galloway and Johnson (2016) found that strict environmental regulations encourage companies to improve technical efficiency to achieve pollution reduction goals. Liu et al. (2018) concluded that environmental regulation uses direct intervention, economic and legal supervision to restrain energy consumption and alleviate energy pressure. Similarly, Fan et al. (2020) collected the provincial-level satellite monitoring data of PM2.5 concentration and conclude that environmental regulations have prompted enterprises to expand investment in pollution control and optimize the structure of energy consumption. Potter hypothesis holds that environmental regulations have a compensatory effect on innovation, which means that strict regulations can drive companies to develop patented technologies to achieve technological progress in pollution control (Chakraborty and Chatterjee, 2017; Rubashkina et al., 2015). How will companies respond to strict environmental regulations? In rich areas with well-developed financial markets and unobstructed information, companies have the motivation and confidence to obtain financial resources from the market even in the face of strict regulations, which can be used to control pollution, update equipment or innovate production technologies (Chen et al., 2019). In poor areas, limited financial capital means high costs for companies under strict environmental regulations, whether it is equipment upgrades or technological innovation. In order to reduce financial costs, companies may choose to reduce production, move out or even go bankrupt to achieve the goal of environmental regulation. Furthermore, in terms of the relationship between environmental regulations and foreign capital introduction, the Pollution Halo hypothesis holds that in the face of environmental regulations, governments in rich regions can introduce foreign capital and advanced technologies to achieve green production, strengthen spillover effects of technology and improve environmental quality because of their market advantages. In contrast, the hypothesis of Pollution Paradise and Race to the Bottom suggest that governments in poor areas may lower the level of regulation to attract high-polluting and high-energy-consuming industries which have moved out to avoid strict domestic environmental supervision (Becker and Henderson, 2000; Keller and Levinson, 2002; List et al., 2003; Copeland and Taylor, 2004; Woods, 2006). In summary, the effect of environmental regulations on pollution varies with the level of regional economic and financial development. In regions with well-developed financial markets, environmental regulations have a stronger effect on reducing pollution. Therefore, we propose the following hypothesis:

Hypothesis3: Environmental regulation plays a moderating role in the process of financial development affecting haze pollution. Moreover, this role has two sides due to differences in regional development. Specifically, the moderating effect in rich areas will strengthen the inhibiting effect of financial development on haze pollution, while the inhibiting effect in poor areas will be weakened.

3.Empirical strategy

3.1 Model

we constructed a linear regression model to estimate the impact of urban financial development on smog. The general form of the model adopted can be written as follows:

$$Y_{it} = \alpha_0 + \alpha fin_{i(t-1)} + \beta' X_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

Where Y_{it} indicates the haze pollution for city i in year t, fin represents the level of urban financial development, including dimensions of financial scale ($finsc$), financial efficiency ($finef$) and financial structure ($finst$). Given that the influence of financial development on the smog may be lagging, we introduce the lagged values of financial development variable into the general regression model. α is the estimated coefficient of the impact of financial development on haze pollution, which is also the coefficient of interest. If α is significantly negative after controlling a series of factors that affect haze pollution, it means that urban financial development can effectively reduce haze pollution in the long term. X_{it} is a vector of control variables, including the level of foreign investment (fdi), the level of urbanization ($urban$), industrial structure ($ind3$), population size ($peosc$) and infrastructure ($infra$). The values of foreign investment, industrial structure and population size are all in logarithmic form. To mitigate potential heteroskedasticity in the model, all control variables are log-transformed in the regressions. β' represents the estimated coefficient of each control variable. μ_i is a time-invariant effect unique to city i. ε_{it} is the error term.

The previous analysis shows that the effect of financial development on smog shows different results in cities with different levels of economic development. To discuss the role of economic development level between financial development and urban haze pollution, we introduce the interaction between the level of urban financial development (fin) and the level of urban economic development (U) in the regression and estimate the following equation:

$$Y_{it} = \alpha_0 + \alpha_1 fin_{i(t-1)} + \alpha_2 fin_{i(t-1)} \times U_{it} + \beta' X_{it} + \mu_i + \varepsilon_{it} \quad (2)$$

Eq. (2) shows that the estimated coefficient of the impact of financial development on haze pollution may be a linear function of the level of urban economic development, namely

$\alpha_1 + \alpha_2 \times U_{it}$. However, due to the interaction term is considered reasonable and meets the assumptions of the linear regression model, Eq. (1) and (2) may have model setting and estimation errors (Li et al., 2019; Du et al., 2020). Therefore, we introduce a PLFC model to avoid the above problems, which can overcome the estimation errors and examine the heterogeneous influence of different levels of urban economic development. Our estimating equation is motivated by Eq. (3):

$$Y_{it} = \alpha_0 + g(U_{it}) fin_{i(t-1)} + \beta' X_{it} + \mu_i + \varepsilon_{it} \quad (3)$$

This model can be divided into two parts: Part $g(U_{it})$ describes the nonlinear impact of financial development on haze pollution under different levels of urban economic development; Part $\beta' X_{it}$ is the linear part which controls other factors affecting technological progress. The variables in Eq. (3) are defined in the same way as in Eq. (1). Furthermore, we use the following estimation methods proposed by Zhang et al. (2020) and Du et al. (2020).

First of all, we use the linear combination of a series of sieve functions to fit the functional-coefficient $g(U_{it})$ in equation (3):

$$h(U_{it})' \gamma = [h_1(U_{it}), \ldots, h_k(U_{it})] \begin{bmatrix} \gamma_1 \\ \vdots \\ \gamma_k \end{bmatrix} \quad (4)$$

Where $h(U_{it})$ and γ are the vectors of primary functions order k by 1 and unknown parameters order k by 1. When k becomes larger, there is a linear combination of $h_i(U_{it})$ that can approximate any smooth function $g(U_{it})$. Therefore, Eq. (3) can be represented as follows:

$$Y_{it} = \alpha_0 + h(U_{it})' \gamma fin_{i(t-1)} + \beta' X_{it} + \mu_i + v_{it} \quad (5)$$

Where $v_{it} = \varepsilon_{it} + g(U_{it}) fin_{i(t-1)} - h(U_{it})' \gamma fin_{i(t-1)}$ represents the sieve error.

Second, we take the first difference of Eq. (5) to remove the fixed effect:

$$\Delta Y_{it} = \Delta(fin_{i(t-1)} h(U_{it}))' \gamma + \beta' \Delta X_{it} + \Delta v_{it} \quad (6)$$

Using the Ordinary Least Squares method to estimate Eq. (6), we get:

$$(\hat{\beta}', \hat{\gamma}') = [\Delta \tilde{X}' \Delta \tilde{X}]^{-1} \Delta \tilde{X}' \Delta \tilde{Y} \quad (7)$$

Where $\Delta \tilde{Y} = \begin{bmatrix} \Delta Y_{12} \\ \vdots \\ \Delta Y_{NT} \end{bmatrix}, \Delta \tilde{X} = \begin{bmatrix} \Delta X'_{12}, \Delta(fin_{11} p(U_{12}) \\ \vdots \\ \Delta X'_{NT}, \Delta(fin_{N(T-1)} p(U_{NT}) \end{bmatrix}$.

Therefore, the functional-coefficient can be approximated as follows:

$$\hat{g}(U_{it}) = h(U_{it})' \hat{\gamma} \quad (8)$$

Lastly, we estimate the following models based on the above analysis:

$$Y_{it} = \alpha_0 + g_1(Log(pgdp)) fin_{i(t-1)} + \beta' X_{it} + \mu_i + \varepsilon_{it} \quad (9)$$

$$Y_{it} = \alpha_0 + g_2(Log(pgdp)) finsc_{i(t-1)} + \beta' X_{it} + \mu_i + \varepsilon_{it} \quad (10)$$

$$Y_{it} = \alpha_0 + g_3(Log(pgdp))finef_{i(t-1)} + \beta' X_{it} + \mu_i + \varepsilon_{it} \quad (11)$$

$$Y_{it} = \alpha_0 + g_4(Log(pgdp)))finst_{i(t-1)} + \beta' X_{it} + \mu_i + \varepsilon_{it} \quad (12)$$

Where $g_1(Log(pgdp))$, $g_2(Log(pgdp))$, $g_3(Log(pgdp))$ and $g_4(Log(pgdp))$ are the functional-coefficients of comprehensive index of financial development, financial scale, financial efficiency and financial structure, respectively.

3.2 Variables and data

3.2.1 Variables

The level of urban financial development is the independent variable. Due to the unavailability of financial data at prefecture-level, we measure the *comprehensive level of urban financial development* (fin) from the dimensions of *financial scale* ($finsc$), *financial efficiency* ($finef$) and *financial structure* ($finst$)（Ge et al., 2018）. *Financial scale* is calculated as the proportion of the total deposits and loans of financial institutions in the regional GDP. Zhang (2011) finds that the expansion of financial scale will accelerate environmental degradation. Generally speaking, the proportion of the total credit loans of the private sector to GDP can measure financial efficiency. However, the data of private sector credit loans at the city level has not been published, so we use the conversion rate from deposits to loans to measure *financial efficiency*, that is, the ratio of the loan balance to the deposit balance of the financial institution. Following Peng et al. (2019), we proxy *financial structure* using the ratio of fiscal expenditure to total fixed asset investment. The core economic meaning of this indicator lies in its ability to capture the relative strength between administrative and market-based resource allocation within a city. A higher ratio indicates that a larger share of resources is directly allocated through government fiscal expenditure, reflecting a financial structure characterized by stronger government intervention. Conversely, a lower ratio suggests more active investment by market participants and a financial system increasingly guided by market signals. This proxy is designed to capture the structural characteristics of China's local financial systems from the perspective of *resource allocation authority*. It aligns closely with our theoretical framework, which emphasizes the "dual nature" of financial development in influencing environmental governance outcomes. Furthermore, we use the **Entropy Method,** which is widely used in the measurement of various comprehensive indicators (Liu et al., 2019; Du et al., 2021), to construct a *comprehensive index of urban financial development* from the dimensions financial scale, financial efficiency and financial structure.

Based on previous research, the control variables in our model include the level of foreign investment, the level of urbanization, industrial structure, population size and infrastructure to avoid omitted variable bias.

The level of foreign investment is expressed as the proportion of the city's actual utilization of foreign capital to its GDP. On the one hand, Foreign Direct Investment can introduce advanced production technology and effective management experience through the flow of high-tech talents and learning effects (Kim et al., 2015), which may indirectly improve regional air quality. On the other hand, preferential policies for foreign investment may also squeeze the living space of local enterprises. Meanwhile, the opening of the domestic market may introduce high-polluting industries and exacerbate environmental degradation (Copeland and Taylor, 1994; Shahbaz et al, 2015).

Shao et al. (2019) point out that the process of urbanization can affect urban haze pollution through agglomeration and structural effects based on the research on China's provincial panel. Therefore, we use the ratio of non-agricultural population to total urban population to measure the level of *urbanization* (Panayotou, 1997).

This study uses the share of tertiary industry value added in GDP as the primary indicator of *industrial structure*, following the approaches of Zhang et al. (2020) and Yi and Liu (2018). The impact of industrial structure on haze pollution operates through a dual mechanism. On the one hand, urban industrial expansion—particularly during stages dominated by energy-intensive manufacturing—tends to increase energy consumption and industrial emissions, thereby exacerbating haze pollution. On the other hand, technological progress and the upgrading of the industrial structure toward a more service-oriented composition can significantly enhance resource use efficiency and facilitate a green transformation of the economic development model, thereby mitigating haze pollution at its source.

Some existing studies have shown that concentrated human production and living activities tend to worsen haze pollution. Therefore, we use population density to measure *population size* referring to previous studies.

The construction of urban infrastructure can significantly improve air quality (Sun et al., 2019). We use the area of paved roads per capita to measure the level of urban *infrastructure*.

3.2.2 Data source

We finally select 276 prefecture-level cities as the sample, in view of the availability of data and the consistency of the statistical caliber. The period of the sample is from 2006 to 2020. We use the concentration of PM2.5 ($\mu g/m^3$) as the dependent variable. The data calculated by three sensing instruments (NASA MODIS, MISR and SeaWIFS) from ACAG matches the judgment of

CMEP on the PM2.5 situation in China (Hammer et al., 2020). The data of independent variable, control variables, environmental regulations and per capita GDP are all taken from the *China City Statistical Yearbook*. In the process of data handling, cities with a large number of missing values have been eliminated from the sample, and the nearest interpolation method (Yu et al., 2015) is used to interpolate some variables with a few missing values. Table 1 contains descriptive statistics and data resource on the variables used in our analysis. Where fin, $finsc$, $finef$ and $finst$ represent the comprehensive index of financial development, financial scale, financial efficiency and financial structure, respectively, and the one-period lagged-value is taken in the subsequent analysis. $Log(pgdp)$ represents the logarithm of GDP per capita. It should be noted that our focus is on the nonlinear effects of financial development on haze pollution. During the sample period, lpgdp in Chinese prefecture-level cities is primarily distributed between 9 and 12, roughly covering the full spectrum of urban economic development, from a per capita GDP of approximately 8,000 yuan to 160,000 yuan (in 2006 constant prices). Analyzing this wide range allows us to clearly reveal the nonlinear patterns in how financial development affects haze pollution across different stages of economic development. inv represents the urban innovation index, which is derived from *China Cities and Industry Innovation Report* in 2017. The report estimates the innovation index of 338 cities in China from 2001 to 2016 based on micro-patent and enterprise-level data, as well as innovation output indicators such as patent output, patent value and the number of newly registered companies. The level of *environmental regulation* is measured by **Entropy Method**, using data on five types of urban environmental indicators, including the removal rate of industrial SO_2 and smoke dust, the utilization rate of industrial solid waste, the centralized treatment rate of sewage and the rate of harmless treatment of household waste.

Table 1. Summary statistics and sources of variables

	Data source	Units	Mean	S.D.
Dependent variables -$PM_{2.5}$				
$PM_{2.5}$	Dalhousie University Atmospheric Composition Analysis Group	μg/m^3	42.194	18.769
Key explanatory variable-Financial development				
comprehensive index of financial development (fin)	Raw data drawn from *China City Statistical Yearbook (2007-21)*	N/A	0.076	0.034
Financial scale ($finsc$)		%	2.229	1.016

Financial efficiency ($finef$)	and calculated by	%	0.658	0.171
financial structure($finst$)	authors	%	0.259	0.131
Other control variables (X)				
Logarithm of foreign investment ($Log(fdi)$)		N/A	-6.485	1.410
urbanization ($log(urban)$)		%	-0.234	0.512
Logarithm of Industrial structure ($Log(ind3)$)	*China City Statistical*	N/A	-0.943	0.271
Logarithm of population size ($Log(peosc)$)	*Yearbook (2007-21)*	Log(persons per square km)	5.761	0.878
Infrastructure ($log(infra)$)		Square metres	2.301	0.547
logarithm of GDP per capita ($Log(pgdp)$)		Log(Yuan per capita)	10.392	0.687
urban innovation index (inv)	*China Cities and Industry Innovation Report(2017)*	N/A	2.300	3.529
Variables of Environmental regulation				
the removal rate of industrial SO2 (*R_so2*)		%	51.502	26.713
the removal rate of industrial smoke dust (*R_smo*)		%	94.841	11.316
the utilization rate of industrial solid waste (*R_solid*)	*China City Statistical Yearbook (2007-19)*	%	79.766	22.541
the centralized treatment rate of sewage (*R_wate*)		%	75.463	22.709
the rate of harmless treatment of garbage (*R_rub*)		%	84.748	24.331
The level of environmental regulation(*ER*)	Calculated by authors	N/A	0.480	0.149

Note:Comprehensive index of financial development (fin) and The level of environmental regulation(*ER*) are measured through Entropy Method by authors.

4.Empirical analysis

4.1 Main results

Table 2 reports the estimation results of the linear regression model in Eq. (1). The coefficient of the comprehensive index of urban financial development is negative and statistically significant at the 5% level, which indicates that if the value of this index increases by 1, the PM2.5

concentration may decrease by about 18 μg/m^3. Furthermore, the coefficients of financial scale and financial efficiency are both negative and statistically significant at the 1% level, while the coefficient of financial structure is positive and statistically significant. These results preliminary confirmed that financial development contributes to urban smog governance in China. As an important factor affecting environmental quality, financial development can improve the efficiency of capital allocation and utilization by reducing adverse selection and moral hazard caused by incomplete or asymmetric information (Freixas et al., 2008), while it can also reduce environmental pollution while reducing supervision costs, improving audit efficiency, promoting technology upgrades and economic development (Laeven et al., 2015). As for the control variables, foreign investment, industrial structure and infrastructure can reduce urban PM2.5 pollution to a certain extent, while the increase in the level of urbanization has significantly increased the concentration of PM2.5. Table 2 reports the linear impact of regional financial development on haze pollution, but ignores the heterogeneity in different regions. In the following analysis, we will discuss the heterogeneous impact of financial development on haze pollution in cities under different economic development levels.

Table 2

The inhibiting effect of financial development on smog pollution (Baseline model)

	(1)	(2)	(3)	(4)
L.fin	-32.2405*** (-3.24)			
L.finsc		-1.8509*** (-6.25)		
L.finef			-7.0462*** (-6.34)	
L.finst				10.1589*** (6.86)
Constant	35.1735*** (5.83)	39.4986*** (6.66)	39.1844*** (6.62)	31.6176*** (5.36)
Control variables	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	35.1735***	39.4986***	39.1844***	31.6176***
Adj.R^2	(5.83)	(6.66)	(6.62)	(5.36)

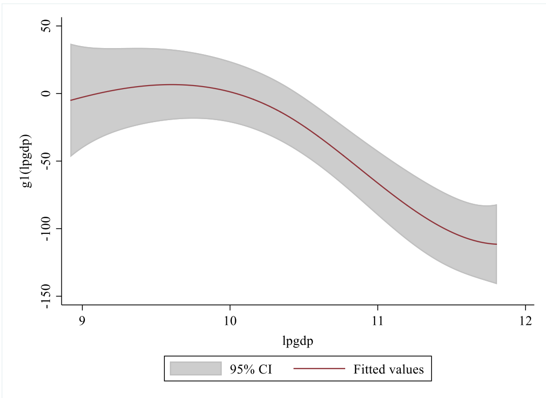
Note: t statistics in parentheses , * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.2 Results of the partially linear functional-coefficient model

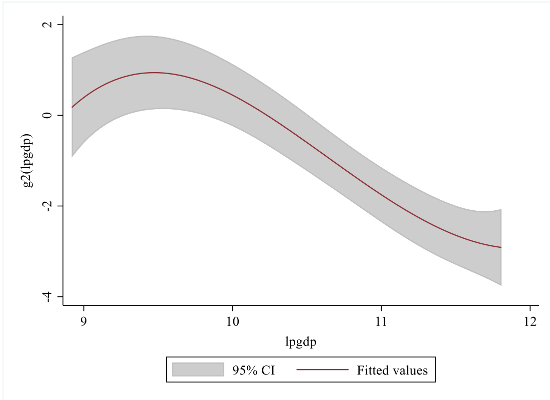
In the previous analysis, we find that financial development has significantly reduced the smog concentration in Chinese cities under the linear assumption. In this section, we discuss whether the impact of financial development on haze pollution is stable under the setting of the

PLFC model. Results of the linear part of the nonlinear models (9) to (12) are reported in columns (1)-(4) of **Appendix** (Table1). Meanwhile, Figure 1 plots the estimation results of the nonlinear functional-coefficient of the comprehensive index of financial development ($L.fin$), financial scale ($L.finsc$), financial efficiency ($L.finef$) and financial structure ($L.finst$), respectively, namely $g_1(Log(pgdp))$, $g_2(Log(pgdp))$, $g_3(Log(pgdp))$ and $g_4(Log(pgdp))$. Figures (a), (b), (c) and (d) show that when $Log(pgdp)$ is less than 10, the coefficient curve of financial development is relatively smooth, and the 95% confidence interval indicates that impact lies in these intervals is not significant or only slightly significant. In terms of the trend, the impact of financial development on haze pollution when $Log(pgdp)$ is larger than 10 varies with different levels of urban economic development, and the estimated coefficients are all significantly negative within the 95% confidence interval, which reflects the limitation that the linear model may not reflect the actual interaction between key variables. When the economy is underdeveloped, the coefficient of financial development fluctuates above zero, which means that it will deteriorate haze pollution. The deterioration of haze pollution caused by finance has gradually slowed down with the development of economy. When the economy is at a well-developed level, financial development turns to have a significant inhibitory effect on haze pollution. We propose the following reasons for the above-mentioned interesting phenomenon. Urban economic development is closely related to the level of financial development. Financial intermediaries and markets in cities with better economic development can provide effective liquidity supply (Fecht et al., 2008), diversify risks (Acemoglu et al., 2006), and reduce adverse selection and moral hazard caused by incomplete or asymmetric information (Bose et al., 1996). Conversely, cities with lagged economic development may inhibit financial development. From the perspective of the relationship between financial development andl innovation, green technological innovation is the core driving force for pollution reduction of companies and industrial transformation (Schumpeter, 1934; Ghisetti et al., 2017; Du et al., 2021). Nevertheless, green technologies often have long research and development cycles and slow investment returns, which directly lead to high risks and uncertain returns in green technology upgrade investment projects (Hsu et al., 2014). As a result, this kind of projects will face higher financing constraints in the underdeveloped financial market, which will hinder the technological innovation activities of enterprises. In summary, compared with the poor regions, the richer regions have a more perfect financial system and more competitive financial markets, which can enable companies to introduce green technologies and clean production processes by broadening financing channels, reducing financing costs, increasing R&D investment and upgrading equipment, which can provide more opportunities for reducing air pollution and improving environmental quality. In view of the analysis of linear and nonlinear results, the **first**

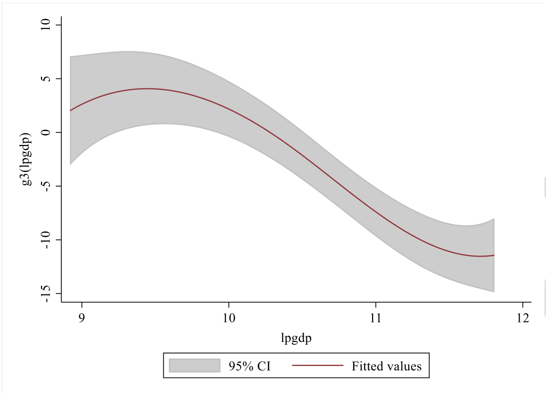
hypothesis has been confirmed[1].



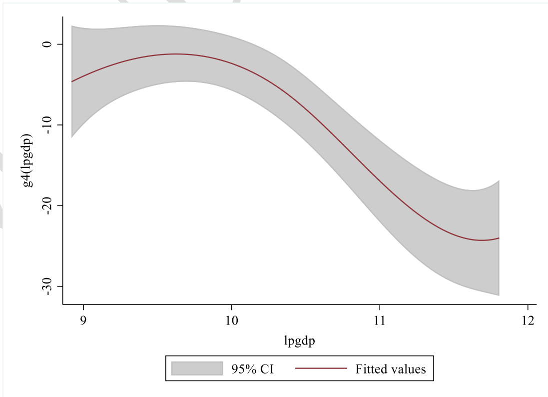
(a) Coefficient curve of *L.fin*



(b) Coefficient curve of *L.finsc*



(c) Coefficient curve of *L.finef*



(d) Coefficient curve of *L.finst*

Fig. 1. The functional coefficient of financial development on haze pollution.

Note: The horizontal axis in the figure represents log-transformed per capita GDP (*lpgdp*). For ease of interpretation, the following correspondences are provided: *lpgdp* values of 9, 10, 11, and 12 approximately correspond to actual per capita GDP of 8,103, 22,026, 59,874, and 162,755 yuan, respectively.

4.3 Robustness tests

Whether it is a linear model or a nonlinear model analysis, the results show that financial development can significantly reduce urban PM2.5. In order to examine whether the results are reliable, we use the following methods for robustness analysis. First, we use Generalized Least Squares (GLS) in the regression to avoid estimation errors that may be caused by the correlation of variables. The results are reported in **Panel A** of Table 3. Second, the four well-developed

[1] It should be noted that, while the above mechanism tests provide evidence consistent with the hypothesized pathway—"financial development → enhancement of innovation capacity → reduction in haze pollution"—we cautiously acknowledge that the relationship between urban innovation capacity and haze pollution may be subject to complex endogeneity. For instance, improvements in air quality could themselves attract high-skilled talent and clean-technology firms, thereby generating feedback effects on urban innovation capacity. Although our model addresses part of the causality concern by lagging the core explanatory variable (financial development), the current results primarily reveal robust associations and suggestive transmission patterns among the variables. Nevertheless, these findings offer important correlational evidence and theoretical insights for understanding the "black box" linking financial development and environmental quality.

municipalities directly under the Central Government, namely Beijing, Shanghai, Tianjin and Chongqing, are all provincial-level administrative divisions and are directly managed by the Central Government. Therefore, we exclude the data of municipalities in regression and the results are shown in **Panel B** of Table 3. Third, the State Council issued the Air Pollution Prevention and Control Action Plan in 2013, which proposed to eliminate heavily polluted weather within 5 years and improve air quality. Therefore, we set a dummy variable ($Air10$) to represent the plan in order to remove the policy effect. The dummy variable will take a value of 1 from 2013 to 2017, otherwise it will take a value of 0. The results are shown in **Panel C** of Table 3. Lastly, we take a one-period lagged-value for the control variables to avoid the endogenous problems caused by them, and the results are shown in **Panel D** of Table 3. After the above analysis, we find that the results are still robust.

Table 3

Robustness checks.

	Panel A Robustness tests 1	**Panel B** Robustness tests 2	**Panel C** Robustness tests 3	**Panel D** Robustness tests 4
L.fin	-56.3728***	-40.5459***	-20.7332*	-20.5011**
	(-8.82)	(-3.71)	(-1.94)	(-2.57)
adj. R^2	-	0.4672	0.5024	0.3898
L.finsc	-1.6494***	-1.8566***	-0.9259***	-2.4816***
	(-6.93)	(-6.25)	(-3.16)	(-7.71)
adj. R^2	-	0.4470	0.4839	0.3986
L.finef	-4.7029***	-6.9086***	-3.8578***	-9.6370***
	(-6.27)	(-6.17)	(-3.52)	(-8.42)
adj. R^2	-	0.4468	0.4843	0.4005
L.finst	-8.5928***	10.6879***	8.8250***	10.8606***
	(-6.50)	(7.16)	(6.16)	(6.91)
adj. R^2	-	0.4489	0.4879	0.3967
N	3864	3804	3864	3864
Controls	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes

Note: t statistics in parentheses , $p < 0.1$*,* ** $p < 0.05$*,* *** $p < 0.01$*.Each coefficients in the table are drawn from the regressions consistent with the mentioned model and conducting with different explanatory variables.*

4.4 Mechanism analysis

The above results indicate that financial development can significantly reduce the concentration of urban PM2.5 in general, and the impact may vary depending on regional economic development, that is, in cities with better economic development, financial development can significantly reduce haze pollution, while the impact is uncertain in cities with a lower level of development. In this section, we study the mechanism of financial development affecting haze pollution and the reasons for nonlinear differences due to different levels of regional economic development from the perspectives of urban innovation ability and environmental regulation intensity.

Innovation can affect technological progress, efficiency improvement and urban pollution control. As the main participants in innovation, the innovation activities of enterprises are inseparable from R&D capital, human capital and technical support, and the investment of these capitals requires a strong financial foundation. Therefore, we use the Urban Innovation Index, which measures urban innovation capabilities, to examine whether financial development can reduce pollution by improving urban innovation capabilities. First, we introduce the Urban Innovation Index as a dependent variable into equation (1) to discuss the impact of financial development on innovation. Columns (1)-(4) of Table 4 show the results. Then we introduce the Urban Innovation Index as a control variable into Eq. (1), and the estimation results are reported in columns (5)-(6) of **Table 4**.

The empirical results in columns (1)-(4) show that the coefficient of financial development is mostly positive and statistically significant at the 1% level, indicating that financial development has significantly improved the level of urban innovation, that is, the effect of financial development on the promotion of urban innovation capabilities has been confirmed, which is in accordance with the previous literature. The results of columns (5)-(8) show that the improvement of urban innovation capabilities can significantly reduce the concentration of PM2.5. In addition, the inhibitory effect of financial development on PM2.5 is still significantly negative after the introduction of urban innovation capabilities, which also confirms the results of the general regression model. Based on the results from columns (1)-(8), financial development can reduce smog by improving urban innovation capabilities, which confirms the innovation channel effect of financial development in reducing pollution. Nevertheless, the above results fail to explain the effect of financial development on haze pollution in the PLFC model, which varies with the economic development of different cities. Therefore, we use a PLFC model to explore the non-linearity of the impact of financial development on urban innovation capacity under different economic development levels. The empirical models is reported as Eq. (1), (2), (3) and (4) in

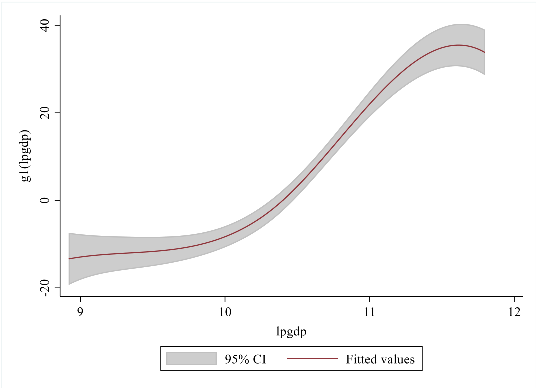
Appendix. The results in **Fig. 2** show that in terms of the comprehensive index of financial development, financial scale, financial efficiency and financial structure, the innovative effect of financial development shows different characteristics with different levels of economic development. When the economy is underdeveloped, financial development has an inhibitory effect on urban innovation; as the economy gets better, the inhibition of financial development on innovation slows down and gradually turns into a promotion effect; the promotion of urban innovation by financial development gradually strengthens and shows a significant upward trend when the economy is developed. Therefore, the nonlinear effect of financial development on urban innovation explains the reason for the nonlinear effect of financial development on haze pollution. In other words, the **second hypothesis** has been confirmed.

Table 4

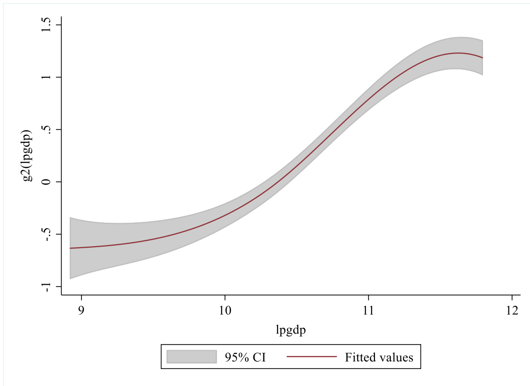
The effect of innovation channels in financial development.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Urban Innovation Index(*inv*)				$PM_{2.5}$			
L.fin	25.7847***				-30.1941***			
	(7.37)				(-2.90)			
L.finsc		1.7414***				-1.6309***		
		(12.39)				(-3.75)		
L.finef			1.9467***				-5.5744***	
			(5.00)				(-4.88)	
L.finst				-1.4365**				0.3828
				(-2.19)				(0.20)
inv					-0.5300***	-0.5005***	-0.5265***	-0.5546***
					(-8.96)	(-8.31)	(-8.98)	(-9.45)
Constant	-4.9335***	-6.8466***	-4.2045**	-2.4594	45.7359***	47.1342***	47.1151***	43.1582***
	(-2.61)	(-3.68)	(-2.22)	(-1.30)	(8.21)	(8.43)	(8.50)	(7.79)
Controlss	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2760	2760	2760	2760	2760	2760	2760	2760
adj. R^2	0.2740	0.3014	0.2655	0.2595	0.1593	0.1612	0.1645	0.1564

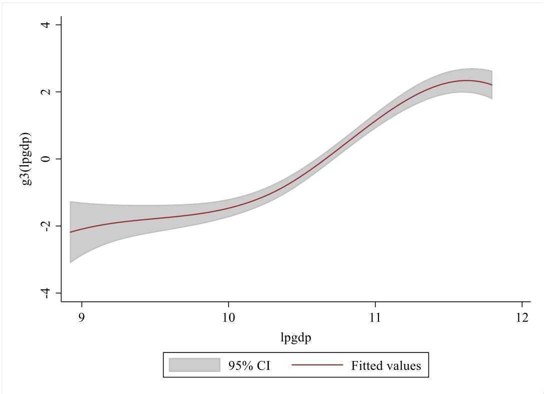
t statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$



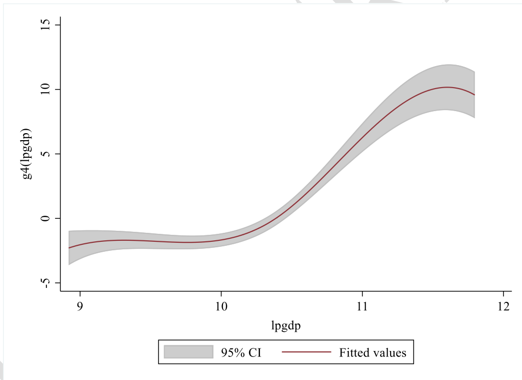
(b) Coefficient curve of *L.fin*



(b) Coefficient curve of *L.finsc*



(c) Coefficient curve of *L.finef*



(d) Coefficient curve of *L.finst*

Fig. 2. The effect of financial development on urban innovation.

Note: The horizontal axis in the figure represents log-transformed per capita GDP (*lpgdp*). For ease of interpretation, the following correspondences are provided: *lpgdp* values of 9, 10, 11, and 12 approximately correspond to actual per capita GDP of 8,103, 22,026, 59,874, and 162,755 yuan, respectively.

Previous studies have shown that environmental regulation can reduce environmental pollution and promote the green transformation of the economy through the innovation of green technology and the upgrading of industrial structure (Du et al., 2021). Under the constraints of economic conditions, innovative elements such as innovative talents, financial capital and technological equipment may also face constraints. In particular, the limitation of financial resources may cause companies to make different choices in front of environmental regulations and affect pollution reduction, that is, environmental regulation can moderate the effect of financial development on pollution. To illustrate the moderating effect of the environmental regulation and the regional differences in this effect, we classify cities according to the median of economic development level. Cities above the median are classified as economically developed groups, and those below the median are classified as underdeveloped groups. The coefficients are estimated by Eq. (13) and (14) respectively.

$$Y_{it} = \alpha_0 + \alpha_1 F_{i(t-1)} + \alpha_2 ER_{it} + \beta' X_{it} + \mu_i + \varepsilon_{it} \quad (13)$$

$$Y_{it} = \alpha_0 + \alpha_1 F_{i(t-1)} + \alpha_2 ER_{it} + \alpha_3 F_{i(t-1)} * ER_{it} + \beta' X_{it} + \mu_i + \varepsilon_{it} \quad (14)$$

Where $F_{i(t-1)}$ represents the level of urban financial development, including the comprehensive index of financial development ($L.fin$), financial scale ($L.finsc$), financial efficiency ($L.finef$) and financial structure ($L.finst$); ER indicates the level of environmental regulation. The control variables are consistent with those in Eq. (1). The estimated results are reported in Table 5.

The odd-numbered columns in Table 5 represent the high-level economic development groups, and the even-numbered columns represent the low-level economic development groups. The results indicate that environmental regulation can strengthen the inhibitory effect of financial development on haze pollution. Moreover, the moderating effects of environmental regulations are different: for cities with high-level economic development, environmental regulations have effectively strengthened the effect of finance to reduce smog; for cities with low-level economic development, environmental regulations have weakened the impact of financial development on haze pollution. Furthermore, we find that environmental regulations also have an impact on urban innovation capability, and this effect varies with different economic levels. In short, the environmental regulation can help high-level cities to enhance the innovation capability, but it may also inhibit the innovation activities of low-level cities. The result is reported as **Appendix (**Fig. 1). Therefore, the **third hypothesis** has been confirmed.

Table 5

The moderating effect of environmental regulation

	(1) H-L	(2) L-L	(3) H-L	(4) L-L	(5) H-L	(6) L-L	(7) H-L	(8) L-L
L.fin	56.8932*	-0.5254						
	(1.93)	(-0.02)						
ER	-18.8159***	-13.6753***	-12.4593***	-2.7766	-0.6610	-27.7728***	-44.0523***	-20.7098***
	(-5.19)	(-3.93)	(-3.51)	(-0.75)	(-0.11)	(-5.51)	(-12.30)	(-6.72)
L.fin×ER	-1.4e+02***	29.0880						
	(-3.27)	(0.67)						
L.finsc			2.6915***	2.7243**				
			(2.85)	(2.48)				
L.finsc×ERR			-7.0553***	-4.7953***				
			(-5.32)	(-2.61)				
L.finef					12.0985***	-9.2026**		
					(2.77)	(-2.49)		
L.finef×ER					-37.2147***	27.4440***		
					(-4.71)	(3.39)		
L.finst							-36.7696***	-10.4676**
							(-3.93)	(-2.44)
L.finst×ER							68.8939***	29.0411***

							(4.72)	(3.53)
Constant	53.0373***	39.4092***	48.9480***	36.0874***	48.6260***	45.0347***	69.4584***	43.0816***
	(5.73)	(5.44)	(5.34)	(4.91)	(5.13)	(6.22)	(7.62)	(6.05)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1982	1606	1982	1606	1982	1606	1982	1606
adj. R^2	0.9022	0.9375	0.9039	0.9377	0.9037	0.9380	0.9026	0.9382

Note:t statistics in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; H-L denotes for high-level economic development groups, L-L denotes for low-level economic development groups

5.Conclusions and discussion

In this paper, we use a prefecture-level panel of 276 cities in China from 2006 to 2018 to construct a urban financial development index from dimensions of financial scale, financial efficiency and financial structure. A partially linear functional-coefficient model is used to explore the impact of financial development on urban haze pollution and the influential mechanism. The results indicate that financial development which including financial scale, financial efficiency and financial structure can reduce haze pollution to a certain extent.

Our findings have several implications. On the whole, the coefficient of the comprehensive index of urban financial development indicates that financial development contributes to smog governance and significantly reduces haze pollution. In terms of the dimensions of financial development, both financial scale and financial efficiency have significantly inhibited urban smog pollution, but the impact of the financial structure is uncertain and even the opposite. From the perspective of regional economic disparity, the results of the PLFC model show that the effects of financial development, financial scale, financial efficiency and financial structure all have nonlinear and differentiated characteristics. Specifically, financial development may exacerbate the deterioration of haze pollution in poor areas; as the economy gets better, the positive effect of financial development on haze pollution slows down and gradually turns into a inhabit effect; the inhabit effect gradually strengthens and shows a significant upward trend when the economy is developed. As for the the mechanism of the impact, financial development can affect smog by improving urban innovation capabilities. However, due to the differences in regional economic development, financial development has a nonlinear impact on urban innovation. In well-developed cities, financial development can enhance the innovation capabilities; otherwise, financial development may have an inhibitory effect on urban innovation. On the other hand, the moderating effect of environmental regulations can change the impact of financial development on haze pollution, and this effect also presents similar nonlinear characteristic. Compared with underdeveloped cities, environmental regulation can strengthen the effect of pollution reduction caused by financial development in more developed cities.

The results presented in this paper provide new empirical evidence for the way in which financial development and haze governance are connected， and also provide new ideas for cities to improve the financial system, optimize the financial structure, improve financial quality as well as the ability of environmental governance, and promote the coordinated progress of economic growth and environmental protection.

The paper concludes that financial development generally supports local haze mitigation, but its effectiveness varies with regional economic development, highlighting the need for stage-specific, tiered financial policies. For less-developed cities (lpgdp < 10), the financial system has yet to establish effective interactions with the real economy, and premature promotion of complex green finance instruments may be counterproductive. Policy priorities should focus on strengthening financial infrastructure: expanding inclusive finance and improving SME credit access; enhancing credit guarantee systems to lower initial financing barriers for green projects; and leveraging fiscal funds to guide commercial capital toward environmental initiatives. The key objective is to bridge the “last mile” between financial resources and the real economy, laying the foundation for subsequent green transitions.

For more developed cities (lpgdp ≥ 10), financial markets are sufficiently mature to deploy advanced instruments for targeted haze reduction. Policy emphasis should shift toward financial innovation and market mechanisms: promoting green credit, green bonds, and insurance linked to carbon or pollution rights; establishing regional environmental trading markets to allow prices to guide emissions; and creating green industry investment funds with risk-sharing and interest subsidies to attract private capital for long-term green technology development. The ultimate goal is to leverage efficient financial markets to catalyze technological innovation and industrial upgrading, achieving a dual win for pollution control and economic development.

The paper further examines the innovation channel of financial development and its nonlinear effects on urban innovation capacity. To strengthen local innovation, governments should increase investment in innovation inputs, direct financial resources toward entrepreneurship and R&D to stimulate firm-level innovation, enhance educational resources to attract and cultivate talent, and foster an innovation-friendly environment that reinforces the local innovation infrastructure. For regions with weaker innovation capabilities, authorities should proactively build platforms connecting local firms and universities with more advanced regions, enabling them to leverage external innovation advantages to overcome local shortcomings and progress toward becoming innovation-driven cities.

Moreover, the moderating role of environmental regulation varies with regional economic development. Policy stringency and implementation must be tailored to local conditions to maximize synergy with financial development. In high-development cities, environmental standards should be maintained and gradually strengthened. Strict regulation in these contexts can generate significant “innovation compensation” effects (Porter hypothesis). Governments should ensure a fair, stable, and predictable regulatory environment, complemented by transparent environmental information disclosure, to stabilize market expectations and incentivize firms to allocate financial resources toward long-term green technology R&D and equipment upgrades.

In less-developed cities, overly rigid regulations may produce “crowding-out” effects. Policy design should be more flexible, such as implementing gradual, stepwise increases in standards to provide firms with adjustment periods; relying more on market-based instruments (e.g., tax incentives or emissions trading) rather than direct administrative shutdowns to reduce compliance costs; and increasing horizontal ecological transfer payments from central and provincial governments to offset short-term economic losses from strengthened environmental protection, avoiding a “race to the bottom.”

In sum, as the “Blue Sky Defense” initiative advances, local governments must recognize the stage-dependent constraints on the effectiveness of financial development and environmental policy. Aligning the allocation of financial resources and regulatory stringency with local economic development stages and factor endowments is essential to achieve the dual goals of sustainable economic growth and environmental protection.

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Appendix:

Table1: The estimation results of the linear part of the nonlinear models

	(1)	(2)	(3)	(4)
Lfdi	0.2009	0.1874*	0.2086*	0.2331**
	(1.55)	(1.77)	(1.87)	(2.34)
lurban	1.2235***	1.3021***	1.4524***	1.2357***
	(4.43)	(5.04)	(4.92)	(4.91)
lind3	-14.0409***	-14.7194***	-14.3194***	-14.1237***
	(-13.18)	(-16.64)	(-18.90)	(-14.81)
lpeosc	-0.4867	-0.3970	-0.4525	-0.5706
	(-0.77)	(-0.63)	(-0.71)	(-0.88)
linfra	-0.2801	-0.1960	-0.0308	-0.3037
	(-0.47)	(-0.36)	(-0.05)	(-0.56)
N	3864	3864	3864	3864
r2	0.0657	0.0776	0.0584	0.0657

$$inv_{it} = \alpha_0 + f_1(Log(pgdp))fin_{i(t-1)} + \beta' X_{it} + \mu_i + \varepsilon_{it} \qquad (1)$$

$$inv_{it} = \alpha_0 + f_2(Log(pgdp))finsc_{i(t-1)} + \beta' X_{it} + \mu_i + \varepsilon_{it} \qquad (2)$$

$$inv_{it} = \alpha_0 + f_3(Log(pgdp))finef_{i(t-1)} + \beta' X_{it} + \mu_i + \varepsilon_{it} \qquad (3)$$

$$inv_{it} = \alpha_0 + f_4(Log(pgdp))fin_{i(t-1)} + \beta' X_{it} + \mu_i + \varepsilon_{it} \qquad (4)$$

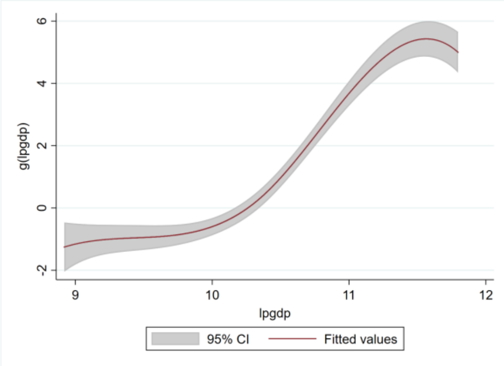

Fig. 1. The functional-coefficient of environmental regulation on urban innovation ability.