The Spatial Effect of Fiscal Decentralization on Haze Pollution in China

Zhonghua Cheng (chengzhonghua0106@163.com)
Nanjing University of Information Science and Technology https://orcid.org/0000-0003-1271-6930
Yeman Zhu
Nanjing University of Information Science and Technology

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Zhonghua Cheng *, Yeman Zhu

(China Institute of Manufacturing Development, Nanjing University of Information Science & Technology, Nanjing 210044, China)

Abstract: This paper empirically analyzes the effects of fiscal decentralization on haze pollution and its mechanism using statistical data from 285 Chinese cities from 2003 to 2016. The results show that increases in the degree of fiscal decentralization not only dramatically aggravate haze pollution in local areas but also significantly worsen the haze pollution in surrounding areas. Further mechanism analyses show that the increase in the degree of fiscal decentralization can also increase the volatility of haze pollution in local areas indicating that local governments do have the ability to control haze pollution in their local area according to their own preferences and interests. However, increases in the degree of fiscal decentralization in the local area can also reduce the volatility of haze pollution in surrounding areas at the same time, indicating that the adjustments in environmental policies in surrounding areas will significantly inhibit the control of environmental policies in the local area, thus preventing haze pollution in the local area from being effectively controlled. This means that there is a destructive environmental 'Race to the Bottom' competition between governments in order to compete in the game.

Key words: Fiscal Decentralization; Regulation Competition; Haze Pollution; Dynamic Spatial Durbin Model.

1. Introduction

The problems of $PM_{2.5}$ pollution in developed countries have not been so obvious due to industrialization over the long-term and the development pattern of 'Treatment after Pollution'. However, $PM_{2.5}$ pollution in China has become more and more serious with its rapid progress of urbanization and industrialization. It is characterized by its high frequency, wide range, high pollution levels and degree of hazard to health. The *2017 China Ecological and Environmental Status Bulletin* indicated that the ambient air quality of 239 cities in total 338 cities exceeded the standard in 2017. In other words, 70.7% of the total number of cities exceeded the maximum levels set by government. These 338 cities had severe pollution for 2311 days and serious pollution for 803 days, with the number of days of elevated $PM_{2.5}$, the primary pollutant, accounting for 74.2% of the days of heavy pollution and above. As a result, the Chinese government views governance and control of $PM_{2.5}$ pollution as very important. The 19th CPC national congress proposed that pollution prevention be one of the three major challenges in building a moderately prosperous society; much should be done to solve the serious environmental problem. The *'Three-year Plan on defending the blue sky'* which was issued by the State Council in July 2018 clearly emphasized that cities that did not meet air quality standards should decrease their $PM_{2.5}$ concentration by at least 18% by 2020 relative to 2015, with the proportion of days of heavy pollution and above to the total declining by more than 25% by 2020 relative to 2015.

The public demands the protection of the ecological environment, decreases in environmental pollution levels and increases in environmental quality. A lot of scholars have conducted extensive

* Corresponding author Tel.: +86 15205186166
E-mail: chengzhonghua0106@163.com (Z. Cheng)

embedded studies on these issues which are mainly concentrated on the following two aspects. First, many scholars have used the factor decomposition method to decompose environmental pollution into several key factors, including, inter alia, economic development factors, industrial structure factors and technical factors. They have then analyzed the relative degree of influence of these factors on environmental pollutants (Su et al., 2017; Li et al., 2017; Yu et al., 2018). Second, many scholars have adopted empirical analysis methods to verify the Environmental Kuznets Curve (Gill et al., 2018) or to analyze the effects of structure (Cheng et al., 2018), technology (Kang et al., 2018), energy (Hu et al., 2018), international trade (Liddle, 2018), foreign direct investment (Zhu et al., 2017) and urbanization (Zhang et al., 2017) on the environment.

The above studies have conducted extensive and thorough analyses on the factors that influence environmental pollution from the perspective of economics. However, the effects of economic factors on environmental quality do not function in isolation from certain institutional factors. In China, fiscal decentralization reform under a politically centralized system can be regarded as an important institutional factor (Zhang et al., 2018). Under this fiscally decentralized system, local governments need to develop the local economy but must also give consideration to improving people's livelihood and protecting the environment. They need to coordinate the relationship between economic development and environmental conservation (Zhang et al., 2017). The traditional theories of fiscal decentralization hold that, on the one hand, local governments can supply public goods more efficiently according to the preferences and jurisdiction of the inhabitants than can central government; this, in theory, is conducive to improving environmental quality (Oates and Portney, 2003). On the other hand, competition between governments under a decentralized system may also lead to fiscal expenditure preferences and a 'race to the bottom' phenomenon in environmental regulations causing further deterioration in environmental quality (Dijkstra and Fredriksson, 2010). However, the foundations on which these traditional theories of fiscal decentralization are based are not entirely applicable to conditions in China. The assumption that 'the goal of local government is to optimize public services' does not hold because it omits the political structure in China; even the incentive system is completely different. Therefore, it is both necessary and crucial in the prevention and control of China's pollution to analyze the effects of fiscal decentralization on environmental pollution and how it works from a practical level.

2. Literature review

International economic circles have basically reached a consensus on the benefits brought by fiscal decentralization. The first-generation theories of fiscal decentralization, which were developed by Tiebout (1956), Musgrave (1959) and Oates (1972), proved that fiscal decentralization can improve the efficiency of the public service through preference matching, optimization and allocation of resources and competitive market mechanisms. The second-generation theories of fiscal federalism developed by Mckinnon (1997) and Qian and Roland (1998) further pointed out that fiscal decentralization can help improve the incentives of different classes of government and increase the efficiency of resource allocation, thus significantly promoting local economic growth. Fiscal decentralization may, at the same time however, also bring adverse consequences. Firstly, fiscal decentralization may cause both an income redistribution effect and local protectionism which may lead to greater income gaps between urban and rural regions and between different regions (Kyriacou et al., 2017). Secondly, fiscal decentralization may push local governments to increase their expenditures for building up the economy and greatly reduce the supply of general public goods such as education and health care thereby resulting in a lack of fairness in public utilities (De Siano and D 'Uva, 2017). Thirdly, fiscal decentralization may lead to market segmentation among regions and thus bring redundancy and efficiency losses (Martinez et al., 2017). Fourthly, fiscal decentralization may cause vicious competition between regions and force local governments to compete to reduce their tax rates and environmental regulation standards, thus aggravating environmental pollution (Zhang et al., 2018). Fifthly, fiscal decentralization may also exacerbate local nepotism and thus aggravate local corruption (Jia and Nie, 2017).

There is no doubt that fiscal decentralization can significantly affect the behavior of local government which then has an important impact on environmental quality. Early theoretical studies mostly supported the idea that a higher degree of fiscal decentralization was conducive to improving local environmental quality. Tiebout (1956) analyzed the incentive effects of fiscal decentralization on local government through the 'voting with feet' theory. The research found that, in order to attract both residents and resources into the jurisdiction, a higher degree of fiscal decentralization could encourage local government to adopt specific financial revenue and expenditure policies; these would meet both the demands of residents and the services of public products, where providing higher levels of environmental quality was an important content. Oates and Schwab (1988) and Wilson (1996) also pointed out that, if there was no imperfect market or redistributive public policy, local government would aim at maximizing welfare and provide an optimal level of environmental quality for its residents, that is, increasing the degree of fiscal decentralization could help improve environmental quality. Wellisch (1995) even noted that, in the case of high openness, because local residents only obtained part of an enterprise's profits while shouldering all the costs of pollution, the competition between regions might lead to excessive environmental protection. Oates (2001) further pointed out that because environmental quality was a local public good and because local government had a better understanding of local information than the federal government, the environmental standards made by local government were more conducive to environmental protection. Levinson (2003) argued that fiscal decentralization would bring the effects of both 'race to top competition' and 'nimbyism'. Local government would then raise its environmental standards and transfer its pollutants to other regions by adopting stricter environmental policies, thus resulting in an even higher environmental quality in the local area.

With the development of further theories of fiscal decentralization more and more scholars have questioned the earlier theories. They hold that local governments would have their own considerations and interests and might make some decisions inconsistent with the rights and interests of local residents. Holmstrom and Milgrom (1991) pointed out that since local government could provide a wide variety of services for local residents in its jurisdiction, the GDP-oriented evaluation mechanism would encourage local government officials to strive towards economic growth resulting in a distortion of how resources are allocated. Qian and Roland (1998) further stated that under a system of multiple targets and multiple tasks only a properly designed mechanism could ensure that the policy decisions made by local governments with the goal of profit maximization in mind could be consistent with the interests of residents. If an incentive-compatible system were lacking local governments would provide only a minimal level of environmental quality for residents; local government would maximize its own interests. Kunce and Shogren (2005) believed, in reality, it was difficult to meet the conditions of perfect market or perfect non-redistribution public policies on just the theoretical premises of Oates and Schwab (1988). As a result, destructive competition related to economic growth was inevitable and this would undoubtedly lead to environmental degradation. Dijkstra and Fredriksson (2010) made further efforts to relax the preconditions of the Oates and Schwab (1988) model hypothesis, and found that decentralized environmental policies would result in poorer environmental standards and trigger a 'Race to the Bottom' effect. Mintz and Tulkens (1986), Wildasin (1988), Ulph (2000), Fredriksson et al. (2003), Kunce and Shogren (2007) also found that local governments could compete with each other by relaxing their local environmental standards so as to reach such goals as the attraction of investment, increases in employment and taxes.

Although a lot of scholars have investigated the effects of fiscal decentralization on environmental pollution from a practical level they differ significantly in their conclusions. Some empirical studies have supported the finding that fiscal decentralization can help local government improve the environment. This is mainly because competition between regions may bring the 'Race to the Top' Effect with higher levels of fiscal decentralization bringing stricter environmental regulations and so making any fiscal decentralization help to improve the environment (Levinson, 2003). Potoski (2001) analyzed whether there was a 'Race to the Bottom' competition among states in air pollution before and after the enactment of the 'US Clean Air Act'. The study found that not only was there no obvious 'Race to the Bottom' among states but that there was what might be called a 'Race to the Top' in that the environmental standards made by the States were higher than that made by the Federal Government. Millimet (2003) also showed that decentralization in the Reagan era had had no significant impact on the environment before the mid-1980s although, after that, the fiscal policies of decentralization had led to an environmental 'Race to the Top'. Based on the US data, Chupp (2011) found that local government would tend to set higher environmental standards when it could get more benefits from the environmental management system.

Some scholars have found that fiscal decentralization has had no significant impact on environmental pollution. List and Gerking (2000) analyzed the effects of decentralization on environmental quality in the Reagan era; the study found that there was no significant 'Race to the Bottom' competition among state governments in terms of environmental quality. Based on the data of 47 countries from 1979 to 1999, Sigman (2014) found that fiscal decentralization did not lead to a deterioration in environmental quality, that is, there was no environmental 'Race to the Bottom' behavior among local governments. Based on Chinese provincial panel data from 1995 to 2010, He (2015) found that fiscal decentralization had had no significant impact on per capita waste water, exhaust gases or solid waste discharge. Based on US data from 1998 to 2011, Sjöberg and Xu (2018) showed that decentralization under the Resource Conservation and Recovery Act had failed to elicit any environmental 'Race to the Bottom' behavior.

There were, however, some studies that found fiscal decentralization could worsen any existing local environmental pollution. Based on 2004 World Bank data from 90 developing countries, Fredriksson et al. (2006) found that fiscal decentralization had had obvious negative effects on environmental quality. Sigman (2007) investigated the effects of fiscal decentralization on water pollution by using global panel data, and the results showed that an increase in fiscal decentralization levels would lead to the acceleration of water pollution. Based on 1970 to 2000 panel data from 80 countries, Farzanegan and Mennel (2012) found that fiscal decentralization would aggravate the pollution and thus confirmed that the environment under decentralization would generate 'Race to the Bottom' behavior. Kamp et al. (2017) studied the effects of fiscal decentralization on environmental governance policies in China. The research found that local governments, in the pursuit of their own interests, often slowed or blocked the implementation of environmental governance reforms authorized by Central Authorities. Based on Chinese provincial panel data from 1995 to 2012, Zhang et al. (2017) found that environmental policies did actually help China control carbon emission growth but in a roundabout way. China's unique fiscal decentralization system had greatly inhibited the emission reduction effects of environmental policies thereby increasing the carbon emissions; this had led to the paradox of a green environment.

In summary, the current literature has already achieved fruitful results, and these studies have strong references and inspire us but there is still some room for improvement. This mainly revolves around the following aspects: (1) In terms of research content, with regards to the underlying reasons for the effects of fiscal decentralization on environmental pollution; in other words, whether fiscal decentralization could lead to the environmental 'Race to the Bottom' behavior among governments or not. The existing literature is only at the stage of qualitative discussion (Kamp et al., 2017); it does not give a clear answer and even lacks rigorous quantitative evidence. As a result, it needs to be further empirically tested. In this paper we use the standard deviation of county-level $PM_{2.5}$ pollution to measure the volatility of $PM_{2.5}$ pollution in each city and empirically analyze the effect of fiscal decentralization on the volatility of $PM_{2.5}$ pollution as well as its spatial spillover effect in order to further verify whether or not fiscal decentralization leads to an environmental 'Race to the Bottom' behavior among governments.

(2) In terms of research methods, the existing literature almost always considers the properties of fast proliferating and strong externalities of environmental pollutants but usually ignores the spatial spillover effects of independent variables. Actually, changes in independent variables in a local area can not only affect dependent variable in that local area but also can affect dependent variables in surrounding areas through spatial spillover effects (Meliciani and Savona, 2015). From the perspective of spatial econometrics, neglecting these spatial effects might result in estimation errors, and we thus use the dynamic spatial Durbin model for analyses.

(3) In terms of sample selection, the existing studies on fiscal decentralization in China are mostly carried out based on provincial data and lack an analysis of data at the city level. In fact, the tax distribution system implemented at the city level is not as thorough and fair as that under the central government and provinces. Often individual provinces implement differing tax sharing policies for cities with different economic conditions. Although the central government proposes to adopt a tax-based or proportional sharing approach, there are still varying degrees of tax classification between provinces and cities based on industries, subjection relationship of enterprises, etc. (Zhou and Wu, 2015). The fiscal decentralization index measured at the provincial level may have major defects, and we thus use the statistical data of 285 Chinese cities from 2003 to 2016 for analyses.

In light of the above, this paper first takes $PM_{2.5}$ pollution in Chinese cities as the research project and empirically investigate the effects of fiscal decentralization on $PM_{2.5}$ pollution and its spatial effect. The paper then analyzes the effects of fiscal decentralization on the volatility of $PM_{2.5}$ pollution and discusses whether local governments can, to some extent, master environmental problems. From the above analyses we reveal the existence of a 'Race to the Bottom' behavior relating to environmental regulations and elaborate on the role of local government on the governance and control of $PM_{2.5}$ pollution. Finally, we re-select the fiscal decentralization index in order to test for robustness.

3. Model establishment, variable description and data sources

3.1 Model establishment

Ehrlich and Holdren (1971) put forward the IPAT analytical framework for the determinants of environmental impacts, a framework that divides environmental impacts into three parts. The IPAT equation is $I = P \times A \times T$ where I represents the environmental impact, measured in this paper by the concentration of $PM_{2.5}$ pollution; P, A, and T represent population, affluence and technology respectively. Dietz and Rosa (1994) then put forward the STIRPAT model which not only retains those three factors in the IPAT model that influence environment impacts but also introduces stochastic terms for empirical analyses. The basic form of STIRPAT is:

$$I_{it} = \alpha \times P_{it}^{\beta} \times A_{it}^{\gamma} \times T_{it}^{\delta} \times \varepsilon_{it} \tag{1}$$

Where i represents the city, t represents the time and ε represents the random error term. The existing literature has shown that fiscal decentralization can significantly affect the behavior of local governments and thus has an important impact on environmental pollution. Therefore, this paper incorporates the variable of fiscal decentralization into the STIRPAT model so as to analyze its effect on environmental impact. The specific formula is as follows:

$$I_{it} = \alpha \times P_{it}^{\beta} \times A_{it}^{\gamma} \times T_{it}^{\delta} \times D_{it}^{\vartheta} \times \varepsilon_{it} \tag{2}$$

Where D represents the variable of fiscal decentralization and ϑ represents the effect elasticity of fiscal decentralization on $PM_{2.5}$ pollution. Combined with the existing studies, we can establish the following ordinary static panel model on the basis of equation (2):

$$\ln I_{it} = \ln\alpha + \vartheta \ln D_{it} + \beta \ln P_{it} + \gamma \ln A_{it} + \delta \ln T_{it} + \varphi \ln X_{it} + \varepsilon_{it} \tag{3}$$

Where X represents the other control variables affecting $PM_{2.5}$ pollution. Compared with studies of Cheng et al. (2017), Xu and Lin (2018), Luo et al., (2018), we select the following three variables as control variables: industrial structure (S), traffic intensity (R) and central heating (H). Considering that there may be dynamic effects of $PM_{2.5}$ pollution in the time dimension, that is, $PM_{2.5}$ pollution may have shown path dependence, this paper incorporates the lag term of $PM_{2.5}$ pollution based on Equation (3) and then establishes the following ordinary dynamic panel model:

$$\ln I_{it} = \ln\alpha + \tau \ln I_{i(t-1)} + \vartheta \ln D_{it} + \beta \ln P_{it} + \gamma \ln A_{it} + \delta \ln T_{it} + \varphi \ln X_{it} + \varepsilon_{it} \tag{4}$$

Where τ denotes the estimation coefficient of the lag term of $PM_{2.5}$ pollution. Considering that both $PM_{2.5}$ pollution and independent variables may have spatial spillover effects in the spatial dimension, we incorporate their spatial lag terms based on Equation (3) and then establishes the following Static Spatial Durbin model:

$$\begin{aligned} \ln I_{it} = {} & \ln\alpha + \rho \sum W_{ij} \ln I_{jt} + \vartheta_1 \ln D_{it} + \vartheta_2 \sum W_{ij} \ln D_{jt} + \beta_1 \ln P_{it} + \beta_2 \sum W_{ij} \ln P_{jt} \\ & + \gamma_1 \ln A_{it} + \gamma_2 \sum W_{ij} \ln A_{jt} + \delta_1 \ln T_{it} + \delta_2 \sum W_{ij} \ln T_{jt} \\ & + \varphi_1 \ln X_{it} + \varphi_2 \sum W_{ij} \ln X_{jt} + \eta_i + \nu_t + \varepsilon_{it} \end{aligned}$$

(5)

$$\varepsilon_{it} = \lambda \sum W_{ij} \varepsilon_{jt} + \mu_{it}$$

Where $\eta_i, \nu_t,$ and ε_{it} represent regional effect, time effect and random disturbance terms respectively and reflect different dimensions of random disturbances affecting $PM_{2.5}$ pollution. W represents the spatial weight matrix and it reflects the spatial association among cities. The spatial effect of $PM_{2.5}$ pollution not only has a direct connection with urban economic output but is also closely related to geographical distance among cities (Ma et al., 2016). This paper therefore adopts economic distance to construct the spatial weight matrix (see more details in Cheng et al., 2017).

Because $PM_{2.5}$ pollution may have dynamic and spatial spillover effects at the same time and because independent variables may also have spatial spillover effects (Cheng et al., 2020), we thus incorporate both the lag term and the spatial lag term of $PM_{2.5}$ pollution at the same time as well as the spatial lag terms of all independent variables based on Equation (3). It then establishes the following Dynamic Spatial Durbin model:

$$
\begin{aligned}
\ln I_{it} = {} & \ln\alpha + \tau\ln I_{i(t-1)} + \rho\sum W_{ij}\ln I_{jt} + \vartheta_1\ln D_{it} + \vartheta_2\sum W_{ij}\ln D_{jt} + \beta_1\ln P_{it} \\
& +\beta_2\sum W_{ij}\ln P_{jt} + \gamma_1\ln A_{it} + \gamma_2\sum W_{ij}\ln A_{jt} + \delta_1\ln T_{it} + \delta_2\sum W_{ij}\ln T_{jt} \\
& +\varphi_1\ln X_{it} + \varphi_2\sum W_{ij}\ln X_{jt} + \eta_i + \nu_t + \varepsilon_{it}
\end{aligned}
\tag{6}
$$

$$\varepsilon_{it} = \lambda\sum W_{ij}\,\varepsilon_{jt} + \mu_{it}$$

3.2 Variable description

3.2.1 Dependent variable: $PM_{2.5}$ pollution (I). Due to measurement of $PM_{2.5}$ really being a recent phenomenon in China, the paper uses satellite data for analysis. According to the measurement method of Van Donkelaar et al. (2016), the international geophysical information network center of Columbia University in the United States used satellites to measure aerosol optical depth and obtained the global annual average of $PM_{2.5}$ from 2001 to 2016 through a mathematical model. This method for estimating is relatively scientific and has high validity and reliability (Cheng et al., 2017; 2020). This paper uses this set of radar data and ArcGIS software in combination with the vector map of Chinese city level administrative regions to parse it into numerical values of the annual $PM_{2.5}$ concentration from 2003 to 2016.

3.2.2 Core explanatory variable: Fiscal decentralization (D). The existing literature mostly uses expenditure and income indexes to measure the degree of fiscal decentralization (Sun et al., 2017; Que et al., 2018). We first adopt the expenditure index to measure the degree of fiscal decentralization and then use the income index to test for robustness. For fiscal expenditure (income) decentralization, considering the differences in urban fiscal management systems, the formula is $D = fdc/(fdc + fdp + fdf)$, where fdc, fdp and fdf represent per capita fiscal expenditure (income) at the urban level, the provincial level and the central level respectively. This index effectively excludes both the influences of population scale and transfer payments from central to local governments, thus measuring urban fiscal decentralization scientifically and reasonably.

3.2.3 Control variables

(1) Population density (P). Considering the great differences in both administrative areas and population sizes among cities, it is more scientific to use population density to measure the effects of demographic factors on $PM_{2.5}$ pollution. Generally, the bigger the population density is, the bigger the demands for energy of the city will be, and thus the higher the pollutant emissions will be. We use the population per unit area to measure population density and expect population density to have a significant positive effect on urban $PM_{2.5}$ pollution.

(2) Economic development level (A). Economic development level is an important factor affecting environmental pollution. Classic EKC theory points out that environmental pollution will show an inverted 'U' curve with improvements in economic development levels. According to Atasoy (2017) and Gill et al., (2018), we incorporate both the linear term and the quadratic term of economic development into the regression equation and empirically investigate the effect of economic growth on $PM_{2.5}$ pollution.

(3) Technological level (T). Both improvements in technological levels and the application of clean technologies are crucial for energy conservation and emissions reduction. Because technological progress is essential for improvements in energy efficiency and energy efficiency is the external reflection of technological levels (Sheng and Guo, 2016), this paper uses energy efficiency to measure the technological level. Considering China's coal-dominated energy consumption structure and the high correlation between coal and electricity, this paper uses the ratio of adjusted GDP to electricity consumption to measure energy efficiency (technological level). We expect that technological level has significant negative effect on urban $PM_{2.5}$ pollution.

(4) Industrial structure (S). Because secondary industry plays a major role in energy consumption and pollution emissions, the structure of industrialization is not beneficial for energy saving and emission reduction. This paper adopts the ratio of third industry GDP to that of secondary industry GDP to measure industrial structure. This index not only directly measures the upgrading of industrial structure but also indirectly measures the trend in services in the industrial structure; it is thus scientific and reasonable to use this index to measure industrial structure (Cheng et al. 2018). We expect industrial structure to have a significant negative effect on urban $PM_{2.5}$ pollution.

(5) Traffic intensity (R). The literature has shown that motor vehicle exhaust can affect $PM_{2.5}$ pollution to a large extent (Xu et al., 2016). Some studies have shown that both more and more motor vehicles and increasing serious traffic congestion have aggravated $PM_{2.5}$ pollution in China (Liu et al., 2017; Cheng et al., 2017). We thus use the traffic intensity to measure the traffic pressure. Considering the availability and validity of data, the traffic intensity can be measured by the ratio of the number of motor vehicles to the total length of roads. We expect traffic intensity to have a significant positive effect on urban $PM_{2.5}$ pollution.

(6) Central heating (H). Many Chinese northern cities generally adopt the central heating so as to cope with the cold weather in winter but this urban central heating burns a lot of coal and emits vast quantities of SO_2 and soot (dust) particles. This is a direct cause of the worsening of $PM_{2.5}$ pollution (Cheng et al., 2017). In this paper, we use 0-1 variables to measure whether a city has central heating or not. We expect the central heating to have a significant positive effect on urban $PM_{2.5}$ pollution.

3.3 Data sources

As there were significant adjustments made to the Chinese national economic industrial classification in 2002, we choose 2003 as the starting year for data selection. According to availability and validity of data, we have selected statistical data from 285 cities in mainland China from 2003 to 2016 for analysis[2]. The data comes from the China Urban Statistical Yearbook (2004-2017), the China Statistical Yearbook (2004-2017) and the Socioeconomic Data and Application Center of Columbia University (SEDAC). In addition, we also perform the multicollinearity test on the independent variables used in the regression and the results show that the variance inflation factors (VIF) of all variables are less than 10, indicating that the model does not have a serious multicollinearity problem.

4. Results and analyses

4.1 Model specification

[2] Bijie, Tongren, Chaohu, Sansha and Haidong are not included in the analysis scope because of the adjustment of administrative divisions, and Lhasa is also not included due to incomplete data.

The selection criteria of spatial econometric models are as follows: By comparing the Wald and LR Statistics, we can know whether the spatial Durbin model should be simplified into a spatial lag model or a spatial error model. If the null hypotheses H_0: $\theta = 0$ and H_0: $\theta + \delta\beta = 0$ are both rejected[3], it means the spatial Durbin model is more preferable. If the null hypothesis H_0: $\theta = 0$ cannot be rejected and the LM tests more supports the spatial lag model, it means the spatial lag model is more preferable; if the null hypothesis H_0: $\theta + \delta\beta = 0$ cannot be rejected and the LM tests more supports the spatial error model, it means the spatial error model is more preferable. In addition, we also use the Hausman test to test whether the spatial panel model should use the form of fixed effect or random effect. For the choice of the form of fixed effects, we also need to use the joint significance test to judge.

In general, there are two main methods to estimate the ordinary dynamic panel model: the system GMM method and the difference GMM method. Compared with the difference GMM method, the system GMM method can better solve the problems of weak instrumental variables and finite sample bias, thus making the estimated results more accurate and reliable. We thus use the system GMM method to estimate the ordinary dynamic panel model. There are three main methods to regress the static spatial Durbin model: the spatial two-stage least squares (S2SLS) method, the GMM method and the improved maximum likelihood estimation method. Compared to the S2SLS and the GMM methods, this improved maximum likelihood estimation method is better in effectiveness, consistency and operability (Lesage and Fischer, 2008; Elhorst, 2010). We thus use the improved maximum likelihood estimation method to estimate the static spatial Durbin model. Usually, there are two main methods for estimating the dynamic spatial Durbin model: the maximum likelihood estimation method and the error correction quasi-maximum likelihood estimation method. Compared to the maximum likelihood estimation method, this error correction quasi-maximum likelihood estimation method is good for small samples (Yu et al., 2008), can effectively solve both endogenous problems and estimation bias problems (Lee and Yu, 2010a) and has more advantages in effectiveness, consistency, stability and estimation accuracy (Lee and Yu, 2010b; Elhorst, 2014). We thus use the error correction quasi-maximum likelihood estimation method to estimate the dynamic spatial Durbin model. We use the stata15.0 software to estimate the above methods with the estimation results shown in Table 1.

Table 1 Estimation results using the three methods

Variable	Ordinary dynamic panel model	Static spatial Durbin model	Dynamic spatial Durbin model
τ (dynamic factor)	0.490*** [11.86]		0.226*** [6.82]
ρ (spatial factor)		0.379*** [3.86]	0.007*** [3.51]
ln*D*	0.072* [1.78]	0.050** [2.16]	0.061*** [3.07]
ln*P*	0.128*** [4.86]	0.147*** [6.58]	0.142*** [5.96]
ln*A*	0.132	0.163**	0.150***

[3] The null hypothesis H_0: $\theta = 0$ and H_0: $\theta + \delta\beta = 0$ are both expressed over the basic form of spatial Durbin model and the specific model is as follows:

$$Y = \rho WY + \alpha l_N + X\beta + WX\theta + \varepsilon$$

$$\varepsilon \sim N(0, \sigma^2 I_n)$$

When $\theta = 0$, the spatial Durbin model could be simplified into the spatial lag model; when $\theta + \delta\beta = 0$, the spatial Durbin model could be simplified into the spatial error model.

	[0.35]	[2.12]	[2.50]
$(\ln A)^2$	-0.005* [-1.74]	-0.008 [-1.29]	-0.007** [-2.21]
ln*T*	-0.053 [-0.60]	-0.074 [-0.86]	-0.065 [-1.06]
ln*S*	-0.132* [-1.79]	-0.093** [-2.05]	-0.109*** [-2.85]
ln*R*	0.077*** [4.95]	0.057*** [4.09]	0.065*** [5.32]
H	0.015*** [3.49]	0.026*** [4.58]	0.024*** [4.26]
*W*xln*D*		0.354*** [4.08]	0.186*** [5.87]
*W*xlnP		0.010 [0.28]	0.425*** [4.20]
*W*xlnA		0.674 [1.03]	0.748 [1.26]
*W*x$(\ln A)^2$		0.113 [0.53]	0.098 [0.84]
*W*xlnT		-0.275 [-0.69]	-0.024 [-0.58]
*W*xlnS		-0.157 [-1.06]	-0.078 [-0.95]
*W*xlnR		0.761*** [8.34]	0.659*** [7.97]
*W*xH		0.056*** [4.81]	0.105*** [5.26]
LogL		3495.86	3756.07
AIC	0.6782	0.6297	0.5784
SC	0.6924	0.6448	0.5936
Obs.	3705	3990	3705
Wald spatial lag		(0.000)	(0.000)
Wald spatial error		(0.000)	(0.000)
LR spatial lag		(0.000)	(0.000)
LR spatial error		(0.000)	(0.000)
Hausman test		(0.000)	(0.000)
Joint significance test for spatial fixed effect		(0.000)	(0.000)
Joint significance test for time fixed effect		(0.000)	(0.000)

Figures in parentheses represent t values. *,** and *** denote significance levels at 10%, 5% and 1%, respectively.

The results in Table 1 indicate that the Wald spatial lag test and the LR spatial lag test both reject the null hypothesis H_0: $\theta = 0$ at the 1% significance level. Meanwhile, the Wald spatial error test and the LR spatial error test also both reject the null hypothesis H_0: $\theta + \delta\beta = 0$ at the 1% significance level. This means that it is more preferable to use the spatial Durbin model for estimation. The Hausman tests are significant at the 1% significance level indicating that it is more appropriate for both the static spatial Durbin model and the dynamic spatial Durbin model to choose the fixed effect models. It can be seen from the results of the Joint significance tests for time fixed effects and spatial fixed effects, the null hypotheses of non-time fixed effects and non-spatial fixed effects are both rejected which means that the time and spatial fixed effects models are more preferable.

Comparing the dynamic spatial Durbin model and the ordinary dynamic panel model, there are certain differences in the estimated results between the two models; the dynamic spatial Durbin model is superior to the ordinary dynamic panel model in terms of the significance levels of the estimated parameters. In addition, by comparing the AIC and the SC, we find that the dynamic spatial Durbin model is also superior to the ordinary dynamic panel model. This is mainly because the ordinary dynamic panel model does not consider the spatial spillover effects, cannot better solve the problem of spatial correlation and brings error and bias into the estimation.

Comparing the dynamic spatial Durbin model and the static spatial Durbin model, there are not only certain differences in the estimated results between the two models but the dynamic spatial Durbin model is superior to the static spatial Durbin model in terms of the significance levels of the estimated parameters. Moreover, by comparing the LogL, AIC and SC, the dynamic spatial Durbin model is also superior to the static spatial Durbin model mainly because the static spatial Durbin model does not consider the dynamic effect of dependent variables, cannot better solve the problem of endogeneity and brings error and bias into the estimation. Overall, this paper adopts the dynamic spatial Durbin model as the final interpretation model.

4.2 Empirical analyses on the effects of fiscal decentralization on urban $PM_{2.5}$ pollution

It can be seen from Table 1 that the coefficient of the first-order lag term of $PM_{2.5}$ pollution is significantly positive in the dynamic spatial Durbin model, indicating that the changes in $PM_{2.5}$ pollution have significant path dependence. This means that it is imperative to take immediate measures to govern and control the $PM_{2.5}$ pollution otherwise it will become more and more difficult. Meanwhile, the coefficient of the spatial lag term of $PM_{2.5}$ pollution is also significantly positive indicating that $PM_{2.5}$ pollution has significant spatial association and spatial spillover. This implies that the control of $PM_{2.5}$ pollution should adopt the strategies of regional joint prevention and control; otherwise, these spillover effects of $PM_{2.5}$ pollution among regions will make unilateral haze treatment efforts futile.

We know that regression coefficients can accurately reflect the effects of independent variables on dependent variables without considering the spatial lag terms of independent variables. However, the regression coefficients can no longer reflect the effects of independent variables on dependent variables when considering the spatial lag terms of independent variables. This is mainly because the changes in independent variables will not only affect $PM_{2.5}$ pollution in the city, but also affect $PM_{2.5}$ pollution in surrounding cities through spatial spillover effect. At this time, the coefficient of spatial lag term based on the spatial Durbin model cannot accurately measure the spatial spillover effect and may thus lead to a bias in the model's results (Elhorst, 2014). Lesage and Pace (2009) proposed, through a partial differential matrix, a direct effect, an indirect effect and a total effect using the Spatial Durbin model; this can accurately reflect the effects of independent variables on the dependent variable. The direct effect denotes the average effect of independent variables on dependent variables in the city, the indirect effect denotes the average effect of independent variables on dependent variables in surrounding cities and the total effect denotes the average effect of independent variables on dependent variables in all cities. In this paper we employ this partial differential matrix method to measure the effects of fiscal decentralization on $PM_{2.5}$ pollution and the specific decomposition results can be seen in Table 2.

Table 2 the decomposition results of the effects of fiscal decentralization on $PM_{2.5}$ pollution

Independent variable	Direct effect	Indirect effect	Total effect
ln*D*	0.071*** [3.23]	0.206*** [5.48]	0.277*** [3.96]
ln*P*	0.147*** [6.02]	0.463*** [3.76]	0.610*** [4.34]
ln*A*	0.172*** [2.56]	0.714 [1.09]	0.886 [0.75]
$(\ln A)^2$	-0.008** [-2.35]	-0.113 [-1.05]	-0.121 [-0.76]
ln*T*	-0.057 [-0.90]	0.023 [0.71]	-0.034 [-0.58]
ln*S*	-0.116*** [-2.97]	-0.093 [-0.82]	-0.219 [-1.13]

ln$R$	0.070*** [5.51]	0.687*** [8.24]	0.757*** [6.36]
H	0.021*** [4.09]	0.093*** [4.86]	0.114*** [4.32]

Figures in parentheses represent t values. *,** and *** denote significance levels at 10%, 5% and 1%, respectively.

It can be seen from Table 2 that the direct effect coefficient of fiscal decentralization is significantly positive indicating that the increase in the level of fiscal decentralization has significantly worsened $PM_{2.5}$ pollution in the local area mainly because of the following two reasons. For one thing, the central government controls both the promotion and the reprimanding of local officials under the Chinese politically centralized, but fiscally decentralized, system. In order to better evaluate and promote local officials, the central government tends to look at economic growth as an important criterion. In order to achieve their political promotions local officials prefer to put current resources into regional economic growth rather than concentrate on improving the environment. The higher the fiscal decentralization is the greater the fiscal autonomy of local governments and the more obvious this tendency will be. For another thing, with increases in the level of fiscal decentralization local governments may further ease environmental supervision standards in order to compete for resources and markets and thus develop the economy. Under such a low standard of environmental constraints, the propensity for enterprises to pollute cannot be effectively controlled and this leads to a deterioration of environmental quality in the local area.

The indirect effect coefficient of fiscal decentralization is significantly positive indicating that an increase in the level of fiscal decentralization not only significantly worsens $PM_{2.5}$ pollution in a local area but also remarkably aggravates the $PM_{2.5}$ pollution in surrounding areas. The possible reasons are as follows: For one thing, with increases in the level of fiscal decentralization, $PM_{2.5}$ pollution in a local area will worsen. The high diffusivity and strong externality of $PM_{2.5}$ pollution will significantly aggravate $PM_{2.5}$ pollution in surrounding areas. This point has previously been proven. For another thing, with increases in the level of fiscal decentralization local government may ease its environment supervision standards so as to promote economic growth. The surrounding areas will correspondingly lower their supervision standards in order to compete in the game and may thus result in 'Race to the Bottom' behavior among regions related to environmental policies. This point will be further verified in the following part.

For the control variables, a higher population density can aggravate the $PM_{2.5}$ pollution in a local area mainly because it can increase the demand by residents for energy and electricity. The first-order coefficient of affluence and its quadratic coefficient are significantly positive and negative respectively, indicating the existence of EKC; that is, as economic development levels increase, $PM_{2.5}$ pollution in China first increases and then decreases. The service industry is conducive to improving $PM_{2.5}$ pollution because, compared to the manufacturing industry, the demands of the service sector for energy are relatively small. On the other hand, high traffic markedly effects $PM_{2.5}$ pollution mainly because the relatively high traffic intensity increases the demand of energy sources and goes against the diffusion and dilution of vehicle exhaust emissions at the same time. In Northern China, central heating can significantly worsen the $PM_{2.5}$ pollution in a local area. This is mainly because urban central heating burns a lot of coal and emits vast quantities of both SO_2 and soot (dust) particles significantly worsening the $PM_{2.5}$ pollution in the local area. We do not expect technological progress has non-significant effect on $PM_{2.5}$ pollution. The possible reasons are as follows: For one thing, the technological progress of China is more biased towards capital and energy with green technologies with applications targeting energy conservation and emissions reduction having a relatively low proportion. For another thing, technological progress may lead to an energy rebound effect, and cause the energy conservation and pollution emissions reduction effects, brought on by improvements in energy efficiency at the technological level, to be offset by a new round of the energy consumption and pollution emissions caused by capital deepening and output growth.

4.3 Empirical analyses on the effects of fiscal decentralization on the volatility of $PM_{2.5}$ pollution

As indicated above, increases in the degree of fiscal decentralization will dramatically aggravate $PM_{2.5}$ pollution both in the local area and in the surrounding areas. We will now give possible explanations as to why, focusing on the specific characteristics of fiscal decentralization in China. Are these explanations reasonable? Will Chinese fiscal decentralization lead to a destructive environmental 'Race to the Bottom' competition among regions? Does this result mean that local government is both powerless and unable to control environmental pollution or that local government intentionally does so for their own benefit? Sigman (2014), Huang (2017) believe that fiscal decentralization not only affects the level of $PM_{2.5}$ pollution but also affects the volatility of $PM_{2.5}$ pollution. Moreover, the level of volatility of $PM_{2.5}$ pollution can actually reflect the ability of local government to control environmental policies to some extent. Based on this logic, we will empirically investigate the effects of fiscal decentralization on the volatility of $PM_{2.5}$ pollution and thus further elaborate on the behavior of local government as regards the environment.

In order to more scientifically and accurately measure the volatility of $PM_{2.5}$ pollution for each city, we further subdivide the urban geographic unit and use the standard deviation of $PM_{2.5}$ pollution at the county level under each city. The specific formulas are as follows:

$$Std_{i,t} = \sqrt{\frac{\sum_{j=1}^{n_i}(I_{i,j,t} - \sum_{j=1}^{n_i} I_{i,j,t}/n_i)^2}{n_i}} \quad (7)$$

Where $Std_{i,t}$ represents the volatility of $PM_{2.5}$ pollution at city i in t year, $I_{i,j,t}$ represents the level of $PM_{2.5}$ pollution of county j under city i in t year, n_i represents the number of counties under city i. The greater the volatility of $PM_{2.5}$ pollution, the more the urban environmental policies must adjust. We first use ArcGIS software to analyze the 2003 to 2016 raster data for specific annual $PM_{2.5}$ concentrations in the 2383 counties and districts of China by combining it with the vector map of Chinese county level administrative regions. Then we use the formula (8) to calculate the volatility of $PM_{2.5}$ pollution of 285 cities from 2003 to 2016. We still use the dynamic Spatial Durbin model for regression analyses. Specific regression results can be seen in S1 with decomposition results shown in Table 3.

Table 3 the decomposition results of the effects of fiscal decentralization on the volatility of $PM_{2.5}$ pollution

Independent variable	Direct effect	Indirect effect	Total effect
ln*D*	0.129*** [5.85]	-0.328* [-1.83]	-0.199 [-0.76]
ln*P*	0.343*** [7.72]	0.220 [1.06]	0.563*** [4.74]
ln*A*	0.164** [2.12]	-0.812 [-0.59]	-0.648 [-0.83]
ln*T*	-0.258 [-1.32]	0.508 [1.17]	0.250 [0.46]
ln*S*	-0.736	0.540**	-0.196

	[-0.72]	[2.06]	[-0.58]
ln*R*	0.028*** [7.51]	0.465*** [8.87]	0.493*** [6.75]
H	0.235*** [3.68]	0.083*** [3.45]	0.318*** [2.86]

Figures in parentheses represent t values. *,** and *** denote significance levels at 10%, 5% and 1%, respectively.

The regression results in S1 show that the volatility of $PM_{2.5}$ pollution has a significant dynamic effect in the time dimension indicating that the adjustment of environmental policies made by governments always tends to track back. Those cities with larger adjustments in environmental policies in earlier years will still have larger adjustments in environmental policies in the year or the following years. Meanwhile, the volatility of $PM_{2.5}$ pollution has an obvious negative spatial effect in the spatial dimension indicating that an increase in the volatility of $PM_{2.5}$ pollution in a local area significantly inhibits increases in the volatility of $PM_{2.5}$ pollution in surrounding areas. This means that the surrounding areas will make corresponding adjustments according to the adjustments in environmental policies in the local area, indicating that there is competition in terms of environmental policies among regions. In the following, we mainly focus on the effects of fiscal decentralization on the volatility of $PM_{2.5}$ pollution and give reasonable explanations.

The decomposition results in Table 3 show that the direct effect coefficient of fiscal decentralization is significantly positive, indicating that increases in the degree of fiscal decentralization in a local area dramatically increases the volatility of $PM_{2.5}$ pollution in that local area. This is mainly because that fiscal decentralization makes local government adjust its environmental policies according to local conditions so as to satisfy its heterogeneous preferences. With increases in the degree of fiscal decentralization, the fiscal autonomy of local governments becomes larger and larger so the environmental policy adjustment window also becomes bigger and bigger. In this sense, Chinese local government does have the ability to control local $PM_{2.5}$ pollution. It can significantly affect the volatility of $PM_{2.5}$ pollution in the local area by adjusting its environmental policies. In other words, local governments can choose a level of environmental quality that reflects its own preferences and interests.

The indirect effect coefficient of fiscal decentralization is significantly negative, indicating that an increase in the degree of fiscal decentralization in a local area can significantly reduce the volatility of $PM_{2.5}$ pollution in surrounding areas. This is mainly because that the local government will have more space to adjust its environmental policies with an increase in its degree of fiscal decentralization. However, in order to compete, the surrounding areas must make corresponding adjustments to their own environmental policies relative to the adjustments in environmental policies in the local area; this further verifies the competitive behavior as regards environmental policies among governments. On the one hand, local government does have the ability to control the $PM_{2.5}$ pollution in the local area according to their preferences and interests; on the other hand, however, adjustments in environmental policies in the surrounding areas can significantly inhibit the control of environmental policies in the local area, thus preventing the $PM_{2.5}$ pollution in the local from being effectively controlled. It essentially means that there is a 'Race to the Bottom' competition in environmental policies among governments.

4.4 Robustness test

The existing studies often use either expenditure indicators or income indicators to measure fiscal decentralization. We use expenditure indicators to perform the above analyses but use income indicators to take the robustness test. The specific regression results are presented in S1, with decomposition results shown in Table 4. Although there are certain changes in both some of the control variable coefficients and the spatial spillover effects, as well as in their significance levels, when looking at the regression and decomposition results, the results of the coefficients of fiscal decentralization and their significance levels are basically in accord with the above regression results. This indicates that the effects of fiscal decentralization on $PM_{2.5}$ pollution and its volatility have reliability and robustness.

Table 4 the decomposition results of the effects of fiscal decentralization on $PM_{2.5}$ pollution and its volatility: robustness test

Dependent variable	Independent variable	Direct effect	Indirect effect	Total effect
$PM_{2.5}$ pollution	ln*D*	0.106*** [4.46]	0.472*** [3.87]	0.578*** [4.05]
	ln*P*	0.096** [2.23]	0.249*** [3.28]	0.345* [1.68]
	ln*A*	0.237*** [2.98]	0.584 [0.93]	0.821 [0.57]
	$(\ln A)^2$	-0.011** [-2.20]	-0.142 [-0.53]	-0.153 [-0.68]
	ln*T*	-0.065 [-0.47]	0.048 [0.66]	-0.017 [-0.52]
	ln*S*	-0.148** [-2.04]	-0.083 [-0.71]	-0.231 [-1.02]
	ln*R*	0.105*** [6.32]	0.426*** [7.73]	0.531*** [5.94]
	H	0.056*** [4.82]	0.181*** [6.06]	0.237*** [5.34]
The volatility of $PM_{2.5}$ pollution	ln*D*	0.094*** [3.52]	-0.252** [-2.17]	-0.158 [-1.14]
	ln*P*	0.217*** [5.63]	0.194 [0.86]	0.411*** [3.99]
	ln*A*	0.232** [2.25]	-0.604 [-0.71]	-0.372 [-0.66]
	ln*T*	-0.216 [-1.14]	0.492 [0.85]	0.276 [0.98]
	ln*S*	-0.688 [-0.72]	0.485** [2.09]	-0.203 [-0.89]
	ln*R*	0.063*** [5.82]	0.386*** [7.25]	0.449*** [6.33]
	H	0.194*** [3.53]	0.058*** [2.59]	0.252*** [3.06]

Figures in parentheses represent t values. *,** and *** denote significance levels at 10%, 5% and 1%, respectively.

5. Conclusion and enlightenment

This paper empirically analyzes the effects of the Chinese fiscal decentralization system on $PM_{2.5}$ pollution and its volatility. The results show that increases in the degree of fiscal decentralization will significantly aggravate $PM_{2.5}$ pollution in both local and surrounding areas. Further mechanism analyses show that on the one hand, local government does have the ability to control its $PM_{2.5}$ pollution according to its own preferences and interests, but on the other hand, any adjustments in environmental policies in the surrounding areas will significantly inhibit the control of environmental policies in the local area, thus preventing $PM_{2.5}$ pollution in the local area from being effectively controlled. It essentially means that there is an environmental 'Race to the Bottom' competition between governments. Based on the above conclusions, we can make the following recommendations:

(1) China should accelerate the establishment of an improved modern fiscal system and rationally divide responsibilities for fiscal affairs and expenditure between central government and local governments. Central government should concentrate on reforming current fiscal

decentralization system. On the one hand, the central government should decentralize the fiscal power as it is currently doing, gradually expand the fiscal powers of local government and make it more compatible with expenditure responsibilities. In addition, on the basis of ensuring the fiscal expenditures required to develop the local economy, local government should gradually increase spending on environmental quality improvements. On the other hand, administrative powers should be adjusted upward on the current basis. China should extend the scope of responsibilities and expenditure of the central government in environmental management, realize a centralized environmental management system and gradually reduce the interference of local governments on environmental management. Meanwhile, we should further improve the fiscal transfer payment system and pass the environmental protection portfolios of higher governments to lower governments.

(2) China should improve the mechanism for the assessment and evaluation of officials, rationally guide the preferences of local government and establish a scientific and reasonable incentive mechanism for the performance assessment and evaluation of officials. For one thing, China should improve the performance evaluation system for local Communist Party and government administration officials, emphasize the importance of green GDP in the evaluation system for promotion of cadres, incorporate environment, education, health and other public utilities into the assessment projects beyond economic indicators, and examine the performances of local government officials from different perspectives. For another thing, the central government should carry out outgoing environmental audits, strengthen the accountability mechanism for the environmental responsibilities of officials and raise their willingness to improve environment quality.

(3) China should perfect both the legal system and market rules and prevent destructive environmental 'Race to the Bottom' competitiveness between governments. For one thing, China should further improve the legal system and market rules and build a competitive environment for the market economy which is conducive to the efficient flow of economic elements; this can be done through scientific constraints and reasonable regulations. For another thing, China should prevent excessive investment, cheap land supply and distorted allocation of resources without considering the environmental costs. We should also make efforts to establish a relatively healthy moderate competition mechanism and reverse the vicious competition strategy of local governments seeking rapid economic growth at the cost of sacrificing the environment.

Ethical Approval

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-Consent to Publish: Not applicable.

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Zhonghua Cheng: Conceptualization; Formal analysis; Methodology; Writing -original draft.

Yeman Zhu: Formal analysis; Writing-review & editing; Software.

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S1 the regression results of the effects of fiscal decentralization on $PM_{2.5}$ pollution and its volatility

Dependent variable	The fiscal expenditure decentralization		The fiscal income decentralization	
Independent variable	$PM_{2.5}$ pollution	Volatility	$PM_{2.5}$ pollution	Volatility
τ (dynamic factor)	0.226*** [6.82]	0.385*** [4.41]	0.274*** [7.36]	0.332*** [3.96]
ρ (spatial factor)	0.007*** [3.51]	-0.012* [-1.73]	0.009*** [4.34]	-0.016** [-2.13]
ln*D*	0.061*** [3.07]	0.116*** [5.62]	0.121*** [4.93]	0.076*** [3.52]
ln*P*	0.142*** [5.96]	0.327*** [7.45]	0.085* [1.78]	0.254*** [6.96]
ln*A*	0.150*** [2.50]	0.164** [2.12]	0.215** [2.21]	0.287*** [2.63]
$(\ln A)^2$	-0.007** [-2.21]		-0.015*** [-2.74]	
ln*T*	-0.065 [-1.06]	-0.258 [-1.32]	-0.082 [-0.73]	-0.195 [-0.93]
ln*S*	-0.109*** [-2.85]	-0.736 [-0.72]	-0.136* [-1.84]	-0.747 [-0.96]
ln*R*	0.065*** [5.32]	0.028*** [7.51]	0.144*** [6.85]	0.051*** [5.28]
H	0.024*** [4.26]	0.235*** [3.68]	0.049*** [4.38]	0.263*** [3.87]
*W*xln*D*	0.186*** [5.87]	-0.337* [-1.64]	0.451*** [3.48]	-0.276** [-2.23]
*W*xlnP	0.425*** [4.20]	0.236 [1.14]	0.258*** [3.62]	0.184 [0.75]
*W*xlnA	0.748 [1.26]	-0.847 [-0.75]	0.617 [1.05]	-0.586 [-0.62]
*W*x$(\ln A)^2$	0.098 [0.84]		-0.124 [-0.48]	
*W*xlnT	-0.024 [-0.58]	0.508 [1.24]	0.041 [0.57]	0.475 [0.78]
*W*xlnS	-0.078 [-0.95]	0.513** [2.02]	-0.096 [-0.84]	0.463*** [2.52]
*W*xlnR	0.659*** [7.97]	0.488*** [9.23]	0.465*** [8.17]	0.359*** [6.86]
*W*xH	0.105*** [5.26]	0.092*** [3.65]	0.163*** [5.78]	0.074*** [2.83]
LogL	3756.07	3249.26	3686.54	3134.43
AIC	0.5784	0.8293	0.6335	0.8784
SC	0.5936	0.8674	0.6476	0.8936
Obs.	3705	3705	3705	3705
Wald spatial lag	(0.000)	(0.000)	(0.000)	(0.000)
Wald spatial error	(0.000)	(0.000)	(0.000)	(0.000)
LR spatial lag	(0.000)	(0.000)	(0.000)	(0.000)
LR spatial error	(0.000)	(0.000)	(0.000)	(0.000)
Hausman test	(0.000)	(0.000)	(0.000)	(0.000)
Joint significance test for spatial fixed effect	(0.000)	(0.000)	(0.000)	(0.000)
Joint significance test for time fixed effect	(0.000)	(0.000)	(0.000)	(0.000)

Figures in parentheses represent t values. *,** and *** denote significance levels at 10%, 5% and 1%, respectively.