Heliyon 9 (2023) e17954

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Can financial development improve environmental quality? New findings from spatial measures of Chinese urban panel data

Ningjing Wang [a], Xiping Zhang [a], Zhen Wang [b], Yingjia Chen [c], Shilong Li [c,*]

[a] College of Mathematics and Statistics, Chongqing University, Chongqing, 400044, China
[b] College of Economics and Business Administration, Chongqing University, Chongqing, 400044, China
[c] School of Management Science and Real Estate, Chongqing University, Chongqing, 400044, China

A R T I C L E I N F O

Keywords:
Financial interrelations ratio
Financial efficiency
Environmental quality
Mediating effect
Spatial spillover effect

A B S T R A C T

China's economy has achieved remarkable success, while it has also paid a high environmental cost. Environmental pollution not only causes great economic losses, but also severely restricts the development of society. Both theory and practice demonstrate that financial development plays a significant role in environmental governance, but the internal mechanism of its impacts has remained to be explored. It is vital to investigate the influence mechanism of financial development on the environmental quality in order to accomplish sustainable economic development through finance and enhance environmental quality concurrently. This paper, using mediating model, spatial Durbin and spatial error model, constructs a theoretical framework financial development on environmental quality from two dimensions, i.e., Financial Interrelations Ratio (FIR) and Financial Efficiency (FE), based on panel data of 234 cities in China from 2010 to 2019. And the results are as follows: (1) the improvement of Financial Interrelations Ratio (FIR) and Financial Efficiency (FE) had not yet reached the level of environmental pollution improvement; (2) in terms of mechanism, the rise of the level of financial development promoted economic growth, but inhibited the optimization of industrial structure, which increased industrial pollution emissions and deteriorates environmental quality; (3) urban environment had significant spatial dependence; (4) the impact of financial development on environmental quality in eastern region has been transformed into an improvement effect, while it still shows a deteriorating effect in central and western regions. Some policy recommendations related to the use of financial development to improve environmental quality are proposed at last, which will help to promote ecological protection and high quality synergistic economic development in China.

1. Introduction

Over the past 40 years of reform and opening up, the level of financial development in most cities has continued to rise as China's economy continues to grow at a rapid pace. In particular, the large-scale reform of the financial system has driven the vigorous development of China's financial industry since the new century began. According to the preliminary statistics of the People's Bank of China, at the end of January 2023, the stock of social financing scale was 350.93 trillion yuan, an increase of 9.4% year-on-year.

However, due to the development model of China's main economic enterprises, which is mainly characterized by high energy

* Corresponding author.
E-mail address: lishilong@cqu.edu.cn (S. Li).

https://doi.org/10.1016/j.heliyon.2023.e17954
Received 16 May 2023; Received in revised form 1 July 2023; Accepted 3 July 2023
Available online 3 July 2023

consumption and high pollution, more and more environmental pollution has followed [1]. The China Environmental Status Bullet in 2021 shows that in terms of air quality, among the 339 prefecture-level and above cities in China, 121 cities have serious problems of air pollution, accounting for 35.7% of the total number of cities. Meanwhile, in terms of precipitation, 30.8% of the 465 cities that monitored precipitation experienced acid rain. At the same time, the rapid development of industrialization has led to rapid consumption of resources. According to the BP World Energy Statistics Yearbook 2022, China's energy consumption in 2021 was 157.65 J, an increase of 7.1% year-on-year, accounting for 26.5% of the total global energy consumption and ranking first in the world. The rapid consumption of natural resources and the deterioration of the ecological environment have become increasingly prominent, which restricts the sustainable development of the economy. As the most populous country and the second largest development economy in the world, China assumes an important responsibility for environmental protection [2]. In order to cope with the increasingly serious environmental pollution, Chinese government has invested a lot of manpower and material resources.

At present, China's economy development is in the stage of shifting from high growth to high quality. Since energy saving and emission reduction is one of the keys to achieving carbon peaking and carbon neutrality, the Chinese government has accordingly put forward higher requirements for enterprises' related work. On the one hand, financial development promotes the transformation of China's economic growth model, and on the other hand, it has an effect on environmental quality by technological innovation, resource supply and human capital accumulation [3]. One of the most crucial steps to achieving green, sustainable development is to use financial tools to improve the real economy and the environment. In order to support the modification of the economic development model and achieve high-quality economic growth, controlling environmental pollution and enhancing environmental quality have emerged as the primary areas of focus [4]. In light of this, the goal of this study is to investigate the mechanisms by which the level and quality of financial development affect environmental quality in Chinese cities.

Looking through the literature, it is clear that the influence mechanisms of economic growth, international commerce, and environmental regulation on environmental quality are the key areas of contemporary research [5]. Financial development was used by Xie Luoqi et al. [6] to examine the relationship between official promotion and environmental pollution. However, in addition to elements like economic expansion and international trade, the role that financial development plays in environmental deterioration is equally significant [7]. Therefore, it is necessary to examine how financial development affects environmental quality, when financial development is regarded as the core explanatory variable. Shi Yong et al. [8] used mediating effects analysis to study the mechanism of the role of financial development on carbon emissions. However, we have to consider that there is a spatial correlation between the environmental conditions of Chinese provinces and cities [9], i.e., the environmental quality of one city can be influenced by neighboring cities. Therefore, in addition to studying the direct and indirect effects of financial development on environmental quality, this study also incorporates spatial econometric models into the modeling framework. This may provide theoretical basis and new insights for the government to formulate policies to coordinate financial development and improve environmental quality.

The findings of earlier research on this topic are uneven, as may be seen. The variations in environmental quality monitoring indicators may be to blame for this [10]. Indicators including carbon dioxide emissions [11], the amount of sulfur dioxide (SO_2) in the GDP [12], and others have been utilized by researchers. Although these indicators do a good job of capturing various facets of environmental quality, it is still questionable whether they should be regarded as an all-inclusive indicator of environmental quality. The composite environmental quality index (CEQI) was created by Fakher and Murshed [13] using six environmental indicators (ecological footprint index, environmental performance, environmental sustainability, environmental vulnerability index, adjusted net savings, and natural stress). We should be aware that the sum of these six indicators can offer a thorough and all-encompassing assessment of environmental quality. However, given that China is the world's largest producer and consumer of coal and one of the nations with the highest SO_2 and soot emissions, the energy structure determines that soot-based air pollution predominates in China's industrial pollution. Industrial wastewater, SO_2, and other figures are provided by the official unified, unlike other pollutants, so their consistency and legitimacy won't be questioned. The dataset for this study is a panel of 234 Chinese prefecture-level cities from 2010 to 2019; however, taking into account the data's availability, this study develops the environmental quality index on the basis of industrial wastewater, SO_2, and smoke and dust emissions.

The contributions of this study are as follows: firstly, this study further enriches the relevant research contents of financial development theory and environmental quality assessment from the perspective of spatial measurement compared with previous research. Secondly, the study analyzes the impact of financial development on environmental quality in a more comprehensive way, taking into the actual situation in China with multiple indicators of industrial wastewater, SO_2 and smoke and dust emissions. Thirdly, by exploring the theoretical framework, this study makes sound and reasonable recommendations for the government to coordinate financial development and policy formulation for improving environmental quality, so that financial development can play a positive role in environmental quality and promote the green development of China's economy.

The rest of this paper is sectioned as follows: the review of the previous literature is introduced in section 2. In Section 3, the research methodology and data sources are explained. The analysis of the empirical results and robustness tests are included in section 4. Section 5 presents the conclusion and policy recommendations, as well as the limitations and future directions of this study.

2. Literature review

The problem of ecological degradation has adversely affected the economic development all over the world, which has made it a common goal for China and even the world to achieve new progress in ecological civilization and continuous improvement of ecological environment. The human and financial resources needed to achieve such a long-term goal are enormous, requiring considerable funding from the government and society, as well as support from the financial sector. Therefore, the relationship between financial development and ecological environment has become a key concern for many scholars.

According to a review of the prior literatures, there are comparatively many empirical publications investigating the connection between financial development and environmental quality on a national and international level, but the conclusions are not generally agreed upon. Numerous indicators have been employed to quantify environmental quality in the research literature.

According to a study of the literature, some studies estimate environmental quality using only one indicator, such as the concentration of PM2.5 (Particulate Matter) or carbon dioxide (CO_2) emissions per capita [14,15]. Single indicators, on the other hand, are frequently biased and under representative; they can only reveal a portion of the environmental quality and are unable to measure the whole environment in a more thorough manner. It is also clear that some studies use a variety of indicators to assess environmental quality from various angles, including environmental performance, environmental sustainability, environmental vulnerability index, adjusted net savings, and natural stress (6 indicators) [16]. These studies, however, only take into account how financial development affects specific environmental quality indicators and don't give a comprehensive account of how it affects environmental quality.

Researchers have looked at the relationship between financial development and environmental quality from many angles in studies that evaluate environmental quality in terms of per capita CO_2 emissions, and they have come up with various conclusions. 26 nations that use renewable energy were chosen by Dogan and Seker [17] as research subjects, and they discovered that financial development could encourage the use of renewable energy while reducing the use of non-renewable energy, hence lowering CO_2 emissions.

Researchers have looked at the relationship between financial development and environmental quality from many angles in studies that evaluate environmental quality in terms of per capita CO_2 emissions, and they have come up with various conclusions. 26 nations that use renewable energy were chosen by Dogan and Seker [17] as research subjects, and they discovered that financial development could encourage the use of renewable energy while reducing the use of non-renewable energy, hence lowering CO_2 emissions. Tasmanian et al. [18] using the panel data of the BRICs (Brazil, Russia, India, China) from 1992 to 2004, found that the higher the level of national financial development, the higher the level of national environmental quality. Baloch et al. [19] examined the data of the Organization for Economic Cooperation and Development (OECD) countries, from 1990 to 2017, and the result showed that financial development promoted energy innovation and improved environmental quality. Similar investigations by Javid et al. [20] utilizing Pakistan as the research subject and the cointegration test method discovered that economic expansion increased carbon emissions and worsened environmental quality. Similar findings were made by Salahuddin et al. [21] using Kuwaiti time series data from 1980 to 2013. According to Sadorsky [22], who examined panel data collected from 22 nations between 1990 and 2006, the growth of the financial industry boosted consumer demand for energy, which made it difficult to improve environmental quality. Based on data from emerging nations, Kumar et al. [23] came to the conclusion that financial development accelerates environmental degradation. Shahbaz et al. [24] discovered that there was an "inverted U-shaped" relationship between financial development and carbon emissions, meaning that as finance developed, carbon emissions initially rose and then fell. By using a panel threshold model in a regression study of provincial panel data, Jin Yingjun et al. [25] discovered that the link between financial efficiency and carbon emissions in China was multi-threshold and non-linear.

Among those studies of measuring environmental quality by industrial pollutant emissions, the relationship between financial development and environmental quality has the following results: based on the provincial panel data from 1998 to 2014, Wang Feng and Liu Huijuan [26] concluded that there was a mutually reinforcing and strengthening relationship between financial development and environmental quality by studying the relationship between the ratio of financial institutions' deposit and loan balance (FD) to GDP and per capita industrial waste gas emissions. He Xiangmin and Lai Yongjian [27] used the system generalized method of moments estimation, and found that loan and deposit ratios of financial institutions significantly promoted SO_2 emissions in cities, while financial agglomeration suppressed SO_2 emissions. Cai Mengmeng et al. [28] found that the increase of the financial development level effectively reduced the level of pollution emissions and improved environmental quality by promoting industrial upgrading and technological progress in China. Ibrahim and VO [29] found that financial development increased environmental pollution, and innovation inhibited the promotion of financial development to environmental pollution through a study of 27 industrialized countries.

In studies that measure environmental quality with multiple indicators, the results obtained are more diverse and fine-grained. Yin et al. [30] used Chinese urban panel data from 2007 to 2014 to measure environmental quality, and took SO_2 emissions accounted for secondary industry output as an air quality index and industrial wastewater emissions accounted for secondary industry output as an urban water pollution index for cities. And the research found that in areas with developed finance, financial development can improve water quality and reduced SO_2 emissions, thereby improving environmental quality., whereas in areas with underdeveloped finance, the impact of financial development on environmental quality was not significant. Hu Zongyi and Li Yi [31] developed a local equilibrium model theory based on the panel data analysis of 30 provinces in China from 1995 to 2016 to analyze the impact of financial development on environmental pollution. The combined environmental pollution index (PI) was calculated by wastewater, SO_2, and smoke emissions, and it was concluded that there was a threshold characteristic between financial development and environmental pollution, i.e., when the level of financial development reached a certain point. By studying the effects of financial scale and financial efficiency on water pollution and air pollution, Fakher et al. [16] used the two-stage system Gaussian Mixture Model (GMM) estimation technique with six environmental indicators namely ecological footprint index (EF), environmental performance (EPI), environmental sustainability (ESI), environmental vulnerability index (EVI), adjusted net saving (ANS) and pressure on nature (PN) to determine the correlation between economic growth, energy consumption, financial development, environmental indicators and trade openness of Organization of the Petroleum Exporting Countries (OPEC) from 2010 to 2019. And it was concluded in their research that financial development was an important and key variable to improve environmental quality, and it played a regulatory role in the negative impact on environmental quality.

In summary, financial development is closely related to environmental pollution, but it is still uncertain whether financial development aggravates or alleviates environmental pollution. Through the above researches, we can assume that the reason may lie in the different selection of the research objects, indicators and models. Economies differ from one period to another and have different emphasis on measuring environmental quality. Therefore, it is important to select the right indicators.

In order to better explore the impact and mechanism of financial development on environmental quality, this study will be conducted based on data of 234 prefecture-level cities in China from 2010 to 2019 and refined from four aspects:

(1) Constructing two benchmark regression models with Financial Interrelations Ratio (FIR) and Financial Efficiency (FE) as the core explanatory variables to preliminarily test the relationship between financial development and urban environmental pollution.
(2) Taking economic growth and industrial structure as intermediary variables to explore their mediating effect.
(3) Selecting spatial Durbin and spatial error models to further explore the relationship between financial development and urban environmental pollution, in order to avoid conclusion bias caused by the spatiotemporal nature of the data.
(4) Dividing the dataset into three aspects (eastern, central and western) to estimate by region, in order to provide empirical evidence at the prefecture level.

3. Research model and data

Since the acronyms of variable names are frequently mentioned in later parts of this paper, a list of acronyms is provided in Table 1:

3.1. Model setting

In order to study the overall effect of financial development on environmental quality, and to preliminarily judge the relationship between them, this paper constructs a fixed effects model with reference to the practice of Deng Rongrong and Zhang Aoxiang [32]. The model is shown in Equation (1):

$$Y_{it} = \alpha_0 + \alpha_1 X_{it} + \alpha_2 C_{it} + v_t + \mu_{it} \tag{1}$$

where i and t stands for cities and time, Y is the dependent variable, namely the comprehensive index of environmental quality (env); X is a vector of explanatory variables, namely, Financial Interrelations Ratio (FIR) and Financial Efficiency (FE); C is a vector of the control variables, i.e., population density (lnP) and Foreign Direct Investment (FDI); μ_{it} and v_t indicate error term and the time effect, respectively.

Financial development may have an indirect impact on environmental pollution through an intermediary mechanism. That is, the environmental quality may be affected by the change of regional industrial structure and economic growth. According to He Jun et al. [33], the following mediating effect model is constructed in Equation (2) and in Equation (3):

$$M_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 C_{it} + v_t + \mu_{it} \tag{2}$$

$$env_{it} = \gamma_0 + \gamma_1 X_{it} + \gamma_2 M_{it} + \gamma_3 C_{it} + v_t + \mu_{it} \tag{3}$$

where M stands for the intermediary variables, which are per capita GDP (lnGDP), industrial structure (stru), and other variables are the same as in Equation (1). The product of β_1 and γ_2 represents the mediating effect.

Many scholars (Lv Youjin and Gao Bo et al. [9]) believe that there is a spatial correlation between the environmental conditions of various provinces and cities in China. That is, besides local financial development, the environmental quality of each prefecture-level city may be related to the environmental quality of the neighboring cities. Accordingly, to discuss the spatial spillover effect of financial development on environmental quality, the spatial Durbin and spatial error model are constructed. Taking the Financial Interrelations Ratio (FIR) as an example, the spatial Durbin model can be shown as follows:

$$Y_{it} = \eta_0 + \rho W Y_{it-1} + \eta_1 WFIR_{it} + \eta_2 WC_{it} + \eta_3 X_{it} + \eta_4 C_{it} + v_t + \varepsilon_{it} \tag{4}$$

where ρ stands for the spatial autocorrelation coefficient, while W stands for the spatial weight matrix. η_1 and η_2 are the coefficients of the spatial interaction term of the core explanatory variable and the control variable, respectively. And the other variables are the same as in Equation (1). Equation (4) examines the spatial spillover effects of the explanatory and explained variables.

Taking Financial Efficiency (FE) as an example, the spatial error model can be shown in Equation (5):

Table 1
The acronyms table.

Acronym	Full name
env	Environmental quality index
FIR	Financial Interrelations Ratio
FE	Financial Efficiency
FDI	Foreign Direct Investment
lnP	Natural logarithm of population density
lnGDP	Natural logarithm of GDP
stru	Industrial structure

$$Y_{it} = \varphi_0 + \varphi_1 FIR_{it} + \varphi_2 C_{it} + \varepsilon_{it} \tag{5}$$

where $\varepsilon_{it} = \lambda \times W + \mu_{it}$, λ denotes the spatial error coefficient, which is used to measure the spatial dependence of the sample, i.e., the influence from the environment of neighboring cities on the environmental quality, as well as its degree and direction. μ_{it} stands for the random error vector that obeys the normal distribution.

The modeling steps of this study are shown in Fig. 1:

3.2. Variable definition

This paper studies the impact of financial development on environmental pollution. Considering the availability of data related to financial development and environmental quality, as well as the fact that environmental quality can be affected by other factors, the following variables are introduced in this paper:

(1) **Dependent variable.** In related researches on environmental pollution, the "three industrial wastes", i.e., industrial wastewater, sulfur dioxide (SO_2), and smoke and dust, are common indicators to measure the status of environmental pollution. Taking into account the availability of data, this paper constructs the environmental quality index (env) based on the emissions of industrial wastewater, SO_2 and smoke and dust, with reference to the research method of Hu Zongyi and Li Yi [31]. The larger the value, the worse the environmental quality. Specifically, it is shown in Equation (6) and Equation (7):

$$env_{ij} = \frac{(pv_{i1} + pv_{i2} + pv_{i3})}{3} \tag{6}$$

$$pv_{ij} = \frac{p_{ij}}{\sum_{i=1}^{n} \frac{p_{ij}}{n}}, i = 1, 2, 3...... \tag{7}$$

where p_{ij} denotes the emissions of pollutant j ($j = 1, 2, 3......$) in region i ($i = 1, 2, 3, ...$), and pv_{ij} denotes the corresponding environmental pollution index relative to the average level of all regions.

(2) **Core explanatory variables.** Financial development is a state of the alteration of the financial structure, the expansion of financial aggregate, and the continual enhancement of the efficiency of the financial system. Generally speaking, the indicators used to measure the level of financial development can be divided into two aspects: financial deepening and financial efficiency. The former focuses on the scale of financial resources, while the latter focuses on the effectiveness of the allocation of financial resources. In order to effectively describe the state of regional financial development, this paper, referring to the practice of Xu Xin et al. [34], adopts the proportion of total deposits and loans to GDP to represent the Financial Interrelations Ratio (FIR), which is also the most widely used indicator to measure the scale of the financial superstructure. Financial efficiency (FE), expressed by dividing loans by deposits, is used to measure the quality of financial development.

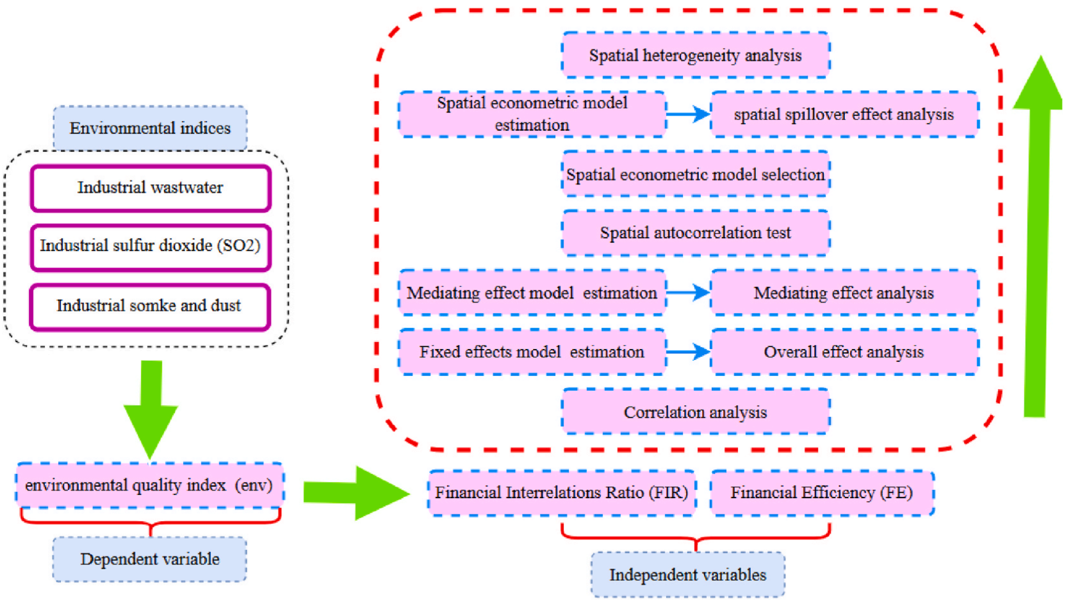

Fig. 1. The modeling steps of this study.

(3) **Control variables.** To avoid the influence of missing variables, this paper sets the following control variables that may affect environmental pollution: (i) Foreign Direct Investment (FDI), which is obtained by converting the actual foreign capital into RMB according to the average exchange rate of the year. (ii) Population density (lnP), which is represented by the logarithm of population per unit area.

(4) **Mediating variables.** To explore the internal mechanism of the impact of financial development on environmental quality, this paper sets the following mediating variables: (i) Economic growth, which is expressed by the logarithm of real per capita regional GDP. (ii) Industrial structure (stru). Considering that the "three industrial wastes" is applied as indicators for the dependent variable, industrial structure is measured by the proportion of the added value of the secondary industry to GDP [35].

3.3. Data source and description

In the selection of sample provinces, Tibet was excluded due to the obvious differences and fluctuations of its data [34]. In addition, as data in some cities in Xinjiang are seriously missing, it is also excluded. Therefore, the final sample data are panel data from 234 cities in 29 provinces (excluding Hong Kong, Macao, and Taiwan) during 2010–2019, and partial missing data is completed with the linear interpolation method. The data are mainly derived from *China Urban Statistical Yearbook, China Financial Statistical Yearbook, China Environmental Yearbook, China Labor Statistical Yearbook*, as well as the statistical yearbooks and websites of relevant provinces and cities. In order to reduce the impact of outliers, all variables are processed with 1% tail reduction [36]. The overall descriptive statistical analysis of the data is shown in Table 2:

3.4. Correlation analysis

In order to test the degree of linear relationship between each explanatory variable, Stata17.0 is used to calculate the Pearson coefficient of all variables, and the correlation coefficient matrix is obtained. As can be seen from Table 3, the correlation coefficients are all less than 0.4, indicating that the correlation between the variables is not strong, and there is no multicollinearity.

4. Empirical r\Results a\Analysis

4.1. Analysis of the benchmark regression results

Based on results of the Hausman test, fixed effects model is used in this paper. The model regression results are shown in Table 4:

In Table 3, Model 1 and Model 3 are the regression results without control variables while Model 2 and 4 are the regression results with control variables. It can be seen that the inclusion of control variables does not change the coefficient symbols of the two indicators of financial development, indicating that the result of the benchmark regression is highly explanatory. The results also show that the two different dimensions of financial variables have negative impacts on environmental quality. As it has been defined above, a larger environmental quality index (env) indicates a worse environmental quality. Besides, the coefficients of Financial Interrelations Ratio (FIR) and Financial Efficiency (FE) are significantly positive, which demonstrates that the expansion of financial development scale and the improvement of financial development efficiency can lead to an increase of pollutants, i.e., the deterioration of environmental quality. This indicates that, in general, the development of financial scale and financial quality promotes industrial development, brings economic growth, and expands household consumption, thus aggravating environmental pollution.

Specifically, the increase in population density (lnP) would increase urbanization and further increase environmental pollutant emissions [37]. Foreign Direct Investment (FDI) has a significantly negative impact on the improvement of environmental quality, due to the fact that China once lowered its environmental governance standards to attract foreign investment and it increased the production of pollution-intensive products, which aggravated environmental pollution. This is consistent with the findings of List and CO [38]. On the whole, financial development and environmental pollution are positively correlated.

4.2. Analysis of mediating effects

In order to further study the mechanism of the above impact of financial development on environmental pollution, lnGDP and FDI are used in this paper as mediating variables for empirical test, and the results are shown in Tables 5 and 6:

Table 2
Descriptive statistics of major variables.

Variable	N	Mean	SD	Min	Max
env	2340	0.989	0.734	0.0690	4.368
FIR	2340	2.646	2.256	0.214	16.14
FE	2340	1.533	2.117	0.172	9.552
lnGDP	2340	10.70	0.558	9.432	12.01
lnP	2340	5.855	0.899	3.185	8.007
FDI	2340	0.0180	0.0180	0	0.0880
stru	2340	0.458	0.134	0	0.757

Table 3
Correlation coefficients of variables.

	env	FIR	FE	lnGDP	lnP	FDI	stru
env	1						
FIR	0.0880	1					
FE	0.197	0.0290	1				
lnGDP	0.282	0.121	0.245	1			
lnP	0.189	0.0802	0.142	0.377	1		
FDI	0.214	0.0941	0.244	0.223	0.266	1	
stru	0.227	−0.297	0.0346	0.0951	0.155	0.266	1

Table 4
Fixed effects model results.

VARIABLES	Model 1	Model 2	Model 3	Model 4
	env	env	env	env
FIR	0.0348***	0.0242***		
	(5.17)	(3.61)		
FE			0.0274***	0.0146**
			(3.67)	(1.96)
lnP		0.0922***		0.1000***
		(5.38)		(5.88)
FDI		5.804***		5.703***
		(6.65)		(6.45)
Constant	0.910***	0.275**	0.980***	0.283***
	(17.96)	(2.56)	(20.34)	(2.63)
Observations	2340	2340	2340	2340
Adjusted R-squared	0.007	0.045	0.002	0.041
F	2.749	10.13	1.425	9.328

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

In Table 5, with lnGDP as the explained variable in Model 5 and Model 7, the regression coefficient of FIR is significantly positive, indicating that FIR development improves economic growth. In terms of financial efficiency (FE), its regression coefficient is significantly negative. This is because the capital allocation efficiency of financial development to the growth of real economy has not been fully revealed due to the non-standard system and market, which seriously restricts the positive effect of financial development on economic growth [39]. The environmental quality index (env) is used as the explained variable in Model 6 and Model 8. FIR and lnGDP are added to the Model 6 and the regression coefficient of FIR (0.0129) is obtained, which is 47% lower than the estimated coefficient (0.0242) obtained from the benchmark regression Model 2. FE and lnGDP are added to Model 8 and the regression coefficient of FE (0.0294) is obtained, which is 50% higher than the estimated coefficient (0.0146) obtained from Model 4.

In Table 6, with stru as the explained variable in Model 10 and Model 12, the FIR regression coefficient is negative, indicating that the development of FIR inhibits the development of stru. This is because FIR and FE have a first facilitating and then inhibiting effect on industrial structure, i.e., an inverted U-shaped relationship between them [40]. In Model 11 and Model 13, env is used as the explained

Table 5
Analysis of mediating effects of lnGDP.

VARIABLES	Model 5	Model 6	Model 7	Model 8
	lnGDP	env	lnGDP	env
FIR	0.0314***	0.0129*		
	(7.23)	(1.96)		
FE			−0.0380***	0.0294***
			(−7.92)	(4.02)
lnGDP		0.359***		0.389***
		(11.53)		(12.48)
lnP	0.179***	0.0277	0.196***	0.0237
	(16.16)	(1.57)	(17.91)	(1.35)
FDI	5.445***	3.847***	6.420***	3.207***
	(9.64)	(4.44)	(11.26)	(3.65)
Constant	9.040***	−2.974***	9.023***	−3.225***
	(130.30)	(−9.90)	(130.28)	(−10.76)
Observations	2340	2340	2340	2340
Adjusted R-squared	0.307	0.096	0.310	0.101
F	87.21	20.11	88.45	21.17

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

Table 6
Analysis of mediating effects of stru.

VARIABLES	Model 10	Model 11	Model 12	Model 13
	stru	env	stru	env
FIR	−0.0160***	0.0400***		
	(−14.23)	(5.80)		
FE			0.00717***	0.00908
			(5.57)	(1.22)
stru		0.989***		0.772***
		(8.09)		(6.49)
lnP	0.0140***	0.0784***	0.00688**	0.0947***
	(4.88)	(4.61)	(2.34)	(5.61)
FDI	1.601***	4.221***	1.342***	4.668***
	(10.97)	(4.78)	(8.77)	(5.24)
Constant	0.418***	−0.139	0.421***	−0.0420
	(23.33)	(−1.18)	(22.65)	(−0.36)
Observations	2340	2340	2340	2340
Adjusted R-squared	0.201	0.070	0.143	0.058
F	50.04	14.64	33.49	12.01

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

variable, and the inclusion of both FIR and stru in Model 11 yields the regression coefficient of FIR (0.04), which was 40% higher than the estimated value of the coefficient obtained from the benchmark regression Model 2 (0.0242). The regression coefficient obtained by adding both FE and stru in Model 13 is not significant, indicating that apart from the direct effect, there is no significant mediating effect. Therefore, this paper concludes that industrial structure is the intermediary variable in the deterioration of environmental pollution.

Industrial structure is the "control entity" of resource consumption and pollutant discharge. With its continuous development and growth, the financial industry will squeeze the profit space of the real economy by virtue of its power of discourse, which is obviously not conducive to the optimization of industrial structure [40]. Meanwhile, the improvement of the quality of financial development, by reducing risks and investment costs, enhances the convenience of enterprise financing. As a result, the proportion of the secondary industry in the national economy increases to 45% and the scale of polluting enterprises expands, thereby exacerbating environmental pollution.

Even though the overall industrial structure in China is currently being adjusted in a reasonable direction, the response of environmental pollution to industrial structure adjustment has a certain lag. In addition, there are significant regional differences in the impact of financial development on industrial structure upgrading, for example, the excessive expansion of financial scale in eastern China has inhibited the optimization of industrial structure to some extent [41], resulting in environmental deterioration.

The results of the baseline regression and mediated effects models are summarized in Fig. 2:

4.3. Analysis of spatial spillover effects

(1) Spatial autocorrelation test

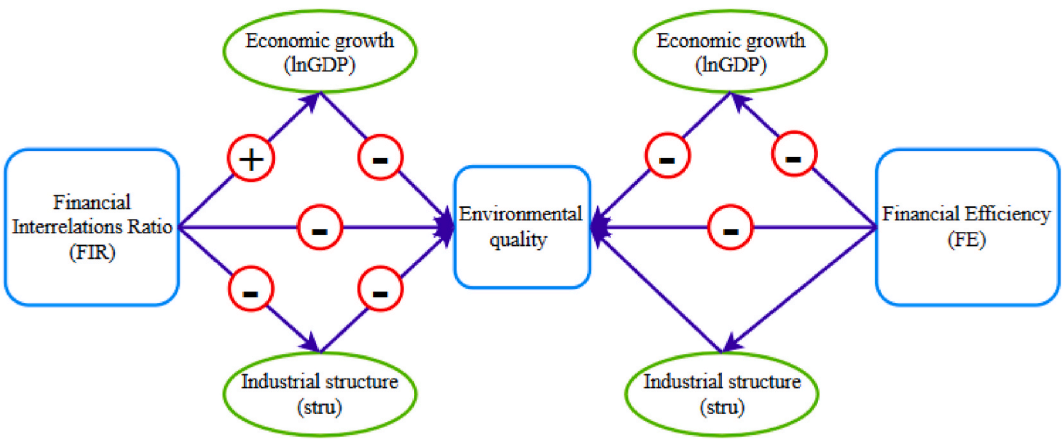

Fig. 2. The results of baseline regression and mediating effects models. Notes: there is no significant mediating effect between financial efficiency and environmental quality with respect to industrial structure.

Before conducting a spatial econometric analysis, it is necessary to test for spatial autocorrelation between env of each prefectural-level city and its influencing factors. Since some data are missing, the adoption of the adjacency matrix may lead to these cities becoming "isolated island" [32]. Therefore, this paper calculates the Moran's I index of each year based on the inverse distance matrix. It can be seen from Table 7 that the Moran's I value of env in the ten years are all positive and have passed the significance test, indicating that the environmental quality among prefectural-level cities has a significant positive spatial correlation.

(2) Selection of S\spatial E\econometric model

As can be seen from Table 8, the LM test for the spatial error model of the FE is significant at the 1% confidence level, while the spatial lag model fails the test. Both the spatial error model and the spatial lag model of FIR pass the LM test, so the spatial Durbin model can be introduced and the corresponding coefficients are tested by LR test. The LR statistics are 44.11 and 29.22, respectively, rejecting the original hypothesis of degenerating into a spatial error model and a spatial lag model. Therefore, the spatial Durbin model can better reflect the relationship between env and FIR among Chinese cities. And after Hausman test, the fixed effects model is chosen in this paper.

(3) Estimation results and discussion of the spatial econometric model

The regression results of the spatial econometric model are shown in Table 9. Firstly, the estimated values of the spatial lag regression coefficient ρ and the spatial error coefficient λ are significantly positive, indicating that there is a significant spatial dependence of the urban environmental quality, i.e., the environmental quality of one city can be negatively affected by neighboring cities. In other words, the environmental quality is characterized by clustering. Secondly, according to the AIC information criterion and the pseudo-likelihood estimation value, it is concluded that FIR and FE fit well with time fixed effects model, and the spatial effect of each financial development index is very significant. Thirdly, in the spatial Durbin model (SDM), the spatial autoregressive coefficient of FIR (WFIR) is significantly positive, indicating that the development of financial scale of neighboring cities plays a significant role in deteriorating urban environmental quality, that is, the more developed the financial scale of the neighboring cities, the closer the connection between the city and the financial scale of neighboring cities. So, the inter-city population flow and industrial structure adjustment are generated. However, analyzing spatial spillover effects between regions simply through point regression results may result in erroneous estimates. Therefore, this paper applies a partial differential method to decompose the spatial spillover effects of Financial Interrelations Ratio on environmental quality in detail. It can be seen that the direct and indirect effects of the FIR on the environmental quality of all cities are positive and significant at the 5% level, indicating that there is a positive spatial spillover effect of FIR on environmental pollution. Fourthly, in the spatial error model (SEM), the regression coefficient of FE is positive, indicating that the improvement of the quality of financial development deteriorates environmental quality, which is consistent with the previous discussion.

The results of the spatial econometric models are summarized in Fig. 3:

4.4. *Spatial heterogeneity analysis*

Through spatial heterogeneity analysis, Zhu Dongbo and Ren Li et al. [42] found that financial development in the eastern regions of China led to an increase of carbon emissions, while financial development in the central and western regions was conducive to the reduction of carbon emissions. This finding reveals the existence of differences in environmental quality and financial development level among Chinese different regions in China. Due to such differences, in order to analyze the impact of financial development in different regions on environmental pollution, cities are divided into three parts: eastern, central, and western, for sample discussion, with the reference to Lei Hanyun et al. [43]. The eastern part includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan; the central region includes Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan; and the western region includes Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Guangxi. Table 10 presents the estimation results for the three major regions.

First of all, the predicted values of the spatial lag regression coefficient and the spatial error coefficient are both considerably positive, indicating a significant geographical dependence of urban environmental quality that is consistent with prior findings. Second, the FIR and Financial FE regression coefficients are significantly negative in the eastern region, indicating that there is a reduction in environmental pollution in the region as scale and quality of financial development increases. The relationship between changes in financial development and environmental quality has an inverted U shape, which could be the cause [44]. The influence of financial development on environmental quality in the eastern areas has reached a tipping point where it is improving rather than

Table 7
Moran's I value of the Composite Index of Urban Environmental Quality (2010–2019).

2010	2011	2012	2012	2014
0.039*** (5.539)	0.038*** (5.354)	0.043*** (6.073)	0.039*** (5.612)	0.045*** (6.246)
2015	2016	2017	2018	2019
0.014*** (2.613)	0.033*** (4.733)	0.023*** (3.400)	0.017*** (2.708)	0.011** (1.909)

Notes: z statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8
LM test results.

test method	FIR	FE
LM test no spatial error	834.639***	842.314***
Robust LM test no spatial error	594.129***	603.790***
LM test no spatial lag	243.510***	240.995***
Robust LM test no spatial lag	3.000*	2.47

Notes: z statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 9
Spatial econometric model results.

VARIABLES	SDM Model (FIR)			SEM Model (FE)		
	Model 13	Model 14	Model 15	Model 16	Model 17	Model 18
	Time Fixed	Individual Fixed	Double Fixed	Time Fixed	Individual Fixed	Double Fixed
lnP	0.185***	−0.128***	−0.131***	0.128***	−0.0975	−0.0928
	(17.12)	(−2.65)	(−2.88)	(12.36)	(−1.47)	(−1.45)
FDI	6.626***	−1.386***	−1.320***	6.062***	−1.584***	−1.585***
	(14.87)	(−3.05)	(−2.89)	(12.29)	(−3.96)	(−3.78)
FIR	0.0149***	−0.0102	−0.00737			
	(2.95)	(−1.08)	(−0.81)			
FE				0.0147*	−0.00672	−0.00697
				(1.69)	(−1.29)	(−1.25)
ρ	0.764***	0.578***	0.527***			
	(21.90)	(10.86)	(7.19)			
λ				0.802***	0.584***	0.567***
				(27.16)	(10.14)	(7.70)
WFIR	0.0444***	−0.0862***	−0.145**			
	(−2.58)	(−2.86)	(−2.32)			
WlnP	−0.630***	0.245	0.596			
	(−16.26)	(0.55)	(0.67)			
WFDI	−12.68**	−5.661*	−8.949**			
	(−2.28)	(−1.78)	(−2.41)			
Direct Effect	0.0164***	−0.0109	−0.00841			
	(3.04)	(−1.10)	(−0.88)			
Indirect Effects	0.254**	−0.226**	−0.320***			
	(2.15)	(−2.41)	(−2.63)			
Total Effect	0.270**	−0.236**	−0.329***			
	(2.25)	(−2.37)	(−2.62)			
R-squared	0.056	0.045	0.043	0.045	0.038	0.038
Log-likelihood	−2485.0358	−530.7211	−528.3519	−2502.97	−533.6634	−533.2066
AIC	4986.072	1077.442	1072.704	5015.94	1077.327	1076.413

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

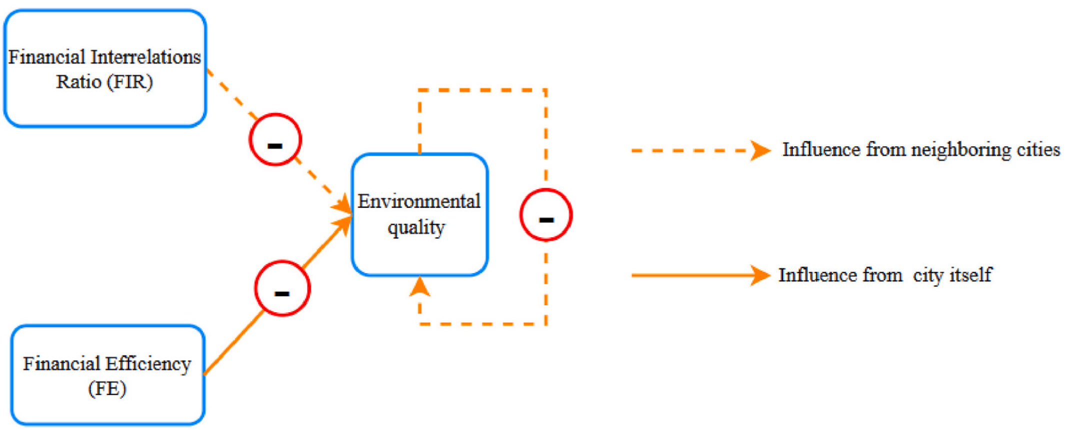

Fig. 3. The results of spatial econometric models.

Table 10
Spatial econometric model results of sub-sample cities in east, central and west.

VARIABLES	Eastern Region (SEM)		Central Region (SDM)		Western Region (SDM)	
	Model 19	Model 20	Model 21	Model 22	Model 23	Model 24
	env	env	env	env	env	env
lnP	−0.187	−0.00506	0.0554***	0.0854***	0.193***	0.174***
	(−1.31)	(−0.03)	(3.80)	(3.45)	(4.31)	(4.26)
FDI	−1.211**	−0.999*	6.701***	7.272***	30.51***	29.02***
	(−2.49)	(−1.96)	(7.31)	(9.09)	(5.31)	(5.09)
FIR	−0.0437***		0.0974***		0.0544*	
	(−3.69)		(3.73)		(1.91)	
FE		−0.232***		0.0158**		0.755***
		(−3.71)		(2.22)		(9.25)
ρ			0.738***	0.716***	−0.261***	−0.382***
			(41.29)	(32.29)	(−3.44)	(−4.26)
λ	0.159*	0.185**				
	(1.77)	(2.22)				
WFIR			−0.346***		0.215*	
			(−7.60)		(1.95)	
WFE				0.113**		2.797***
				(2.14)		(3.92)
WlnP			−0.198**	−0.477***	−0.0627	0.518***
			(−2.43)	(−2.77)	(−0.24)	(3.45)
WFDI			−7.589*	−3.958	−41.92***	−41.12***
			(−1.69)	(−0.58)	(−3.30)	(−6.55)
Direct Effect			0.0863***	0.0208**	0.0531*	0.715***
			(3.19)	(2.55)	(1.79)	(7.41)
Indirect Effect			−1.039***	0.416**	0.162*	1.832***
			(−6.10)	(2.54)	(1.75)	(3.69)
Total Effect			−0.953***	0.437***	0.216**	2.547***
			(−5.44)	(2.60)	(2.55)	(6.21)
R-squared	0.037	0.027	0.038	0.003	0.195	0.199
Log-likelihood	−180.8494	−182.0266	−839.5008	−845.2972	−710.9636	−705.0165
AIC	371.6987	374.0532	1695.002	1706.594	1437.927	1426.033

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

degrading, indicating that environmental quality can improve as a result of financial development in the eastern regions. But the inflection point has not yet been achieved in the central and western regions, where financial growth continues to worsen the state of the environment. The elasticity coefficient of spatial spillovers is much higher in the western regions than the central regions, as indicated by the regression coefficients of FE (WFE) in the central and western regions. Accordingly, the quality of environmental development in nearby cities is likely to have a major impact on the environmental quality in less developed western regions.

The results obtained after regression by sub-region are summarized in Fig. 4:

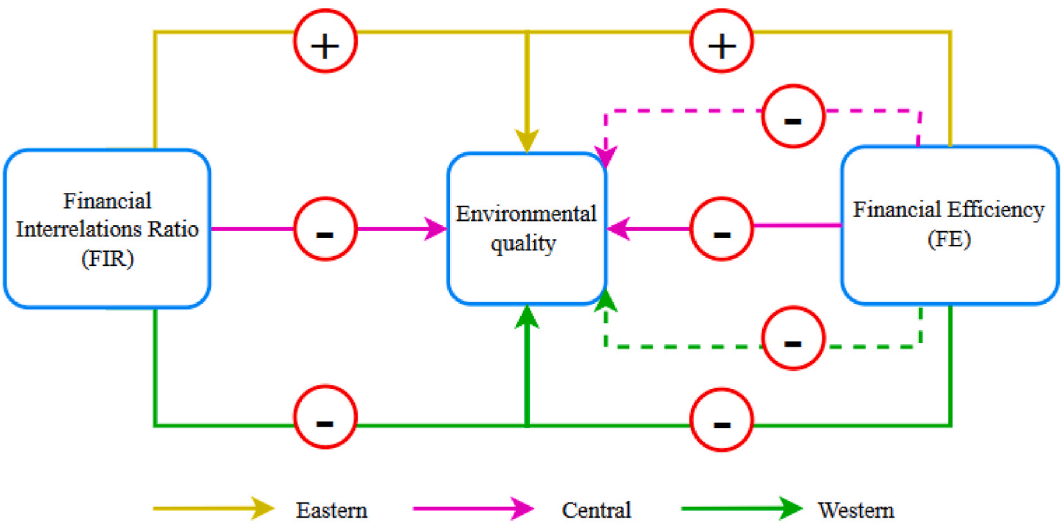

Fig. 4. The results of spatial heterogeneity analysis. Notes: The dotted lines represent the influence from neighboring cities, while the solid line represent the influence from neighboring city itself.

4.5. Robustness test

To ensure that the impact of financial development on environmental pollution is not disturbed by the control variables, population density (lnP) and Foreign Direct Investment (FDI) in the model are removed, and the spatial Durbin and spatial error models are reconstructed. Results are shown in Table 11, from which it can be seen that the spatial effect of financial development on environmental pollution is basically consistent with the findings obtained from the original model, and the variable parameters and spatial autocorrelation coefficients (i.e., spatial lag regression coefficient ρ and spatial error coefficient λ) are approximately the same. Therefore, the model passes the robustness test.

On the basis of regional correlation, some studies have conducted relevant research by using financial concentration (FC) as a proxy variable of financial development quality [45]. Referring to these studies, FC is adopted as a proxy variable for the core explanatory variables in this paper to verify the robustness of the empirical results. The regression results of the fixed effects model for the core explanatory variables are shown in Table 12, from which it can be seen that the regression coefficients of the core explanatory variables are still significantly positive after replacing them with FC, and the regression coefficients of the control variables are roughly the same as the benchmark regression results, indicating that the empirical results of this paper are robust.

In the above fixed effects regression, the explained variable env is a composite index obtained after determining the weights of industrial SO_2, wastewater and smoke and dust emissions through the entropy method, so there are certain differences. The variable substitution method is used in this paper to make the empirical regression again. Replacing the explanatory variable env with the log value of industrial sulfur dioxide emissions (lnSO2), the empirical results are shown in Table 13, where it can be seen that each variable is significant at the 1% significance level. Here, the influence direction of FIR has changed compared with the above regression, which may be due to the inverted U-shaped influence relationship proposed by previous researchers, and the change of FIR has a bidirectional influence on industrial SO_2 emissions. At this time, FIR has reached a certain critical value, which brings benign effects to environmental pollution. Therefore, to sum up, the replacement of environmental pollution index passed the robustness test.

5. Conclusions and policy implications

Because low-level financial development would worsen environmental quality while high-level financial development could improve it, and because Chinese governments hope to achieve a green and low-carbon production mode through the industrial structure reform, the research findings will support the creation and implementation of pertinent policies in the area of financial development.

5.1. Conclusions

Based on the panel data of 234 cities in China from 2010 to 2019, this study calculates the weights of the “three industrial wastes” data in each city with the entropy method. In this paper, the environmental quality index is constructed and fixed effects model, mediating effect model, spatial Durbin and spatial error model are constructed to empirically analyze the impact and mechanism of financial development on environmental quality. The main conclusions are as follows:

First, on the whole, the expansion of the scale of financial development and the improvement of the quality of financial development play a role in promoting the emission of pollutants, i.e., deteriorating the environmental quality. The conclusion is still valid after the robustness test by using the method of replacing core explanatory variables, which is similar to the research results of Zhang [46].

Second, Financial Interrelations Ratio (FIR) inhibits the industrial structure, and Financial Efficiency (FE) promotes the industrial structure, which is consistent with the research of Li Wen et al. [40], in which industrial structure is a mediating variable for the development of financial efficiency to deteriorate environmental quality. Furthermore, FIR has a positive spatial spillover effect on environmental pollution.

Third, in terms of regional heterogeneity, due to the inverted U-shaped relationship between financial development changes and environmental quality [44], the impact of financial development on environmental quality in the eastern region has been transformed into an improvement effect, while it has not yet reached the inflection point in the central and western regions and still shows a deteriorating effect. Furthermore, the environmental quality in the less developed areas in the west is significantly affected by the Financial Efficiency of neighboring cities.

Along with the results, the current study has certain limitations in terms of opening up new areas for investigation. The model is deficient in research on technical innovation and indicators connected to green finance due to the availability of data and the model's emphasis and scope. It is rational to suppose that financial growth influences technical innovation, which in turn influences environmental quality. In the meantime, the financial sector's green finance sector is a significant one in terms of environmental governance. As a result, it is advised that future research investigate include the intermediary variable of technological innovation in time series and panel data design in order to further explore the relationship between green money and environmental quality. Additionally, the model's environmental quality index, which incorporates data from three different aspects (gas, liquid, and solid), is skewed toward industrial data. Therefore, future research should also think about how to gauge changes in environmental quality brought on by other factors.

Table 11
Model results with control variables removed.

VARIABLES	SDM Model (FIR)	SEM Model (FE)
	Model 25	Model 26
	env	env
FIR	0.0349***	
	(6.63)	
FE		0.0233**
		(2.37)
ρ	0.583***	
	(11.30)	
λ		0.580***
		(5.75)
WFIR	−0.0389*	
	(−1.92)	
Direct Effect	0.0349***	
	(6.66)	
Indirect Effect	−0.0468	
	(−1.07)	
Total Effect	−0.0119	
	(−0.30)	
R-squared	0.007	0.002
Log-likelihood	−3057.514	−3063.392
AIC	6123.027	6132.784

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

Table 12
Model results for replacing core explanatory variables.

VARIABLES	Model 27	Model 28	Model 29
	Time Fixed	Individual Fixed	Double Fixed
FC	0.0144**	0.00665	0.00665
	(2.37)	(1.35)	(1.35)
lnP	0.115***	−0.0878	−0.0878
	(6.43)	(−0.71)	(−0.71)
FDI	5.674***	−1.820***	−1.820***
	(6.43)	(−2.58)	(−2.58)
Constant	0.137	1.629**	1.629**
	(1.12)	(2.02)	(2.02)
Observations	2340	2340	2340
Adjusted R-squared	0.047	0.826	0.826
F	9.483	42.39	42.39

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

Table 13
Model results for replacing explanatory variables.

VARIABLES	Model 30	Model 31
	lnSO2	lnSO2
FIR	−0.0259**	
	(−2.16)	
FE		0.0559***
		(4.18)
lnP	0.350***	0.335***
	(11.20)	(10.86)
FDI	17.87***	16.49***
	(11.36)	(10.37)
Constant	7.733***	7.754***
	(39.66)	(39.86)
Observations	2340	2340
Adjusted R-squared	0.272	0.276
F	71.03	72.50

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

5.2. Policy recommendations

On the basis of the aforementioned findings, this study provides policy recommendations for improving environmental quality and encouraging high-quality financial development.

(1) Give full play to the positive role of finance

Since high-level financial development can effectively curb environmental pollution, relevant government departments should strengthen macro-management, correctly examine financial positioning, and promote the development of the financial industry. In order to give full play to the positive role of finance in environmental governance, the following measures can be taken. First, bank credit should be tilted toward green and low-carbon enterprises, especially encouraging and supporting the development of resource-saving and environment-friendly enterprises, and accelerating the green transformation and upgrading of industries through financial development. Second, the government should improve relevant legal measures and gradually promote the development of green bonds, green insurance, green credit, etc., as well as explore its financial development mode according to local conditions and focusing on the development of green finance. At the same time, the government should fully utilize the technological progress effect of financial development to improve the efficiency and quality of financial services to the real economy and promote environmental governance.

(2) Improve the financial regulatory system

Improving environmental quality through financial development inevitably involves risks. Therefore, in developing green financial derivatives, the government should establish a sound financial regulatory system and strengthen information disclosure and risk alert. It should also bring about the remarkable advantages of financial technology to comprehensively improve risk control and promote the healthy and steady development of finance, so that it can better serve green development.

(3) Promote the optimization of industrial structure

Currently, the industrial structure in China is not reasonable enough, which to a certain extent deteriorates the environmental quality; and meanwhile, the extensive economic growth mode of industrial development increases the emission of pollutants. Therefore, it is necessary to promote the optimization of the internal structure of the secondary industry by shifting industrial development from enterprises relying on industrial wastewater and industrial dust pollution to high-yield and low-emission economies. The government should actively guide enterprises to change to the green development direction of resource-saving, sustainable and environment-friendly development. Such as accelerating the cultivation of strategic emerging industries, relying on the advanced technology and concept of emerging industries to drive the transformation and upgrading of traditional industries. Optimizing industrial structure will contribute to the coordination and unification of the financial development and environmental governance of domestic enterprises.

(4) Coordinate population density and economic level

Considering the current level of financial development in China, the population density should be reasonably controlled so as to match it with the level of economic development. In this way, the development of finance can promote the improvement of environmental quality. In the formulation and implementation of policies, it should be noted that there are certain differences in the levels of economic development in each city. Therefore, local governments should take into account local development levels and take measures such as introducing talents and granting subsidies to encourage fertility, so as to further realize the coordination and unification of population density and economic level. At the same time, in cities with developed economy and high population density, urban infrastructure construction and pollution control mechanism should be done well to avoid the accumulation of intra-city living pollution.

(5) Establish regionalization strategies

Considering the phenomenon of spatial aggregation of environmental pollutants in regional distribution, governments should strengthen inter-regional cooperation. At the same time, they should comprehensively analyze the conflict of interests with neighboring regions to get out of the situation of fragmentation, as well as enhance the efficiency of resource utilization and the capacity of pollution reduction. In addition, policies should be implemented in accordance with local conditions. The classification service mode of green finance should be explored, focusing on the different policy effects in the eastern, central and western regions. For example, in the Yangtze River Delta region, attention should be paid to prevent the vicious circle of high-pollution industries, while in the central and western regions, common improvement of the environment should be promoted through radiation-driven effect, so as to form a virtuous circle between regions and promote the regionalization of China's financial development.

Author contribution statement

Ningjing Wang: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Xiping Zhang; Shilong Li: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Zhen Wang; Yingjia Chen: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

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

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