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Does the public haze pollution concern expressed on online platforms promoted pollution control? – Evidence from Chinese online platforms

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ABSTRACT

With the continuous deterioration of haze pollution and the increasing public awareness of environmental protection, more and more netizens are paying attention to the problem of haze pollution on online platforms, expressing environmental demands, supervising and accusing corporate pollution. Environmental concerns expressed by netizens on social media platforms exert strong public pressure on polluting enterprises with the popularity of smart phones. In this paper, a dynamic spatial econometric model is used to study the effects of network demand intensity on environmental pollution, taking into account the endogenous, regional differences and spatial spillover effects of explanatory variables. The total number of posts, likes, retweets, and comments on Weibo with the predefined search terms "haze" and the number of Baidu index comprised the public concern. Geographical detector model confirmed that the public's concern about haze pollution expressed on new media is closely related to haze condition. The results showed that new media network public opinion can alleviate haze pollution, but there are significant regional differences. From a regional point of view, the inhibition effect of new media network public opinion on haze pollution was the most significant in the central region, but it was not significant in the eastern and western regions. In addition, haze pollution showed obvious "cumulative effect" characteristics in the time dimension, and "spillover effect" characteristics in the space dimension.

1. Introduction

According to the data released by the World Health Organization (WHO) in 2016, nearly 92% people of the worldwide lived with serious air pollution. In more than 80% Chinese cities, $PM_{2.5}$ concentration severely exceed the World Health Organization (WHO) suggested standard and over 1.6 million people dead of disease which lead by air pollution. Serious haze pollution not only generate great harm to human health, but also impede the global sustainable development (Song et al., 2019; Zhao et al., 2018). Therefore, haze pollution is becoming a hot topic at present and an urgent problem need to be settled. (e.g., Izhar et al., 2021; Ding et al., 2019; Chen et al., 2020).

Haze pollution mainly occurs in the form of fog, that easy to be seen with the naked eyes and has received high attention from the government and the public in recent years (Wang et al., 2020; Zhang et al., 2019b). It is obvious that haze pollution has caused various of influence on people's life. With the continues aggravating of haze pollution, environmental awareness of the public began to awaken, environmental demands upsurge, government is strongly requested to perform environmental governance responsibility (Li et al., 2020). However, "negative externality" character of haze pollution, coupled with public goods attributes of environmental governance, add the ambiguity of property rights make environmental governance face the risk of "market failure" under the market mechanism. Local governments at all levels have taken effective methods to supervise and manage environmental pollution. However, in the process of environmental governance by local governments, governance behaviors will be distorted due to competition in "economic championships" or local financial constraints (Forsyth, 2014). In addition, the problem of "government failure" in environmental governance has become increasingly prominent.

As the direct victims or stakeholders of environmental pollution, the public will conduct all-round supervision over environmental pollution through environmental petitions, environmental organization intervention and environmental litigation, so as to improve the scientific

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nature of the government's environmental governance policies, the effectiveness of law enforcement and the pertinence of investment. Therefore, public participation in environmental protection is an important way to improve the level of environmental governance in China and to solve the problem of "government failure" in environmental governance (Li et al., 2020a).

In recent years, more and more members of the public and non-governmental environmental organizations have openly appealed to the government and relevant departments to solve some urgent environmental problems. In view of the environmental infringement or environmental hidden danger that has been or will be introduced in the government policy, the public openly appeals and protests to the government and relevant departments, so as to participate in the formulation and adjustment of relevant environmental policies. Whether the haze pollution concern expressed on public online platforms promoted pollution control is a question remained to be explored.

This paper tries to exam the effect of the public concern expressed on online platforms on haze pollution. The innovation of this paper is mainly reflected in the following aspects: Compared with the traditional method of measuring the intensity of online public opinion through search volume (Li et al., 2021), this paper takes "haze" as a predefined search term and uses the number of posts, likes, retweets, and comments on obtained by Sina Weibo crawler to measure it. In this way, the intensity of public opinion on Sina Weibo network can be measured more accurately and objectively. Finally, combining with Baidu index, the new media network public opinion index is established to discuss whether new media network public opinion can promote haze pollution control.

As shown in Fig. 1, the structure of this paper is organized as follows: Section 2 put forward the hypothesis of this paper based on the literature review. Section 3 introduced theories of geographical detector model and spatial econometric model. Section 4 summarized the experimental results. Section 5 concluded the conclusion and put forward some policy suggestions.

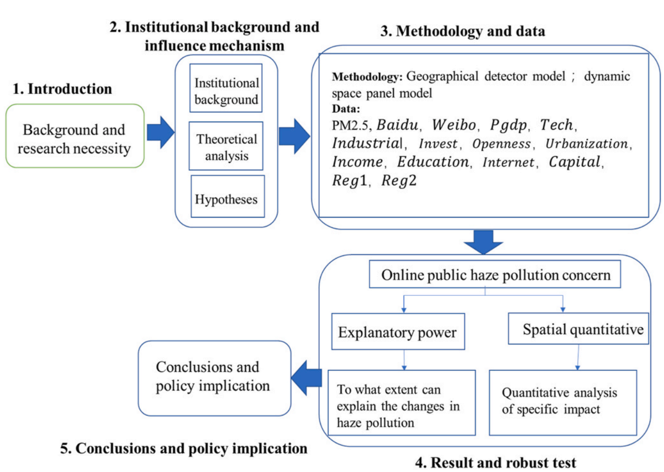

Fig. 1. Basic ideas for thesis research.

2. Literature review and research hypothesis

2.1. Literature review

With the enhancement of the public awareness of environmental protection and the increase of the power of environmental supervision, more and more studies have begun to pay attention to the impact of the public's environmental demands on haze pollution (Komendantova et al., 2021; Li et al., 2021).

Study on the legal rationality and willingness of public participation. Wu and Hong (2015) took China's environmental governance policy as an example to study the interactive relationship between public participation and government decision-making in the process of environmental policy making. Their results showed that the government-led air pollution prevention and control work has a continuous "pulling effect" on the introduction of environmental governance policies, and the social pressure formed by public opinion and behavior has a continuous "driving force" on the introduction of environmental governance policies. The official introduction of environmental governance policy is the result of "push and pull joint force". Zhou and Zhang (2020) explored the internal hierarchical structure and interaction mechanism of public participation in environmental protection, as well as the influence mechanism of external factors on public environmental protection participation. The empirical analysis results found that public environmental protection participation presenting obvious gradations, and there is a significant positive interaction mechanism between all gradations.

Research on environmental regulation structure and modern public participation function in China. Based on panel data from 30 provinces in China from 2003 to 2013, Li (2017) empirically examined the impact of online and offline public participation on the effectiveness of local government environmental governance. They found that environmental groups, i.e. the National People's Congress (NPC) and the Chinese People's Political Consultative Conference (CPPCC) played a positive role in promoting legislation at the NPC, while the average daily level of environmental web searches did not play a significant role. Zhang et al. (2020) took the number of pages of provincial air pollution projects from 2000 to 2012 obtained by Baidu search engine as the measure of network public opinion, and analyzed the effect of network public opinion on haze mitigation by using spatial measurement. They found that online public opinion has played a positive role in alleviating haze pollution. Zhang et al. (2019) analyzed the impact of public participation on the environmental regulation policy results of local governments by using the provincial panel data from 2007 to 2014, aiming to further observe the significance of public participation and local government environmental regulation on the environmental governance effect.

Study on the level of public participation and its effects on environmental governance and economic and social development. Liao (2018) analyzed the impact of public supervision and public environmental participation policies on the efficiency of industrial pollution treatment, and believed that public environmental participation had a positive effect on environmental pollution treatment and could slow down the deterioration of environmental conditions. Ouyang et al. (2020) empirically investigated the impact of different ways of public participation on environmental governance results from the perspective of new media. Results showed that the effect of public participation in new media channels on environmental governance is better than that of traditional channels, and the effect of internet search is the best. Guo and Xu evaluated the impact of public participation on environmental governance by using the 2011–2015 provincial balance panel data in China. The study found that public participation in environmental governance can not only indirectly participate in environmental governance through government environmental law enforcement, but also directly participate in environmental governance through deterrence to polluting enterprises.

Through reading the literatures on the mechanism and effect of informal environmental regulation on environmental pollution (Zhang et al., 2019; Ouyang et al., 2020), we find that new media represented by Sina Weibo and Baidu (as shown in Fig. 2) accelerated the speed of information dissemination and provided a platform for the public to express their opinions and comments on environmental pollution incidents. These opinions spread through the internet and eventually form a consensus, forming a powerful force of public opinion, having a huge impact on polluting enterprises and realizing the supervision and control of environmental pollution. It is noted that literatures have discussed the influence of network public opinion on environmental pollution control, but few studies use the number of posts, likes,

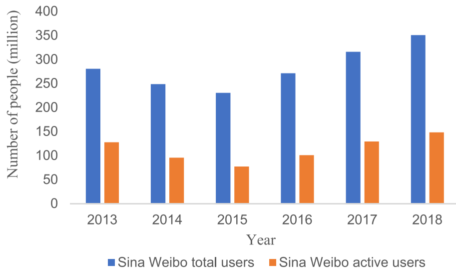

Fig. 2. Sina Weibo user's data.

retweets, and comments on Weibo to express the intensity of Weibo online public opinion.

As we all know, particulate matter, SO_2 and NOx are the main components of haze. However, $PM_{2.5}$ is a key contributor to haze pollution (Zhang and Li, 2017). Before developing strategies to deal with haze pollution, it is necessary to understand the explanatory power of the driving factors of haze. (Wu et al., 2020). Decomposition analysis method is a common method to study the change of factors' driving force, of which Index decomposition analysis (IDA) and structural decomposition analysis (SDA) are two typical ways used wildly in recently research. Both approaches have been used in a series of studies to address the drive force of decomposition factors (e.g., Su and Ang., 2016). The new spatial geographic detector model proposed by Wang et al. (2017) in 2017 can solve the same problem. Compared with IDA and SDA, it has obvious advantages in evaluating the interaction between factors. Geographical detector model is a spatial statistical method based on spatial heterogeneity to reveal the driving forces of factors. Because of its beautiful shape and clear physical meaning, it is widely used in various fields.

2.2. Theoretical basis and hypotheses

Traditional econometric approaches ignored the spatial autocorrelation of haze pollution, violating the "first law of geography", which states that everything is related to other things, but things that nearer are more related than things that are far away. Air resources are non-exclusive and shared public goods. The mobility of the atmosphere leads to the diffusion and transfer of haze pollution between neighboring provinces, leading to the emergence of regional haze clustering characteristics. Thus, the following hypotheses are put forward:

H1. Haze pollution has an obvious spatial correlation character. It is appropriate to use spatial econometric methods to deal with the influence of the new media network on haze.

The traditional means of public participation in environmental governance include letters, petitions, environmental groups, rallies and demonstrations, as well as proposals from the National People's Congress and the Chinese People's Political Consultative Conference. However, the traditional way of public participation has weak feedback, limited transmission scope and influence degree, and high participation cost. As a social platform in China, Sina Weibo has a strong influence and penetration. Sina Weibo users continued to grow, with 241 million daily active users and 550 million monthly active users. Besides, Baidu is China's largest search engine and the main way for the public to access new information. Data in above two social platforms is reprehensive enough to on behalf of the public's concern.

Compared with traditional complaint channels, new media represented by the internet and mobile internet are characterized by immediacy, openness, interaction and openness, providing information support for public participation and creating public space. It has greatly improved the public's voice and participation enthusiasm, especially in promoting the formulation of policy agenda, the unity of stakeholder groups, and the innovation of the interaction and communication mechanism between the government and the public. Public participation in environmental governance has gradually become a new way of governance. With the expansion of the scope of government environmental information disclosure, as well as new media channels such as Weibo and WeChat, more and more people have begun to consciously and systematically express their concern for environmental pollution and the urgent need for environmental governance. Therefore, the following hypotheses is put forward in this study:

H2. In typical new media online public opinion platforms, Sina Weibo and Baidu will have a positive impact on haze pollution control.

New media has become a crucial way for the public to obtain information, express their willingness, participate in environmental decision-making, supervise environmental management and law enforcement, and express green choices. It provides many opportunities for the establishment of environmental protection information sharing mechanisms, public consultation mechanisms, supervision mechanisms, and in-depth exchange and interaction mechanisms among various subjects. As shown in Fig. 3, the distribution of online public opinion between Sina Weibo and Baidu is unbalanced, leading to differences in the effect of new media online public opinion. Therefore, the following hypotheses are proposed in this study.

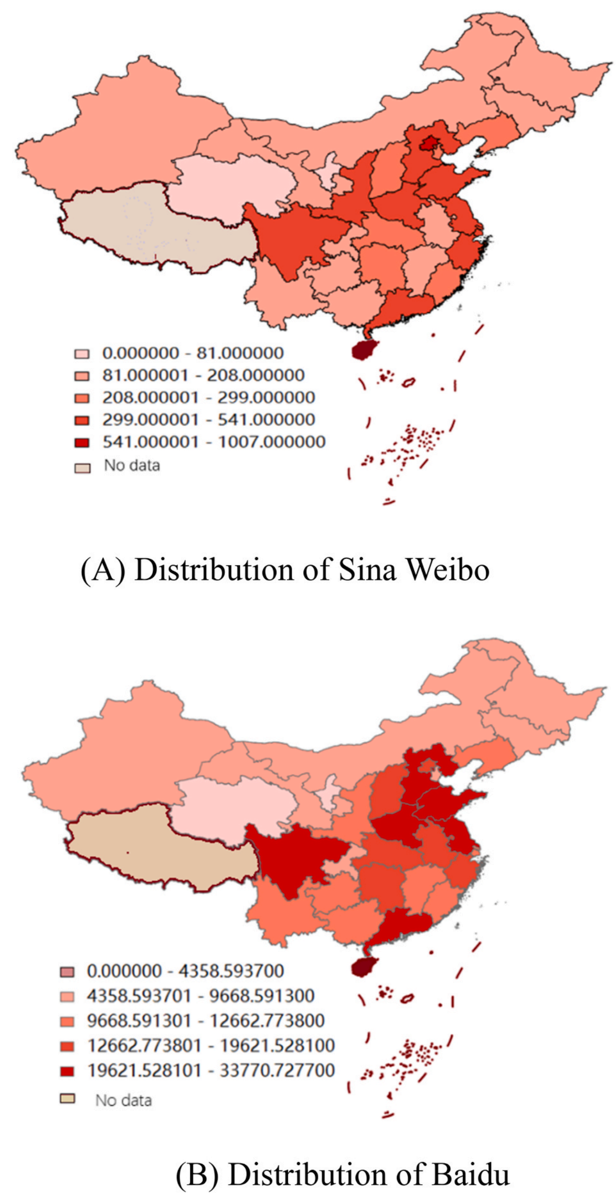

Fig. 3. The distribution of public opinion intensity in the new media network.

H3. New media network public opinion is conducive to haze pollution control.

H4. The positive effect of new media network public opinion on haze pollution control varies from region to region.

3. Econometric model and data description

3.1. Data source and index processing

Explained variable: The average annual concentration of $PM_{2.5}$ in each province. Many researches use $PM_{2.5}$ concentration to measure haze pollution, which reflects its scientific nature and effectiveness (e.g., Zhang et al., 2020b; Huang et al., 2017). A satellite-based grid of global mean $PM_{2.5}$ concentrations published by Columbia University's Socio-Economic Data Center was used in this paper. Satellite Aerosol Optical Thickness (AOD) data has been available since 1998 and covers the largest area (Donkelaar et al., 2010). This kind of data is generally considered valid and scientific.

Core explanatory variables: New media network public opinion. Since Sina Weibo and Baidu are the most commonly used suggestion feedback websites and also the most widely used mobile applications by the public, therefore, we used data obtained from Sina Weibo and Baidu to conduct experiments. Firstly, we obtained the data of Sina Weibo and Baidu index online (http://index.baidu.com/v2/index.html#/). The number of posts, retweets, likes, comments on with the predefined search terms "haze" obtained by the Python crawler on Sina Weibo is selected to represent the public opinion on Sina Weibo. Then, the entropy method is used to integrate it into the new media network public opinion index.

Other control variables: The level of economic development was represented by the per capita GDP of each region, and the GDP index in the 2000 base period was adopted to adjust for deflation. Technological innovation is measured by the equivalent of full-time R&D and experimental developers in each province. Industrial structure is expressed with industrial structure rationalization index. The rationalization of industrial structure refers to the quality of industrial aggregation, which reflects the degree of coordination between industries and the effectiveness of resources. The calculation of the industrial structure rationalization index referred to the calculation method of Tian et al. (2021), TL = i = 1nYiYln-(YiLi/YL). Where, TL represents Theil index, Y denotes output value, L refers to employment, i stands for industry, and n indicates the number of industrial sectors. The level of investment in environmental governance is expressed by the proportion of investment in environmental governance in real GDP. The level of urbanization is expressed by the urbanization rate.

The income level of residents is represented by the urban-rural income gap Teil index. The imbalance between urban and rural development has gradually become an important factor restricting the balanced development of China's economy. We use Theil index to measure the urban-rural income gap. T = i = 1nFiFln-(FiPi/FP),Where, F represents the total income (economic input or output) of the country (or all regions), Fi denotes the income (economic input or output) of the ith region, P refers to the total population of the country, and Pi is the total population of the ith region. The value range of T is [0, ln(N)], where T = 0 means complete equality, and ln(N) means extremely inequality (a certain bank creates all net profits), and N means the number of researched banks.

The education level of the public is denoted by the average years of education. The calculation method is: (Population with elementary school education*6+Population with junior high school education*9+Population with high school education*12+Population with college education and above*16)/Sample population over six years old. The development level of the internet is expressed by the penetration rate of the internet. Capital input is represented by fixed capital formation per capita, with data from the Wind database. Government work is divided into government environmental management intensity and government environmental economic regulation, represented by the total member of provincial governments in the environmental protection system and the amount of pollutant discharge fees levied respectively.

The original data of each variable comes from "China Statistical Yearbook", "China Environmental Statistics Yearbook", "China Environment Yearbook", "China Science and Technology Statistical Yearbook" and statistical yearbooks of each province. The definition and descriptive statistics of each variable are shown in Table 1.

As shown in Table 1, the average annual average concentration of the explained variable ($PM_{2.5}$) is 40.237, and the difference between the minimum value 10.487 and the maximum value 82.379 is large, indicating that there are large differences in the level of haze pollution among provinces. The minimum value 47 and maximum value 1119 of Baidu index exists quite difference. In addition, the minimum value 1003.676 and the maximum value 64312.80 of the number of microblogs have great difference, indicating the difference among the level of new media network public opinion of each province are huge. Therefore, it is reasonable and necessary to analyze according to regional division.

3.2. Geographical detector model

The existence or not of the spatial dependence directly decided the choice of the method. In order to figure out whether spatial dependence exist, we use the most popular method- Moran's I to explore it. Moran's I has the most accuracy when investigate the existence of the spatial dependence. The calculate formula are as follows:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}(x_i-\overline{x})(x_j-\overline{x})}{\sum_{i=1}^{n}(x_i-\overline{x})^2} \tag{1}$$

$$I_i = \frac{(x_i-\overline{x})}{S^2}\sum_{j=1}^{n}\omega_{ij}(x_j-\overline{x}) \tag{2}$$

Where, ω_{ij} is the element in the spatial weight matrix; x_i represents haze observation value of the i th province; $\overline{x} = \frac{1}{\sum_{i=1}^{n}x_i}$, $S^2 = \frac{\sum_{i=1}^{n}(x_i-\overline{x})^2}{n}$.

When calculate the global Moran's I, equation (1) was used. Equation (2) was applied to calculate the local Moran's I. Moran's I value range from −1 to 1. If the value is greater than 0, represents positive autocorrelation. If Moran's I value smaller than 0, denotes negative autocorrelation. The Moran's I value closer to 0, showing the spatial distribution is random and no spatial autocorrelation existed.

Geographical detector model is a spatial statistic method based on the spatial autocorrelation theory (Wang and Xu, 2017). The theoretical basis of this model is that the more similar the spatial distribution of any of the driving factors is to haze pollution, the closer the relationship between them will be. One of the advantages of this model is that it has no data type constraints and is good at analyzing type variables. Other data types, such as serial or ratio quantities, can also be studied by discretization. In addition, the interaction detector is another bright spot. The most commonly used method to study the interaction between factors is to add cross terms to the regression equation. However, factors are not always related through multiplication. The Geographical detector model overcomes this shortcoming by comparing the q value of single factor and the q value of superimposed two factors. Whether it's linear or non-linear, you can find any relationship that exists.

Geographical detector model has four detectors, respectively are factor detector, interaction detector, ecological detector and risk detector. In this paper, factor detector has been used to solve problems. The factor detector was used to investigate the extent to which factor X explained the spatial heterogeneity of feature Y. It is measured by the q statistic, which is calculated as:

Table 1
Variable descriptive statistics.

Variables	Explanation	Mean	Std. Dev.	Min	Max
PM2.5	The average annual concentration of $PM_{2.5}$ (ug/m^3)	40.237	15.494	10.487	82.379
Baidu	Baidu index	290.353	190.046	47	1119
Weibo	Number of Sina Weibo	15148.070	10264.660	1003.676	64312.8
Pgdp	GDP per capita/10000 yuan	54480.930	24262.640	23151.000	128994
Tech	R&D and experimental development full-time personnel equivalent (person-year)	126052.900	134645.90	4008.000	565287
Industria l	Industrial structure rationalization index	0.960	0.328	0.256	1.836
Invest	Pollution control investment/GDP	2.246	1.395	0.395	7.023
Openness	Actual use of foreign capital/10,000 yuan	5365281	5009944	1039.219	20600000
Urbanization	Urbanization rate/%	57.667	11.935	37.830	89.600
Income	Teil index of urban-rural income gap	0.096	0.042	0.020	0.220
Education	Average years of education/year	9.331	0.943	7.662	13.227
Internet	Internet penetration rate/%	50.856	11.115	32.462	78.000
Capital	Per capita fixed capital formation/yuan	3.181	1.270	1.355	7.475
*Reg*1	The total number of people in the government environmental protection system	6984.600	5057.976	901.000	27017
*Reg*2	Sewage discharge fee collection amount/10000 yuan	65266.850	49907.140	3146.000	254114

$$q = 1 - \frac{\sum_{h=1}^{L} N_k \sigma_k^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \tag{3}$$

$$SSW = \sum_{h=1}^{L} N_k \sigma_k^2 \tag{4}$$

$$SST = N\sigma^2 \tag{5}$$

where, q denotes the explanatory power degree of factor x_i; $h = 1, \cdots, L$ represent the strata of the dependent variable Y or factor X; N_k and N are strata h and whole region respectively. SSW and SST represent the sum of inner squares and the total sum of squares respectively.σ_k^2 means the variance of the strata h, σ^2 stands for the variance of the Y value in total region. q ranges from 0 to 1.

The value of q measure the explanatory power of variable X. If the value of X is closer to 1, then the independent variable x has a better explanation for the variable Y. A q value of 0 means that the variable X has nothing to do with the dependent variable Y.

3.3. Spatial quantitative model

Due to the spatial overflow characteristics of air pollution, spatial factors need to be considered. In addition, air pollution is dynamic and continuous. The haze pollution in the previous period will have an impact on the haze pollution control in the current or lag period. Therefore, the dynamic space panel model was selected.

$$\begin{aligned} lnPM2.5_{it} = {} & \lambda lnPM_{i,t-1} + \rho W \times lnPM2.5_{i,t} + a_0 lnPio_{i,t} + a_1 lnPgdp_{i,t} \\ & + a_2 lnTech_{i,t} + a_3 lnIndustrial_{i,t} + a_4 lnInvest_{i,t} + a_5 lnOpenness_{i,t} \\ & + a_6 lnUrbanization_{i,t} + a_7 lnIncome_{i,t} + a_8 lnEducation_{i,t} + a_9 lnInternet_{i,t} \\ & + a_{10} lnCapital_{i,t} + a_{11} lnReg1_{i,t} + a_{12} lnReg2_{i,t} + \varepsilon \end{aligned} \tag{6}$$

Where, i and t are province and year respectively; *Pio* represents new media network public opinion index; W denotes the spatial weight matrix. In order to ensure the robustness of the regression results, three space weight matrices are constructed. The first is the geographical distance spatial weight matrix (W^C), whose elements are represented by the reciprocal of the nearest highway mileage between provincial capitals. The second type is the economic distance spatial weight matrix (W^E), whose elements are represented by the reciprocal of the absolute value of the difference between the average per capita GDP of region i ($\overline{g_i}$) and the average per capita GDP of region j ($\overline{g_j}$) in the study area. $W^E = 1/\left|\overline{g_i} - \overline{g_j}\right|$,$i \neq j$. The third is the nested spatial weight matrix of economic geography (W^{CE}). According to the practice of Li et al. (2017), the weighted sum of the spatial weight matrix of geographical distance and the spatial weight matrix of economic distance is used to represent it. For simplicity, each weight is 0.5. *Pio* denotes the new media network public opinion index.

4. Empirical analysis

4.1. Explanatory power of factors results

Before calculating the Moran's I value, we need to make a statistical analysis to obtain the mean value of the each province's PM2.5 concentration by gridding statistics data. Export the data in the form of shp file and import into the GeoDa. We can acquire the spatial weighting matrix in the GeoDa. Finally, Moran's I value is calculated.

As shown in Table 2, Moran's I value of haze calculated by utilizing the Geoda. Results show that all Moran's I value passed the significant test at 1% level, and the value varied from 0.6 to 0.85 showing high spatial dependence. The positive value indicates the significant positive autocorrelation exists in the seven years, which also means high values are adjacent to high values、low values are adjacent to low values. According to the analysis above, we can draw the conclusion that it's necessary to take the spatial influencing factor into consideration. Hypothesis 1 is confirmed.

$PM_{2.5}$ concentrations are affected by many factors. In order to clarify the explanatory power of haze pollution, this paper adopts the geographic detector model. We have examined all the explained factors used in this paper using geographic detector model. However, Columbia University's Center for Social and Economic Data and Applications publishes satellite-monitored global averages PM2.5 concentration raster data has only updated to the year of 2016. Limited by data, we calculated the explanatory power of factors in the last four years.

As shown in Table 3, the explanatory power of new media network public opinion has a remarkable impact on haze pollution in China. Both Sina Weibo and Baidu are vital for the variation of $PM_{2.5}$ concentration. Hypothesis 2 is confirmed. The public acts as vital role in haze control, social media to express concern is no doubt an important path. It indicates the necessarily to further examine the effect of the concern

Table 2
Moran's I value.

	2016	2015	2014	2013	2012	2011	2010
Moran's I value	0.846	0.653	0.662	0.660	0.673	0.672	0.648
p	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Table 3
Explanatory power evolution of factors.

Variables	2013	2014	2015	2016	Average
Baidu	0.503	0.454	0.361	0.303	0.405
Weibo	0.478	0.456	0.310	0.325	0.392
Pgdp	0.037	0.049	0.154	0.153	0.098
Tech	0.402	0.412	0.355	0.361	0.383
Industria l	0.296	0.392	0.288	0.359	0.334
Invest	0.219	0.271	0.303	0.231	0.256
Openness	0.003	0.471	0.366	0.422	0.316
Urbanization	0.081	0.113	0.156	0.122	0.118
Income	0.080	0.162	0.506	0.496	0.311
Education	0.136	0.224	0.119	0.093	0.143
Internet	0.094	0.287	0.113	0.061	0.139
Capital	0.172	0.337	0.211	0.102	0.206
*Reg*1	0.377	0.293	0.239	0.258	0.292
*Reg*2	0.257	0.262	0.299	0.385	0.301

All the results of q value is significant at 1% level.

people expressed on social platform on haze control. Since haze pollution is affected by various factors in social life, all control variables will have more or less effects on haze pollution.

4.2. Spatial quantitative results

Panel data estimation usually involves the choice of random effects model or fixed effects model. The Hausman test was used to determine whether the fixed effect (FE) or random effect (RE) was used. According to the test results, Chi^2 is 67 and P is 0.000. At the significance level of 1%, the null hypothesis of the random effects model is rejected, so the fixed effects model is selected. Taking the annual average $PM_{2.5}$ concentration of 30 Chinese provinces (autonomous regions and municipalities directly under the central government) from 2014 to 2017 as the explanatory variable (Tibet, Hong Kong, Macao and Taiwan were not analyzed), using the new media network public opinion index and other control variables as the explanatory variable, Model (6) was applied to the fixed-effect regression. The regression results of the influence of new media network public opinion on haze pollution under the three spatial weight matrices are shown in Table 4. *Wald* and *Log* − *Likelihood* test values show that the model fitting effect is well.

As can be seen from the third column of Table 4, the lag coefficient of haze pollution is significantly positive, indicating that $PM_{2.5}$ concentration in the early period has a significant positive impact on the current period, that is, with the passage of time, haze pollution continues to increase. This means that the task of environmental control is arduous and urgent, and pollution control needs no delay. Otherwise, with the continuous accumulation of pollutants, the difficulty of treatment will increase. From the point of view of model selection, the estimation result of spatial dynamic panel is more reliable.

From the spatial dimension, the environmental pollution lag coefficients under the three spatial weight matrices are all significantly positive, indicating that the environmental pollution has a significant spatial spillover effect. Hypothesis1 is twice confirmed. Driven by multiple natural factors such as rainfall, wind direction, and atmospheric circulation, as well as social and economic factors such as inter-regional industrial transfer and industrial trade, the pollution situation in this region is closely associated with the areas with close geographical distances or economic geographical distances. It shows the characteristic of "club convergence", that is, the pollution control must adopt the coordinated control strategy of regional joint prevention and control. Otherwise, the "leakage effect" of inter-regional pollution will occur, making the "unilateral governance" of a single government inefficient. The spatial interaction effect of environmental pollution is greater than the time lag effect, that is, the spatial "spillover effect" of haze pollution

Table 4
Estimation results of dynamic spatial panel model.

Variable	Geographical distance spatial weight matrix (W^C)	Economic distance spatial weight matrix (W^E)	Nested spatial weight matrix of economic geography (W^{CE})
$lnPM_{i,t-1}$	0.2407 (0.154)	0.3948* (0.195)	0.2434 (0.167)
$W \times lnPM2.5_{i,t}$	1.0343*** (0.114)	0.7698*** (0.138)	0.9939*** (0.129)
$lnIpo_{i,t}$	−0.0691* (0.029)	−0.0966** (0.035)	−0.0764*** (0.032)
$lnPgdp_{i,t}$	0.2169 (0.256)	0.2280 (0.311)	0.2612 (0.278)
$lnUrbanization_{i,t}$	0.6637 (0.908)	0.2965 (1.105)	0.7607 (0.994)
$lnIncome_{i,t}$	0.2681 (0.120)	0.2856* (0.145)	0.2792* (0.130)
$lnInvest_{i,t}$	−0.0180 (0.031)	−0.0280 (0.037)	−0.0219 (0.033)
$lnTech_{i,t}$	−0.1124 (0.153)	−0.1655 (0.184)	−0.1300 (0.165)
$lnOpenness_{i,t}$	0.0039* (0.011)	0.0046 (0.013)	0.0045 (0.118)
$lnEducation_{i,t}$	0.8831* (0.363)	0.8583* (0.441)	0.8269* (0.394)
$lnCapital_{i,t}$	−0.1452* (0.129)	0.7698 (0.158)	−0.1820 (0.141)
$lnInternet_{i,t}$	−0.1045* (0.223)	−0.1930 (0.266)	−0.1780 (0.240)
$ln\mathrm{Industrial}_{i,t}$	0.0752 (0.175)	−0.3306 (0.211)	0.1085 (0.189)
$lnReg1_{i,t}$	0.0346 (0.175)	−0.0444 (0.131)	−0.0159 (0.117)
$lnReg2_{i,t}$	−0.0210 (0.032)	−0.0706* (0.038)	−0.0382 (0.034)
cons	5.2778	−1.6514	4.4777
Wald test(*p*)	268.5214 (0.000)	159.8388 (0.000)	217.8968 (0.000)
Log − *L*	−153.3462	−103.4528	−142.9599
Sargan(*p*)	228.1673 (0.1264)	217.951 3 (0.1853)	209.6514 (0.1965)

Note: ***, **, * indicate that the coefficient test is significant at 1%, 5%, and 10% respectively.

is greater than the dynamic continuous "cumulative effect". Haze pollution shows continuous, cumulative, and intersecting evolution characteristics in the time dimension, space dimension, and space-time dimension.

Taking 30 provinces as samples, under the three spatial weight matrices, the regression coefficients of the new media network public opinion index are all significantly negative, indicating that the public opinion of "haze" pollution on Weibo and Baidu plays a certain role in pollution control. This result is consistent with the expectation of Hypothesis 3 in this paper.

According to relevant studies, the impact of haze pollution on new media networks such as Weibo and Baidu mainly come from two aspects. First of all, polluting enterprises will be exposed on the Internet, which in turn will affect the corporate image and market reputation, such as the collapse of stock prices and the national boycott of the purchase of the company's products, which will directly affect the pollution behavior of enterprises. On the other hand, the government will strengthen environmental inspections on enterprises to reduce pollution discharge. In recent years, with the spread of smartphones, the public's access to information has increased. Once a piece of information enters the hot search list of Weibo, it will be read hundreds of millions of times. When a polluting enterprise causes a hot topic, its stock price and image will be negatively affected, and its emission will be adjusted or shut down.

In the control variables, under the three spatial weight matrices, the regression coefficients of per capita GDP are all positive, but not significant, indicating that China is still in the stage of increasing pollution with GDP growth. The problem that economic growth restricts environmental regulation still exists, and the task of transforming the mode of economic development remains the current one. The regression coefficient of urbanization is positive but not significant, indicating that the improvement of living standard in the process of urbanization brings excessive energy consumption and pollution emission. The regression coefficient of urban-rural income gap is positive at the significant level of 10%, indicating that the expansion of urban-rural income gap will aggravate environmental pollution.

The impact of the urban-rural income gap on the environment is mainly reflected in two aspects. On the one hand, the income of urban residents is growing faster than that of rural residents, and the gap between urban and rural incomes is widening. Rural residents still have relatively low incomes, and their income is mainly used for basic living expenses such as housing and cars. These products will lead to energy inefficiency in the production sector. On the other hand, with the widening of the income gap between urban and rural areas, the hourly income of low-income people is getting lower and lower. In order to meet the basic needs of family members, they must do more work than those with higher incomes. Therefore, there is no time and money to learn professional knowledge and improve their labor skills. Moreover, in the same unit of energy consumption, the GDP created by low-skilled workers is lower than that of high-skilled workers, that is, the energy consumption per unit of GDP is higher, which limits the improvement of energy productivity and reduces energy efficiency.

The regression coefficient of pollution control investment is negative, but not significant, indicating that the capital investment in pollution control can achieve the purpose of alleviating pollution, but the effect is relatively limited. The regression coefficient of technological innovation is negative, but not significant, indicating that technological progress will improve productivity and resource utilization efficiency, reduce the input of factors in the production process, and finally weaken the impact of production on the natural environment. In addition, the development, application, renewal and replacement of pollution technologies will also effectively reduce pollution emissions. At the significance level of 10%, the regression coefficient of FDI is positive, indicating that foreign-invested enterprises will have a negative impact on China's environmental pollution, which supports the "pollution paradise" theory.

The regression coefficient of the average number of years of public education is positive and significant at the significant level of 10%, indicating that the improvement of public education level has not alleviated environmental pollution. The level of public education will affect the daily energy conservation and environmental protection behavior of resident. However, due to the imperfection of public education facilities in China, the current level of public education has no effect on reducing environmental pollution. On the other hand, as the number of years of public education increases, more human capital will be invested in non-GDP productive activities, reducing energy efficiency.

The coefficient of fixed capital formation per capita is negative, indicating that the increase of investment level has no negative impact on environmental pollution. The regression coefficient of the

Table 5
Dynamic panel model estimation results by region.

Variable	East			Mid			West		
	W^C	W^E	W^{CE}	W^C	W^E	W^{CE}	W^C	W^E	W^{CE}
$lnPM_{i,t-1}$	1.6269***	1.5673**	1.2364*	1.4571**	2.3051**	2.2508**	1.6147**	2.7413***	1.6147**
	(0.244)	(0.528)	(0,478)	(0.445))	(0.811)	(0.720)	(0.543)	(0.715)	(0.543)
$W\times\ lnPM2.5_{i,t}$	0.2237***	1.0417**	1.4924***	1.4827***	2.0295***	1.8039***	0.9289	0.0785 (1.160)	0.9289
	(1.647)	(0.383)	(0.323)	(0.366)	(0.516)	(0.438)	(0.811)		(0.811)
$lnIpo_{i,t}$	−0.0784	−0.1191	−0.0852	−0.2013*	−0.1938*	−0.1822*	−0.1677	−0.1868*	−0.1677
	(0.0744)	(0.088)	(0.051)	(0.091)	(0.090)	(0.086)	(0.105)	(0.109)	(0.105)
$lnPgdp_{i,t}$	1.5155**	1.0843	0.8570*	0.8845	0.2776	0.7148	0.0176	0.5044 (1.024)	0.0176
	(0.453)	(0.815)	(0.434)	(0.861)	(0.824)	(0.782)	(1.048)		(1.048)
$lnUrbanization_{i,t}$	0.4262	5.1212	−1.1765	−3.3607	−1.8098	−2.3830	2.6459	1.1278 (2.674)	2.6459
	(1.562)	(6.429)	(2.108)	(2.519)	(2.968)	(3.017)	(2.700)		(2.700)
$lnIncome_{i,t}$	−0.2920	0.4244	0.2410	0.7972*	0.9187*	0.8452*	0.9131*	0.9359 (0.557)	0.9131*
	(0.428)	(0.451)	(0.205)	(0.366)	(0.377)	(0.367)	(0.513)		(0.513)
$lnInvest_{i,t}$	0.0909	0.0532	−0.0049	−0.0110	−0.0100	−0.0078	−0.0933	−0.1538	−0.0933
	(0.059)	(0.098)	(0.065)	(0.056)	(0.057)	(0.055)	(0.115)	(0.113)	(0.115)
$lnTech_{i,t}$	0.1306	0.2855	−0.0987	0.0699	0.4925	0.2299	−0.4148	−0.2768***	−0.4148
	(0.385)	(0.654)	(0.418)	(0.497)	(0.583)	(0.575)	(0.333)	(0.400)	(0.333)
$lnOpenness_{i,t}$	0.0374*	0.0369	0.0209	−0.0283	0.0325	0.0258	−0.0718	−0.0613	−0.0718
	(0.0149)	(0.028)	(0.016)	(0.090)	(0.075)	(0.068)	(0.054)	(0.055)	(0.054)
$lnEducation_{i,t}$	1.3481	0.7096	0.2563	1.6754	0.7521	0.9859	1.7297*	1.2646 (1.136)	1.7297*
	(0.889)	(1.317)	(0.715)	(0.987)	(1.029)	(0.999)	(0.956)		(0.956)
$lnCapital_{i,t}$	−0.5664*	−1.0903*	−0.7349	0.5151	0.8957	0.7358*	0.5678	0.5368 (0.475)	0.5678
	(0.301)	(0.439)	(0.275)	(0.424)	(0.418)	(0.428)	(0.439)		(0.439)
$lnInternet_{i,t}$	−0.1787	−0.2232	−0.2401	−0.3046	−0.3233	−0.6081	−3.0039*	−3.7886*	−3.0039*
	(0.312)	(0.510)	(0.306)	(0.524)	(0.657)	(0.659)	(1.345)	(1.411)	(1.345)
$lnIndustrial_{i,t}$	−0.0993	0.8493	0.3665	−0.6710	−0.9200	−0.7607	−0.3891*	−0.6289	−0.3891
	(0.343)	(0.569)	(0.363)	(0.619)	(0.659)	(0.636)	(0.564)	(0.597)	(0.564)
$lnReg1_{i,t}$	−1.3938**	−0.1364	−0.4308	−0.4443	−0.1134	−0.2759	0.1640	0.0555 (0.213)	0.1640
	(0.497)	(0.898)	(0.585)	(0.714)	(0.689)	(0.665)	(0.217)		(0.217)
$lnReg2_{i,t}$	−0.0244	−0.1206	−0.0532	−0.0939	0.0058	−0.0689	−0.2106	−0.2824	−0.2106
	(0.070)	(0.103)	(0.483)	(0.176)	(0.195)	(0.183)	(0.171)	(0.166)	(0.171)
cons	−5.4782	−4.5679	−2.6196	−23.1078	−2.3142	−6.1976	−11.8413	−25.2732	−11.8413
$Waldtest(p)$	174.1454	42.1218	95.6658	98.2160	94.8531	103.1859	79.1853	77.3805	79.1853
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$Log-\ L$	−32.8328	−20.9940	−17.3548	−5.0623	−4.4699	−4.9486	−0.7986	−19.3185	−0.7986

Note: (1) ***, **, * indicate that the coefficient test is significant at 1%, 5%, and 10% respectively. (2) East, middle, and west regions are divided referring to the traditional regional division method. The eastern region includes 12 provinces, autonomous regions and municipalities:Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi, and Hainan; Central region includes 9 provinces and autonomous regions:Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan; Western region includes 9 provinces, autonomous regions, and municipalities:Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Ningxia, Qinghai, and Xinjiang. Missing data in Tibet, Hong Kong, Macao, and Taiwan are too much, which are not included in the scope of the study.

development level of the Internet is negative, indicating that the development of the Internet has broadened the regulatory channels for polluting enterprises. In terms of government work, the effect of increasing administrative personnel on pollution control is not obvious, indicating that the current pollution inspection has little effect. The regression coefficient of pollutant discharge fee is negative, and it is significant at the significance level of 10%, indicating that pollutant discharge fee levied by enterprises can alleviate haze pollution.

Impact of Weibo and Baidu Internet public opinion on haze pollution from the overall level of the country has been conducted. However, due to the huge differences in economic and social development and institutional environment in different regions of China, the impact of new media network opinion on haze pollution is bound to be different in different regions. Therefore, according to the traditional regional division method, the eastern, central and western regions were tested respectively. As shown in Table 5, the results of *Wald* test and *log*−*Likelihood* test show that the model fitting effect is well.

In the case that the three spatial weight matrices are different, the time delay coefficient and spatial lag coefficient of haze pollution in the three regions are significantly positive, indicating that there are time delay effect and spatial spillover effect in the three regions. From the perspective of regional comparison, the spatial spillover characteristics in the central region are the most obvious, and the significance of joint prevention and control is the most significant. The regression coefficient of new media network public opinion is significantly negative only in the central region, while the regression coefficient is negative but not significant in the eastern and western regions, indicating that the participation of new media network public opinion in the central region can alleviate haze pollution. The result supports the fourth hypothesis of this paper. This may be due to the gradual migration of polluting enterprises from the east to the central and western regions, resulting in an increased public demand for the environment in the central region.

Among the control variables, the regression coefficient of per capita GDP in the eastern region is significantly positive, while it is positive but not significant in the central and western regions. The results show that the performance evaluation of local officials with GDP as the core is the main reason why the eastern region attaches importance to economic growth and neglects environmental protection. The regression coefficient of income gap is significantly positive in the central and western regions, but not significant in the eastern regions. This is because education levels in the central and western regions are still booming, and the main consumer goods for residents are still cars and houses. The income gap between urban and rural areas is one cause of the haze in central and western China. The regression coefficient of education level was significantly positive in the western region, but not significant in the eastern and central regions. It may be because the education level in the eastern and central regions is already relatively complete, while the western regions are still in a stage of rapid development, with more people entering non-GDP creative jobs, reducing energy efficiency and having a negative impact on haze pollution.

The per capita fixed capital formation in the eastern region is significantly negative, while the per capita fixed capital formation in the central and western regions is not significant, indicating that the investment in the eastern region is gradually shifting to non-environmental pollution projects. The coefficient of Internet penetration is significantly negative in the western region, and the regression coefficient is negative but not significant in the eastern and central regions. It shows that the improvement of Internet penetration rate in western China has a certain effect on the alleviation of haze pollution. It may be related to the speed of internet penetration. Internet penetration in the eastern and central regions is already high, while in the western region it accelerated from 2013 to 2017, leading to increased public participation online.

4.3. Robustness test

(1) In order to ensure the reliability of the results, we used three different spatial weight matrices in the spatial dynamic panel regression model. Under three different spatial weight matrix regression conditions, the coefficients and significance of each variable did not change significantly, and the signs of the core variables were in line with theoretical expectations. Therefore, the empirical results of this paper are robust.
(2) The choice of control variables will affect the robustness of the spatial quantitative model. Therefore, on the basis of the original model, we added two control variables, the proportion of the output value of the secondary industry and the proportion of the average annual income of residents, to conduct robustness test. As shown in Table 6, the size and sign of the coefficient of the core variable did not change significantly, indicating that the model is robust.

5. Conclusions and policy implications

Haze, as an environmental risk, has rapidly attracted public's attention in recent years. Driven by the internet, the public's understanding of corporate pollution information has undergone substantial changes, and its influence on corporate behavior is gradually becoming prominent, and it will also have a direct impact on corporate environmental protection decisions. The number of posts, likes, retweets, and comments on Weibo can reflect the public's concern about the environment. Whether the haze pollution concern expressed on public online

Table 6
Robustness test.

Variable	Geographical distance spatial weight matrix (W^C)	Economic distance spatial weight matrix (W^E)	Nested spatial weight matrix of economic geography (W^{CE})
$lnPM_{i,t-1}$	0.355* (0.1526)	1.2045*** (0.1757)	0.2366 (0.1651)
$W \times lnPM2.5_{i,t}$	1.0212*** (0.1099)	0.8394*** (0.1269)	0.9974*** (0.1386)
$lnIpo_{i,t}$	−0.0795* (0.0355)	−0.1128** (0.0464)	−0.0752** (0.0328)
$lnPgdp_{i,t}$	0.0869 (0.3827)	0.1251 (0.4853)	0.2862 (0.3421)
$lnUrbanization_{i,t}$	1.6400 (1.8112)	2.8834 (3.0791)	0.6936 (1.0899)
$lnIncome_{i,t}$	0.2690* (0.1488)	0.3103 (0.1980)	0.2777* (0.1322)
$lnInvest_{i,t}$	−0.0177 (0.0333)	−0.0196 (0.0411)	−0.0222 (0.0339)
$lnTech_{i,t}$	−0.1063 (0.1667)	−0.0822 (0.2017)	−0.1319 (0.1677)
$lnOpenness_{i,t}$	0.0063 (0.0127)	0.0090 (0.0165)	0.0044 (0.0119)
$lnEducation_{i,t}$	1.0401 (0.4349)	1.1344* (0.5514)	0.7994* (0.4242)
$lnCapital_{i,t}$	−0.1252 (0.1451)	−0.1316 (0.1763)	−0.1914 (0.1429)
$lnInternet_{i,t}$	−0.1023 (0.2623)	−0.3883 (0.3214)	−0.1536 (0.2566)
$lnS\text{Industrial}_{i,t}$	0.0120 (0.2296)	0.1716 (0.3010)	0.0936 (0.2059)
$lnReg1_{i,t}$	0.0324 (0.1348)	−0.0164 (0.1833)	−0.0167 (0.1128)
$lnReg2_{i,t}$	−0.0196 (0.0391)	−0.0769 (0.0497)	−0.0374 (0.0354)
lnSindustrial	−0.2503 (0.7779)	−1.1557 (1.2981)	0.0159 (0.5382)
lnRincome	0.0896 (0.3831)	−0.1112 (0.5157)	0.0401 (0.3232)
cons	2.2831	−0.3799	6.0607
Wald test(*p*)	245.768 (0.000)	180.0985 (0.000)	216.3464 (0.000)
Log − *L*	140.4699	26.3109	143.3301

platforms promoted pollution control is a question remained to be examined. It provides a scientific basis for understanding and verifying the important role of public environmental supervision. Based on the panel data of 30 provinces (municipalities and autonomous regions) in China from 2013 to 2017, the dynamic spatial panel method was adopted to study the impact of new media network public opinion on haze pollution.

The main conclusions can be summarized as: (1) In general, new media network public opinion has a significant positive impact on reducing haze pollution. It means that environmental protection complaints on public social networking platforms have a deterrent and supervisory effect on corporate pollution. Even if different spatial weight matrices are replaced, the regression results are still stable. (2) When experiments were conducted in different regions, new media network public opinion had a significant inhibitory effect on haze pollution in the central region, but had no significant relieving effect on haze pollution in the eastern and western regions. This is due to the difference in the degree of environmental pollution suffered by the public in different places and the difference in the level of network development. (3) During the five-year study period from 2013 to 2017, haze pollution has a significant “time lag effect” in the time dimension, and a significant “space spillover effect” in the space dimension. It makes haze pollution control present a national integration situation. The empirical conclusion of this paper has important policy significance.

(1) As can be seen from the empirical results, new media network supervision has a significant effect on improving haze pollution. In the process of haze pollution control, governments at all levels and relevant functional departments should consider how to make full use of the increasingly powerful supervision power of new media and network public opinion, so that it can play an important role in pollution control. Government need to take full advantage of the prestige and appeal of official microblogs, and pay close attention to public comments and feedback. New media network environment should be improved. It needs to set up a special area for environmental protection knowledge on the new media platform. The dissemination of environmental knowledge needs to be strengthened continually. Only in this way, can we better play the powerful power of the new media network platform.
(2) The difference in the impact of haze pollution concern of public on haze control origin from the difference in air quality on the one hand, environment protection awareness on the other hand. The public is not only pollution producer, but also pollution suffer. Environmental protection awareness can protect people from suffering air pollution by environmental protection behavior or encouraging them to supervise the discharge of pollution. To enhance the environmental awareness of people is the key to play the supervision role. Knowledge of environmental protection needs to be incorporated into education so that everyone is familiar with the need for environmental protection and safeguarding their own environmental rights.
(3) Haze pollution has significant spillover character. Government should improve the joint prevention and control mechanism of haze in each region to realize the eradication of haze pollution. Local governments must not only prevent and control haze pollution in their own regions strictly, but also coordinate governance with neighboring regional governments to implement unified planning, unified standards, unified monitoring, and unified prevention and control measures. In accordance with the scientific principle, a detailed joint prevention and control system should be established to achieve the long-term goal of haze prevention and control.

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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