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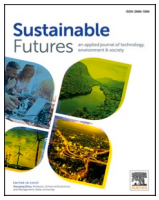

Impact of public environmental participation on air pollution control: A dual examination of we-media attention and government environmental regulation

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ABSTRACT

In the new governance system characterized by the participation of the entire population, public environmental participation (Pub) has become a powerful means of promoting the in-depth improvement of air pollution (PM). Using data from 268 Chinese cities from 2011 to 2020, this study constructs multivariate econometric models within the regulatory frameworks of We-media attention (WA), local government environmental regulation (Er), and the Central Environmental Protection Inspection (Ep) to empirically analyze the impact of Pub on PM. The main results show that: (1) public complaints through traditional platforms (Pub1) have a significant negative correlation with PM, while public environmental concerns via new media channels (Pub2) only have a significant emission-reduction effect in the resource-based cities. (2) WA further weakens the negative impact of Pub1 on PM, but Er and Ep can effectively combine forces to enhance the emission-reduction effect of Pub1 on PM in resource-based cities. (3) Moreover, Pub1 has a single-threshold effect on PM under different levels of per capita GDP (Pgdp), and Pub2 has a dual-threshold effect on PM. Therefore, it is essential to strengthen the coordination and cooperation between Er and Ep to form a more effective regulatory synergy, optimize the management of We-media platforms and improve the compatibility between public participation tools and external governance channels to maximize the potential of Pub in PM.

1. Introduction

At the 2025 National Conference on Ecological and Environmental Protection, the governance of air pollution once again took center stage as a core issue. It is intrinsically connected not merely to the well-being of residents in terms of their physical health and daily quality of life, but also intricately interwoven with the overarching sustainable development strategy of the nation. This connection underscores the significance of PM in achieving a harmonious coexistence between environmental conservation and long-term social-economic progress.

Related studies have shown that air pollution may lead to the emergence of cardiovascular and cerebrovascular diseases such as dementia and hypertension [1,2], which seriously affects human health, production and life, and has become a major challenge to the sustainable development of China's economy and society [3]. In recent years, the Chinese government has adopted a large number of policies and regulations in PM, such as the Air Pollution Prevention and Control Action Plan, the Blue Sky Defense War, and low-carbon city pilot policy, which have improved air quality to some extent [4–6]) The structural, root-cause, and trend-related contradictions existing in the field of ecological and environmental protection are deeply ingrained. Local government departments are tasked with multiple responsibilities such as economic development, social security, and environmental protection. Due to limited energy, insufficient professional knowledge, and the influence of performance assessment orientation, they face the problems of bounded rationality and selective bias in decisions related to PM. In such a situation, as the direct victims of PM, the public can keenly perceive environmental changes and report problems in a timely manner. The extensive participation of the public in environmental supervision has generated strong public opinion pressure, prompting polluting enterprises to be more proactive in pollution control, with the aim of generally improving air quality. As shown in Fig. 1, Pub1 and

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Pub2 about PM have been increasing year by year. In addition, in recent years, Pub have gradually increased as their income level, education level, and ability to access information have improved [7]. As a “bottom-up” environmental governance mechanism, the public, acting as a “link” in the system, breaks the limitations of the “top-down" approach. Moreover, it drives the shift to multi-stakeholder collaborative governance and sparks the third wave of environmental regulation after administrative command-and market-incentive-based tools [8]. One cannot help but pose the question: during this critical juncture when economic and environmental pressures are converging in our context, Pub fully actualize its advantageous effects and thereby drive the enhancement of both the quality and efficiency of PM?

A report from the Media Center of the American Press Institute defines WA as "a way for the general public to convey their views on the news to other audiences by integrating digital technology means with the global knowledge system." The rapid development of digital information technology and new media platforms has provided new opportunities for Pub. It not only broadens the channels for public participation but also lowers the threshold and cost of public participation. The advantageous effects of public participation are enhanced, leading to the reshaping of the linkage relationship among the public, the government, and enterprises within the framework of environmental pollution control [9]. Moreover, under the China’s distinct decentralized institutional framework, Er and Ep still play a key role in determining how to promote the quality of PM [10]. And drawing on the experiences of developed economies like the United States and the European Union, within an ecosystem where the collaborative efforts of multiple stakeholders are essential for achieving successful holistic outcomes, the provision of environmental public goods necessitates the engagement of as wide a range of entities as possible in this collective endeavor [11]. Therefore, to effectively control the PM, aside from the crucial participation of the public, it is imperative to rely on the central government to chart new directions, formulate novel guidelines, offer new safeguards, and the local government to take specific regulatory measures, optimizes the public participation mechanism, perfects the public participation system, and promotes the fundamental solution to air pollution. This approach is vital for comprehensively propelling the construction of a Beautiful China [12–15]. So, under the moderating mechanisms of external WA, Er, and the Ep, how will the emission reduction effectiveness of Pub change? Meanwhile, in which areas should government policies prioritize coordination? Answering these questions is of great significance at both the theoretical and practical levels, offering valuable insights for academic research and environmental governance strategies.

As we all know, Significant economic development disparities often lead to imbalanced environmental resource allocation and unequal environmental burdens. In underdeveloped regions, the public, lacking resources and sufficient voice, endures heavier pollution but struggles to contribute effectively to PM due to various constraints. Conversely, in developed regions, Pub has matured into a well - structured system, with

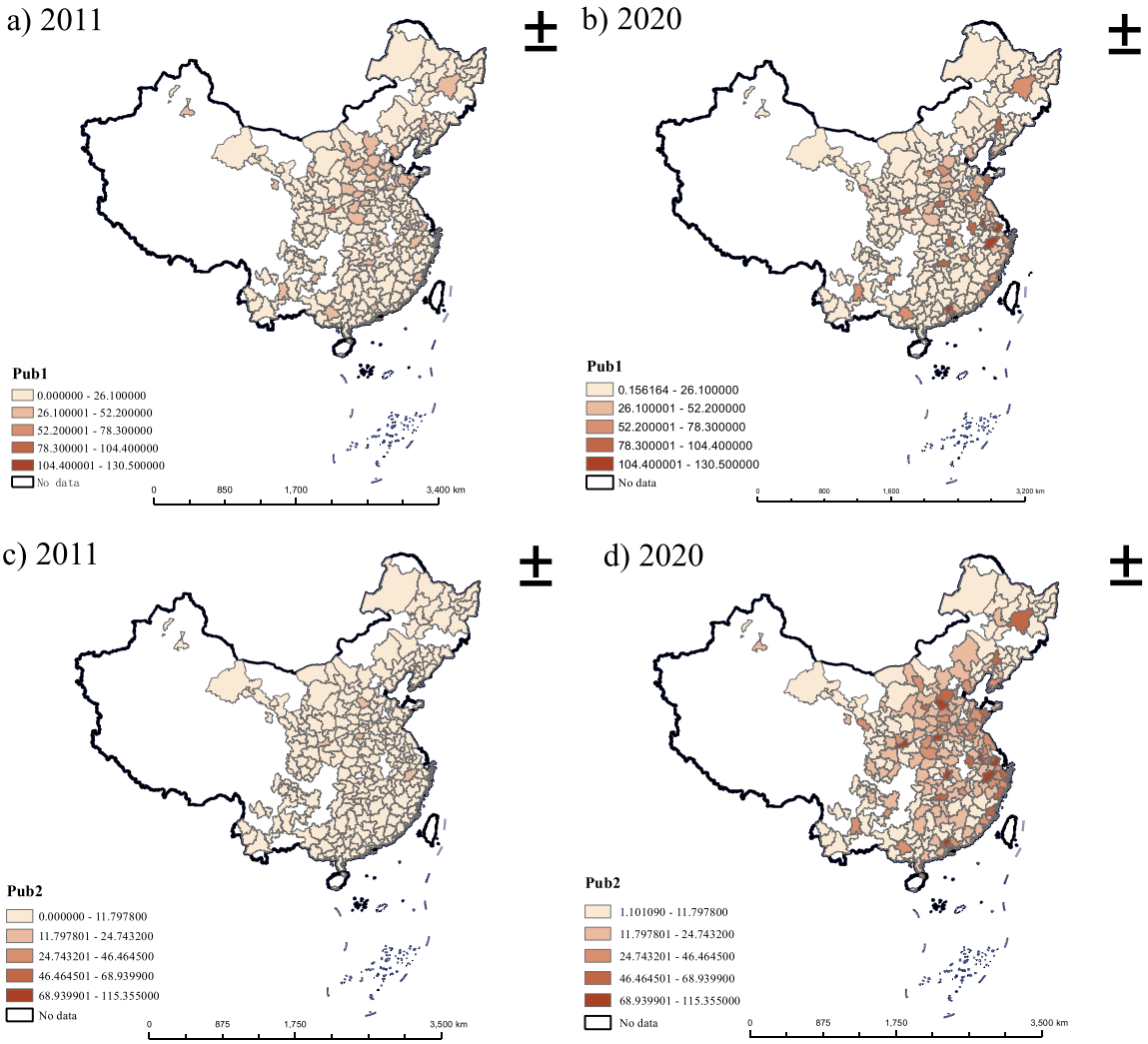

Fig. 1. Spatial distribution of public environmental complaints (Pub1) and public environmental concerns (Pub2).

the public actively involved through diverse means, leveraging their educational, informational, and financial advantages. Moreover, as economies progress through different stages, the effectiveness of public environmental participation is intricately shaped by factors like income, education, and institutional environment, showing complex non-linear patterns [16]. Thus, it is urgent to deeply explore the threshold effect of public environmental participation on air pollution management across different economic development levels. This exploration will offer policymakers and environmental stakeholders precise and practical insights for formulating tailored pollution control strategies.

To solve the research problems, this paper integrates the data of 268 prefecture-level cities in China from 2011 to 2020, to empirically test the direct impact effect of Pub on PM, and analyze the impact of Pub1 and Pub2 on PM under the moderating mechanism of WA, Er and Ep. Furthermore, analyzing the threshold effect of Pub on PM under different levels of economic development (Pgdp). There are three prominent marginal increments in terms of research contributions: **First**, it innovates the research perspective. By incorporating traditional and new media participation methods into the same framework for comparative analysis, it reveals the different impact between Pub1 and Pub2 on PM, which opens up a new perspective for understanding the mechanism of Pub. **Second**, it explores the unique relationships between Pub and PM under the different regulation mechanism of WA, Er and Ep. In addition, it further explores the double superposition moderating effect of Er and Ep on Pub. The research discovers that in the sample test of resource cities, there is a significant substitution effect between WA and Pub1. While Both Er and Ep can only positively reinforce the emission reduction effect of Pub1 on PM. This study fills the gap in improving the government's environmental governance system and provides empirical evidence for resource-based cities to formulate pollution control strategies. **Third**, it reveals the dynamic effect of different economic thresholds. By innovatively exploring the dynamic impact of Pub1 and Pub2 on PM under different Pgdp, it is found that Pub1 shows a single-threshold effect and Pub2 has the characteristics of a double threshold. However, when the Pgdp exceeds 11.1769, the effect of Pub2 on PM is no longer significant, which provides empirical evidence for highlighting the importance of improving the traditional complaint mechanism.

The remaining of the paper is organized as follows: Second 2 presents the literature analysis and theoretical assumptions. Section 3 describes the research design, including the theoretical model setting, variables definition and data source. Section 4 reports the empirical results, including benchmark regression results, robustness test, endogeneity test, heterogeneous analysis and moderating effects. Section 5 is a further analysis of the thresholds of the impact effects on PM by Pub under different economic conditions. Section 6 presents the conclusions and policy suggestions. The research frameworks is shown in Fig. 2.

2. Literature review and hypothesis development

2.1. The direct effect of Pub

The contradictions in ecological and environmental protection are intractable. However, local governments need to balance multiple tasks, which leads to biases in decision-making for PM and gives rise to new problems [17]. The theory of new institutional economics points out that compared with the influence of formal institutions, informal institutions have a greater restraint on environmental pollution. Besides, according to the classic theory of resource mobilization in political participation, the outcome of individual interest expression can directly compel the transfer of some resources to environmental governance activities, achieving both the quality of economic growth and environmental governance performance. Therefore, in addition to relying on various powerful government regulations, Pub demonstrates a significant binding force on environmental pollution behaviors that fall outside the scope of the government regulations[18]. This binding force is particularly prominent in resource-based cities. Predominantly engaged in industrial production, these cities generate abundant pollutants, causing substantial environmental impacts. These problems directly impinge on public living standards and health, readily attracting public attention to environmental pollution and inspiring the public's eagerness to partake in emission reduction efforts. A large number of empirical studies have shown that as the most direct experience of the quality of the environment, Pub can significantly improve the efficiency of PM [19–21]. Except for the traditional ways of participation, such as disclosure of information, letters and visits, as stipulated in laws and regulations, the new media ways, such as internet forums, Weibo and WeChat, are also widely used [22]. On the one hand, Traditional platforms such as the 12,369 Environmental Protection Reporting Hotline provide the public with a direct and authoritative channel for feedback on pollution information. Through platforms like 12,369, the public can promptly and accurately convey such pollution information to the environmental protection department, reflecting the difficulties and pain points in real-life pollution control, which provides an important basis for local governments to take effective measures to promote environmental pollution control and serves as a significant force in

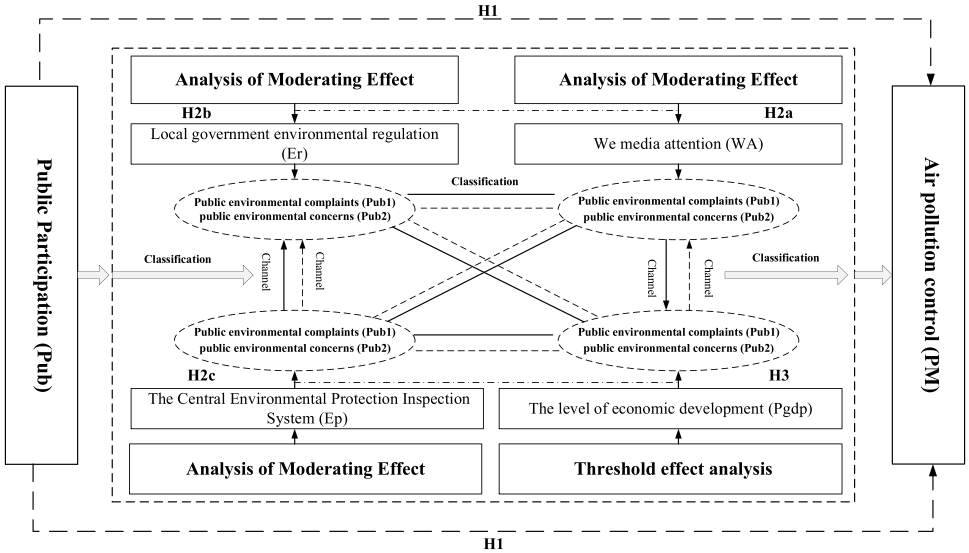

Fig. 2. Research frameworks.

solving environmental pollution problems. On the other hand, Within the new media development, new media platforms, such as Weibo, WeChat official accounts, etc., are characterized by fast dissemination speed and wide coverage. Numerous environmental protection organizations, self-media individuals, and enthusiastic members of the public release a large amount of content related to popular science knowledge about air pollution, environmental protection concepts on these platforms. Therefore, the openness and interactivity of new media platforms enable the public to quickly express their opinions and comments on air pollution incidents, forming a powerful public opinion field. For example, when a serious air pollution incident occurs in a certain area, the public exposes the relevant information through new media platforms, triggering widespread public concern in society, thereby promoting government and enterprises to take measures for the environmental management and reduce pollution emission. It can be seen that the Pub1 and Pub2 play a positive role in PM. They jointly contribute to improving air quality and making contributions to the construction of a beautiful and livable environment. Therefore, based on the above analyses, we put forward the following hypothesis H1:

H1: The Pub can have an emission reduction effect on PM through Pub1 or Pub2, especially in resource-based cities.

2.2. The moderating effect of WA, Er and Ep

2.2.1. The moderating effect of WA

The governance theory in the digital age posits that the integration of WA and Pub can generate new governance models [23–25]. On one hand, WA can enhance the dissemination of environmental information, improve environmental information disclosure and ease information asymmetry, thus boosting the public's environmental awareness and supervision level [26–28]. However, on the other hand, With the ascendance of We-media attention (WA), the public gains rapid access to and dissemination of environmental information via new-media platforms. This convenient information-acquisition paradigm may engender a scenario wherein the public deems that simply voicing concerns or engaging in discussions through new media, under the sway of WA, suffices. Consequently, they tend to be less predisposed to adopt the more time-consuming and labor-intensive method of Pub1. The above situation is especially obvious in resource-based cities. Because these cities face more complex and severe environmental problems, which attract social media's attention. So, media coverage often focuses on major or sensational environmental incidents there. Thereby triggering extensive public attention and heated online discussions. Most people then believe online media pressure is enough, reducing their motivation to file environmental complaints [29]. Besides, Zhou and Ding [30], and Luo et al. [31] proposed that these novel channels are likely to be more alluring to the public in comparison to traditional complaint mechanisms. They afford a sense of immediate feedback and broader social impact in resource-based cities. Thus, instead of relying on Pub1, the public might opt to articulate their environmental concerns through new media in the limelight of WA. It can be seen from this that WA is likely to supplant Pub1, emerging as the dominant mode of public participation in PM and restructuring the landscape of public engagement in environmental affairs [32,33]. Therefore, based on the above analyses, we put forward the following hypothesis H2a:

H2a: WA may weaken the negative effect of Pub1 on PM, especially in resource-based cities.

2.2.2. The moderating effect of Er

Public value theory posits that addressing citizens' collective environmental preferences is central to the government's people-centered pollution control decisions [8,10,34–36]. As the steward of development, the government environmental regulation can promote public's pro-environmental behaviors, then reducing the PM. From the perspective of the local government environmental regulation (Er), when the government emphasizes PM in work report, formulates a series of strict and reasonable environmental laws, regulations and standards, Er conveys to the public the government's firm determination to rectify the environment. The public can truly feel the government's sincerity and action in PM, which greatly stimulates the enthusiasm of Pub1. The public will promptly report to the relevant departments, forming a good interactive cycle with Er. Among them, resource-based cities face the dual pressures of resource depletion and PM so that governments usually attach greater importance to PM by actively promoting Pub1 and Pub2 and paying more attention to public opinions and suggestions, which further ensures that Pub can elicit better responses and support, thereby enabling it to play a more effective role in reducing PM. However, it is easily affected by a combination of various factors such as media publicity orientation, and public personal interest preferences. It is possible that the public's search attention to PM-related content will be dispersed because the media focuses a large amount of resources on other non-environmental fields. Consequently, although the Er has achieved remarkable results in stimulating the Pub1 and promoting PM, due to the interference of the above-mentioned complex factors on the Pub2, the Er might encounter difficulties in reducing PM through positively modulating the Pub2 [37]. Therefore, based on the above analyses, we put forward the following hypothesis H2b:

H2b: Er can enhance the negative effect of Pub1 on PM compared with Pub2, especially in resource-based cities.

2.2.3. The moderating effect of Ep

From the perspective of the implementation of central government policies, against the backdrop of the increasingly severe smog problem and the gradually growing public opinion calling for the improvement of environmental quality, the Central Committee of the Communist Party of China and the State Council issued the "Environmental Protection Inspection Plan (Trial)" in July and August 2015 respectively, and launched three rounds of nationwide environmental protection inspections [38]. Aiming at environmental governance, these inspections mobilize local governments, through the form of the Central Environmental Protection Inspection Teams being stationed in various provinces, to coordinate various departments and mobilize all kinds of resources within the specified time to address and improve the problem of air pollution. Ep attaches great importance to Pub and regards Pub1 as an essential part of environmental protection inspection work. In particular, during their stay in resource-based cities, the Central Environmental Protection Inspection Teams set up dedicated channels for public complaints, such as hotlines and email addresses, to facilitate public reporting of environmental issues. They also provide timely feedback on the handling results, making the public feel that their opinions are valued. This further stimulates the enthusiasm of Pub1, which can enhance the effectiveness of the inspection, and reduce the frequency of pollution incidents. Kou et al. [39] found that Ep have corrected the behavior of local governments and prompted Pub1 orderly, which has improved air quality in resource-based cities. However, although participating in environmental governance through new media platforms has become the mainstream trend among the public nowadays, the information on air pollution control obtained by the public through Baidu searches is rather complex, lacking in authority and pertinence. Besides, although the Ep attaches importance to Pub and has set up channels such as Pub1, the increase in Pub2 cannot directly prompt the public to effectively utilize these channels. In actual operation, due to the lack of clear guidance, the public may not know how to fill in reporting information in a standardized manner or which department to turn to, resulting in the loss of a large number of valuable pollution clues and making it difficult to effectively contribute to PM.

In addition, Ep is seen as a vital tool to encourage local implementation of environmental protection responsibility [40,41]. Especially in the resource-based cities, the Ep through the supervision and assessment of local governments, prompts the governments of resource-based cities to attach greater importance to PM and enhance the implementation intensity of Er. On the one hand, Ep will promote

the positive adaptation of Er. Being held accountable and under the authority of the central government, local governments will quickly prioritize the public environmental protection complaint mechanism through actions such as establishing leading groups, coordinating cross-sectoral resources, and enacting new institutional norms, which will boost the enthusiasm of the public for environmental protection complaints, and in turn, have a positive effect on reducing the PM. On the other hand, although there is a gap between the formal tasks assigned by the central government and the capabilities of local governments to carry out those tasks, both central and local efforts align in encouraging public participation in environmental protection. During the Central Environmental Protection Inspection Team's deployment, local governments must publicly announce the inspection period, public-reporting hotlines, email addresses, and reporting hours on the TV stations, Party newspapers, and government websites. Once the inspection team receives public reports, cases are relayed to provincial, municipal, and county-level governments for handling. Rectification plans are then submitted upward through the same channels. After the inspection team reviews these plans, provincial governments disclose the rectification outcomes on the aforementioned media platforms. This prompt and resolute rectification of public-reported environmental issues significantly enhances the positive impact of Pub1 on PM control. Therefore, based on the above analyses, we put forward the following hypothesis H2c:

H2c: Ep would enhance the negative effect of Pub1 on PM compared with Pub2; And Ep can form an effective cooperation with Er positively moderate Pub1, especially in resource-based cities.

2.3. The threshold effect of Pub

The theory of social and economic development stages points out that with the development of the economy, systematic changes will occur in social structure, public concepts, and institutional construction. Therefore, in the field of PM, the impacts generated by Pub under different levels of economic development (Pgdp) exhibit complex characteristics of non-linear marginal effects.

Specifically, in the stage of underdeveloped economy, resources are often preferentially allocated to production activities that meet basic survival needs, resulting in relatively limited investment in environmental governance. The public also focuses more on improving their material life and has a lower sensitivity to environmental issues. At the same time, due to limited information dissemination channels, the public has relatively scarce access to environmental protection information and participation channels, leading to a lack of awareness of participation channels such as environmental protection hotlines. As the research by He et al. [42] found, in regions with lagging economic development, due to the low awareness of environmental protection hotlines among the public and concerns about retaliation, the utilization rate of these hotlines is not high, making it difficult for public participation in environmental protection to effectively reduce the PM. However, when the economy enters the developed stage, according to the Environmental Kuznets Curve theory, there is an inverted U-shaped relationship between economic growth and environmental quality. After the economy develops to a certain extent, people's demand for environmental quality will significantly increase. At this time, the social system is more complete, information dissemination is efficient and diversified, and the public's environmental awareness and participation ability are enhanced. The research by Buntaine et al. [43] shows that in economically developed regions, complaints through public channels have significantly reduced illegal and excessive sewage discharge. This is precisely because a higher level of economic development has created favorable conditions for public participation in environmental protection, including better education that has improved the public's environmental protection literacy, perfect laws that have guaranteed the public's rights and interests in participation, and convenient media platforms that have broadened the participation channels, thus strongly promoting pollution control efforts. Based on the above theoretical basis, this study proposes research hypothesis H3:

H3: Under different levels of Pgdp, Pub have a significant threshold characteristic for PM.

3. Research design

3.1. Theoretical model

To avoid the endogeneity bias caused by this mutual causality, this study takes the variable of Pub which is lagged by one period as the core explanatory variable and includes it in the model [44]. We construct a regression model to estimate the effect of Pub1 and Pub2 on PM. The specific model is as follows:

$$PM_{i,t} = \alpha_0 + \alpha_1 Pub_{i,t-1} + \sum_{j=2}^{7} \alpha_j Controls + \lambda_i + \nu_t + \varepsilon_{i,t} \quad (1)$$

Where subscripts i and t denotes prefecture-level cities and years, respectively; PM refers to the annual average concentration of $PM_{2.5}$; Pub indicates Pub1 and Pub2; Controls contains the level of economic development (Pgdp), industrial structure (Ind), degree of local fiscal decentralization (Fin), level of technological innovation (Inv), population density (Den), degree of openness (Open); Given that there is significant heterogeneity across regions, and special years when economic shocks or policy changes may affect the results, we control for region fixed effects λ_i and time fixed effects ν_t in this model. $\varepsilon_{i,t}$ denotes the random disturbance term.

In order to test the moderating effect of WA, Er, and Ep, we introduce the interaction term between WA, Er, Ep and Pub in model (2–4) respectively. The interaction term coefficient α_3, β_3 and $\theta_3$represents the impact of Pub on PM under the moderating mechanism of WA, Er and Ep. If α_3, β_3 and θ_3 is significant, the WA, Er and Ep has a significant moderating effect on Pub. Besides, the interaction term coefficient ϑ_5 in model (5) represents the impact of Pub on PM under the double moderating mechanism of Ep and Er.

$$PM_{i,t} = \beta_0 + \beta_1 Pub_{i,t-1} + \beta_2 WA_{i,t-1} + \beta_3 WA_{i,t-1} \times pub_{i,t-1} + \sum_{j=2}^{7} \alpha_j Controls + \lambda_i + \nu_t + \varepsilon_{i,t} \quad (2)$$

$$PM_{i,t} = \alpha_0 + \alpha_1 Pub_{i,t-1} + \alpha_2 Er_{i,t-1} + \alpha_3 Er_{i,t-1} \times Pub_{i,t-1} + \sum_{j=2}^{7} \alpha_j Controls + \lambda_i + \nu_t + \varepsilon_{i,t} \quad (3)$$

$$PM_{i,t} = \theta_0 + \theta_1 Pub_{i,t-1} + \theta_2 Ep_{i,t-1} + \theta_3 Ep_{i,t-1} \times pub_{i,t-1} + \sum_{j=2}^{7} \alpha_j Controls + \lambda_i + \nu_t + \varepsilon_{i,t} \quad (4)$$

$$PM_{i,t} = \vartheta_0 + \vartheta_1 Pub_{i,t-1} + \vartheta_2 Er_{i,t-1} + \vartheta_3 Ep_{i,t-1} + \vartheta_4 Ep_{i,t-1} \times Er_{i,t-1} \vartheta_5 Ep_{i,t-1} \times Er_{i,t-1} \times pub_{i,t-1} + \sum_{j=2}^{7} \alpha_j Controls + \lambda + \nu_t + \varepsilon_{i,t} \quad (5)$$

Environmental Kuznets Curve suggests that environmental pollution has a strong correlation with economic development. Therefore, in order to further test the threshold effect, based on model (1), this study establishes a threshold regression model shown in Eq. (6) with Pgdp as the threshold variable, exploring the nonlinear effect of Pub on PM.

$$PM_{i,t} = \alpha_0 + \alpha_1 Pub_{i,t-1} I(Pgdp_{it} \le \gamma_1) + \alpha_2 Pub_{i,t-1} I(\gamma_1 \le Pgdp_{it} \le \gamma_2) + \alpha_3 Pub_{i,t-1} I(Pgdp_{it} \ge \gamma_2) + \sum_{j=4}^{97} \alpha_j Controls + \lambda_i + \nu_t + \varepsilon_{i,t} \quad (6)$$

where I (.) is the indicator function, and$\gamma_1$and γ_2 are the value of thresholds, α_1, α_2 and α_3 are the impact coefficients of the independent variables in different intervals.

3.2. Variable definition

3.2.1. Explained variable

PM: $PM_{2.5}$ is chosen as a proxy variable for PM in this paper for two reasons. First, $PM_{2.5}$ is the most hazardous pollution in most cities and is also the pollution of most public concerning. Second, $PM_{2.5}$ is a commonly used indicator of PM and is often used by scholars as a monitoring indicator to assess the effects of PM on human health.

3.2.2. Explanatory variables

Pub1: China's government set up the "12,369″ official hotline for Pub1 in 2009, and then, with the development of Internet technology, gradually set up online complaint platforms and WeChat complaint platforms, which provides a convenient channel for the public to directly report environmental pollution through complaints. Drawing on the practices of existing literature, we construct Pub1 based on the number of public complaints on the 1236 platform [42].

Pub2: Pub2 mean the public takes the initiative to obtain environmental information on the Baidu platforms. Therefore, this study uses Pub2 to indicate public environmental attention. Specifically, based on the methods in existing literature, using "雾霾" as keywords in the Baidu search index, we manually collated the daily average number of searches for each keyword in each city for each year from 2011 to 2020, to construct the Pub2 [45].

3.2.3. Moderating variables

WA: Considering Sina Weibo is more open and more conducive to the formation of public opinion, and is the most advanced, active, best-developed, and most users microblog in China. We choose the number of posts of we-media accounts authenticated by Sina Weibo as a proxy variable for WA. Specially, because the number of Weibo related to air pollution before 2013 is lacking much, so we grabbed all the Weibo related to haze and air pollution in each city from 2013 to 2020. The specific content of the crawl includes: user nickname, user location, release content and release time. Next, we screened out tweets from authenticated We Media accounts, manually collated and counted the total number of tweets posted in city within a given year.

Er. This study uses the frequency of words appearing in local government work reports related to the term environmental protection as a percentage of the number of words in the complete report [46]. Two reasons for choosing this measurement method are as follows: Firstly, this indicator measures to a large extent the willingness and determination of local governments to engage in PM, and can provide a more comprehensive picture of the overall level of environmental regulation in China. Secondly, the work report of each prefecture-level city is published at the beginning of each year, while the report related to PM is usually published at the end of the year, which alleviates the endogeneity of environmental regulation to a certain extent.

Ep. In recent years, in order to reduce the PM and improve environmental quality, the Chinese government has implemented a series of policies and measures [40]. The establishment of the Central Environmental Protection Inspection System (Ep) aims to strengthen the implementation of the system of shared responsibility of Party and local government for ecological and environmental protection. It is characterized by continuous tracking and long-term effectiveness. Therefore, drawing on the approaches of existing studies, when the central environmental protection inspection team is stationed in a province, all cities in that province are assigned a value of 1 for the current year and subsequent years, and a value of 0 for the years before. The time of the inspection teams' stationing is determined by the announcement time on the website of the Ministry of Ecology and Environment for each inspection team [47].

3.2.4. Control variables

Based on several factors affecting environmental pollution, this study combined Environmental Influence Factor Model (IPAT) theory and existing literature practices to select the level of economic development (Pgdp), industrial structure (Ind), degree of fiscal decentralization (Fin) [48], technological innovations (Inv), density of population (Den), and the level of openness (Open) as the control variables.

3.3. Data source

The research sample is the panel data of prefecture-level cities in 268 cities from 2011 to 2020. In particular, centrally-administered municipality and cities with a lot of missing data are excluded. The data of PM are obtained from the grid data of $PM_{2.5}$ concentration average based on satellite monitoring and ground-based monitoring stations released by Atmospheric Composition Analysis Group. The data of Pub1 and Pub2 comes from the "12,306″ platform and Baidu search index based on the keyword "$PM_{2.5}$″. Other data come from China City Statistical Yearbook, Government Work Reports, local Bureau of Statistics and China Stock Market & Accounting Research Database (CMSAR). Table 1 summarizes the descriptive statistics of key variables.

4. Results and discussion

4.1. Benchmark results

The results of the baseline regression of Pub in PM are presented in

Table 1
Descriptive statistics of variables.

Variables	Definition	mean	sd	min	max
PM	Annual average $PM_{2.5}$ concentration(ug/m3)	41.930	15.200	11.610	108.500
Pub1	The number of public complaints based on the "12,369″	13.020	18.020	0.000	130.500
Pub2	The Baidu search index of haze	40.510	46.930	0.000	420.900
Pgdp	Logarithm of real GDP per capita (yuan)	10.690	0.545	8.745	12.470
Ind	Value added of secondary production divided by GDP (%)	0.455	0.108	0.114	0.893
Fin	The per-capita expenditure at the county-level divided by the sum of per-capita expenditures at the county-level, provincial-level and national level (%)	0.341	0.061	0.167	0.616
Inv	Number of patents for green inventions granted during the year	79.41	227.5	0.000	2990
Den	Logarithm of the resident population of the area divided by the size of the administrative area (%)	5.693	0.979	1.734	9.071
Open	Total exports and imports divided by GDP (%)	0.169	0.278	0.000	2.490
WA	Number of posts related to air pollution by Sina Weibo	275.9	550.4	0.000	3641
Er	Frequency ratio of environmental protection-related words in government reports	0.003	0.001	0.000	0.012
Ep	The Central environmental protection inspection policy	0.232	0.183	0.000	1.000

Table 2
The impact of Pub on PM.

	OLS		FGLS	
	(1) PM	(2) PM	(3) PM	(4) PM
L.Pub1	−0.058**		−0.025***	
	(0.023)		(0.010)	
L.Pub2		−0.011		−0.001
		(0.007)		(0.003)
Pgdp	−4.159***	−4.285***	−4.756***	−4.933***
	(1.178)	(1.171)	(0.566)	(0.553)
Ind	10.309***	10.227***	5.642***	5.301***
	(3.906)	(3.922)	(1.814)	(1.787)
Fin	−23.636***	−22.669***	−20.252***	−19.500***
	(5.631)	(5.535)	(2.647)	(2.626)
Inv	−0.000	−0.002*	−0.001*	−0.002***
	(0.001)	(0.001)	(0.001)	(0.001)
Den	−7.226**	−7.925***	−8.792***	−9.698***
	(2.831)	(2.845)	(1.277)	(1.170)
Open	−6.241***	−5.900***	−6.116***	−5.471***
	(1.819)	(1.681)	(0.936)	(0.906)
Year/Region	Y	Y	Y	Y
Cons	136.575***	140.837***	196.502***	202.748***
	(23.949)	(23.913)	(12.975)	(12.379)
N	2412	2412	2412	2412

Note: *** and ** indicate significance at the 1 % and 5 % levels, respectively.

Table 2. Column (1) presents the results of the regression of Pub1 on PM, which shows that Pub1 suppress PM at the 5 % significance level. Specifically, the air pollution was reduced by an average of 0.07 standard deviations with each standard deviation increase in Pub1, **H1 was confirmed**. Column (2) presents the results of the regression analysis of Pub2 on PM, which show that although "Pub2″ has a positive effect on PM, but it is not statistically significant. The potential reasons may be the government lacks a systematic and long-term monitoring system for Pub2. As a result, it is difficult to track the dynamic changes of Pub2 in real-time and comprehensively. Besides, even if the government captures the information of Pub2, due to the complexity of the current administrative management structure, delays and distortions are likely to occur. When Pub2 is concentrated on the PM in a specific area, the relevant information may not flow smoothly among multiple departments such as environmental protection, urban management, and planning, and it is impossible to quickly integrate and form effective pressure on the competent department.

In addition, Ind has a significant impact on PM at 1 % significance level, indicating that the higher the proportion of the secondary industry, the more serious the air pollution. For example, in areas where manufacturing and heavy industries are concentrated, air pollution is often more severe. Fin also shows a significant positive effect at the 1 % level, revealing that under the current performance evaluation and fiscal systems, local governments, in pursuit of short-term economic growth and political achievements, have distorted resource allocation. Developing the secondary industry has led to environmental degradation. For instance, some local governments have ignored environmental protection in order to attract highly polluting enterprises. Open, however, has a significant negative correlation with the PM. The higher the proportion of imports and exports to GDP, the lower the level of air pollution. It is because, On the one hand, trade openness promotes the adjustment of the industrial structure and eliminates high-energy-consuming and high-polluting industries. On the other hand, it is conducive to the introduction of advanced production and pollution control technologies.

4.2. Robustness test

To test Hypothesis 1′s robustness, we conduct three checks. First, to handle heteroskedasticity and autocorrelation, we modify the model. The results are in Table 2, columns (3) and (4). Second, to reduce extreme observations' impact, we winsorize all variables at the 1st and 99th percentiles, with results in Appendix 1, columns (1) and (2). Third, to exclude haze control policies and the COVID - 19 pandemic's effects, we re - estimate using 2013 - 2019 samples, and the results are in Appendix 1, columns (3) and (4). All these tests re - affirm H1.

4.3. Endogeneity test

Addressing endogeneity is crucial in economic research. First, we perform the Durbin-Wu-Hausman test on Pub1 and Pub2. With PM as the explained variable, DWH statistics are 17.63 and 20.21 for Pub1 and Pub2 respectively, and both P-values are 0.00, indicating an endogeneity issue in public environmental participation. To mitigate this, following Ma et al. [49], We construct interaction terms by combining the number of fixed-line telephones per 100 people in each city in 1984 (which is related to individual-level changes) with the national internet investment amount in the previous year (which is related to time) as instrumental variables. Because the past communication technologies in residents' cities affect their internet-tech acceptance and use in the sample period, fulfilling the instrument-variable correlation condition. Also, as a macro-level social-infrastructure variable, fixed-line telephone numbers mainly offer communication services and do not directly impact PM, satisfying the exogeneity condition. Table 3 shows the regression results, after controlling for endogeneity, Pub1 still has a significantly positive effect on PM.

4.4. Heterogeneity analysis

There are significant differences in PM among cities with different resource endowments. Therefore, effectively identifying the emission reduction effects of Pub on PM in resource-based cities and non-resource-based cities is important for local governments to formulate differentiated governance strategies. This paper classifies cities based on the National Sustainable Development Plan for Resource-based Cities (2013–2020) issued by the State Council. Specifically, the sample was divided into resource-dependent cities and non-resource-dependent cities. And then bringing subgroup samples into model (1) for regression, Table 4 presents the regression results. The results show that Pub1 and Pub2 have a significant impact on resource-dependent cities, with no significant impact on non-resource-dependent cities. This is probably caused by the fact that resource-dependent cities mainly rely on resource extraction and processing to obtain economic development, with typical characteristics of high energy consumption and high emissions, which leading to the public suffering from more serious pollution. For the pursuit of a better living environment, the more frequent the Pub, the local government under the combined effect of pressure from superiors and public supervision, they have to carry out measures, thus promote

Table 3
The test results of the instrumental variable method.

	(1) first Pub1	(2) two PM	(3) first Pub2	(4) two PM
Pub1		0.032**		
		(0.014)		
Pub2				0.115
				(0.102)
IV	0.076**		0.103**	
	(0.032)		(0.048)	
Weak instrument variable test		201.256***		198.015***
Year/Region	Y	Y	Y	Y
Control variables	Y	Y	Y	Y
_cons	121.489***	113.024***	135.712***	115.469***
	(34.059)	(37.851)	(29.586)	(28.766)
N	2412	2412	2412	2412
Adj-R^2	0.634	0.579	0.512	0.437

Note: *** and ** indicate significance at the 1 % and 5 % levels, respectively.

Table 4
Heterogeneity of urban resource.

	PM		PM	
	(1) No-res	(2) Yes-res	(3) No-res	(4) Yes-res
L.Pub1	−0.043	−0.111**		
	(0.027)	(0.050)		
L.Pub2			−0.002	−0.056***
			(0.007)	(0.021)
Year/Region	Y	Y	Y	Y
Control variables	Y	Y	Y	Y
_cons	152.451***	117.177***	159.156***	117.757***
	(35.926)	(30.980)	(36.493)	(29.078)
N	1411	999	1411	999
Adj-R^2	0.761	0.734	0.760	0.739

Note: *, **, and *** are significant at the 10 %, 5 %, and 1 % levels respectively.

the emission reduction.

4.5. Moderating effect from WA, Er and Ep

Considering that both Pub1 and Pub2 only have a significant effect on reducing PM in resource-based cities, in order to explore the differential impact effects of Pub1 and Pub2 on PM under the different regulatory mechanism of WA, Er and Ep, regression analysis is conducted here only on the sample data of resource-based cities.

4.5.1. The moderating effect from WA

First, to explore the moderating effect of Weibo (WA), we regress model (2), with results in Table 5. The interaction-term coefficient in column (1) is significantly positive at the 1 % level, indicating a significant substitution effect between WA and Pub1 regarding PM. That means as WA's influence grows, Pub1′s impact on PM weakens. Because public believe WA will prompt environmental action by relevant organizations motivated by the free-rider mentality and the desire to minimize government interaction, they might reduce complaint-lodging. Besides, WA has a greater chance of mobilizing the public to shape public opinion. The government often attaches more importance to issues debated on WA platforms. As a result, WA's influence crowds out resources that would have been allocated to Pub1. However, in column (2), the negative interaction-term coefficient is not statistically significant, showing WA had no notable moderating effect on Pub2. This is because on the one hand, WA's fragmented and entertainment-oriented content doesn't match the public's need for professional, systematic environmental knowledge on Baidu. On the other hand, WA emphasizes social interaction, Pub2 is for professional search. Their functions and user habits vary greatly, and with no information integration or guidance between them, users seldom switch from WA to Pub2 for environmental searches. Thus, WA can barely positively and significantly moderate the reduction effect of Pub2 on PM. **H2a was confirmed.**

4.5.2. The moderating effect from Er

Secondly, from the perspective of government attention, this study explores the moderating effect of Er on Pub. We conduct a regression analysis for model (3) and the results are shown in Table 5. The coefficient of the interaction term in column (3) is significantly negative at the 5 % level, indicating that Er can positively reinforce the promoting effect of Pub1 on PM in resource-based cities, that is to say the stronger Er, Pub1 have a stronger inhibitory effect on PM. Although the previous research has shown that Pub2 has a significant negative effect on PM in resource-based cities, under the regulatory mechanism of Er, the coefficient of the interaction term is not significant in column (4), which indicates Er has no significant moderating effect on Pub2. **H2b was confirmed.** This is because Pub2 focuses on the aspects of daily life, such as the immediate impacts of smog on travel and health. In contrast, the Er places more emphasis on formulating macro policies and controlling overall indicators. Moreover, Pub2 is characterized by immediacy, while the Er requires a complex process. As a result, the focus of attention and the response timeliness between the two parties are inconsistent, making it difficult for them to impact each other.

Table 5
The moderating effect of WA, Er and Ep.

	(1) PM	(2) PM	(3) PM	(4) PM	(5) PM	(6) PM
L.Pub1	−1.912***		−1.071**		−0.973***	
	(0.439)		(0.421)		(0.349)	
L.Pub2		1.266		−2.547***		−1.357*
		(1.179)		(0.916)		(0.797)
L.WA × *L*.Pub1	0.194**					
	(0.088)					
L.WA × *L*.Pub2		−0.322				
		(0.394)				
L.WA	−0.913***	−0.811***				1
	(0.153)	(0.189)				
L.Er × *L*.Pub1			−0.303**			
			(0.141)			
L.Er × *L*.Pub2				−0.357		
				(0.303)		
L.Er			−0.255*	−144.093		
			(0.138)	(95.750)		
L.Ep × *L*.Pub1					−0.317**	
					(1.285)	
L.Ep × *L*.Pub2						−0.769
						(2.712)
L.Ep					−0.484***	−0.465***
					(0.109)	(0.339)
Year/Region	Y	Y	Y	Y	Y	Y
Control variables	Y	Y	Y	Y	Y	Y
_cons	36.888	31.193	134.077***	117.131***	46.231***	38.762***
	(22.902)	(25.630)	(24.023)	(29.256)	(17.498)	(13.302)
N	792	792	999	999	999	999
Adj-R^2	0.783	0.769	0.748	0.743	0.651	0.636

Note: *, **, and *** are significant at the 10 %, 5 %, and 1 % levels respectively.

4.5.3. The moderating effect from Ep

Thirdly, from the perspective of the implementation of government policies, this study explores the moderating effect of the Ep on Pub. The results are shown in Table 5 based on the Model (4). The coefficient of the interaction term in column (5) is significantly negative at the 1 % significance level. This indicates that the Ep can positively reinforce the promoting effect of Pub1 on PM in resource-based cities. However, under the regulatory mechanism of Ep, the coefficient of the interaction term in column (6) is not significant, suggesting that the Ep has no significant moderating effect on Pub2. The reason is the fundamental difference between Pub1 and Pub2. Pub1 directly addresses specific pollution issues. Ep has an effective feedback mechanism: once the public complains, the inspection team intervenes promptly, urging relevant departments to efficiently handle and rectify the problem. This positive feedback boosts public enthusiasm, creating a virtuous cycle and enhancing PM emission reduction. Conversely, Pub2 is an information - seeking behavior, having no direct link to Ep's operations. Public Baidu searches, filled with diverse content like knowledge popularization and policy interpretations, can't closely interact with Ep driven environmental governance. Thus, Ep barely has a significant positive impact on Pub2.

4.5.4. The superimposed moderating effect between Ep and Er

Furthermore, this study aims to explore the dual superimposed effects of Ep and Er on Pub. We incorporated Er and Ep into the unified Model (5) to test the emission reduction effect of Pub on PM under the dual regulatory mechanisms of Er and Ep. The results are shown in Table 6. In column (1), the coefficients of the interaction term between Ep and Er, as well as the interaction term among Ep, Er, and Pub1, are significantly negative at the 1 % level. This indicates that Ep and Er can form an effective joint force, enhancing the emission reduction effect of Pub1 on PM in resource-based cities. In contrast, in column (2), the coefficient of the interaction term among Ep, Er, and Pub2 is not significant. Although Ep can reinforce the emission reduction effects of Er and Pub1, it neither has a positive regulatory effect on Pub2 nor can it form an effective joint force with Er to reduce PM through Pub2. **H2c was confirmed.** The reason is Pub1, a direct public participation form, aligns well with Ep's on-site work and Er's policy-related tasks, allowing public feedback to reach and be addressed by relevant departments effectively. Conversely, Pub2, like Baidu searches, is an abstract information - gathering behavior with content scarcely related to Ep and Er's practical regulation, and its scattered information lacks a targeted integration way, leading to Ep and Er's inability to form a synergy with it and Ep having no positive regulatory effect.

Table 6
The superimposed moderating effect between Ep and Er.

	(1) PM	(2) PM
L.Pub1	−0.892***	
	(0.237)	
L.Pub2		−0.910*
		(0.532)
L.Er	−0.207**	−0.336***
	(0.092)	(0.128)
L.Ep	−0.451***	−0.502***
	(0.156)	(0.111)
L.Ep × *L*.Er	−0.387**	−0.415***
	(0.178)	(0.133)
L.Ep × *L*.Er × *L*.Pub1	−0.263**	
	(0.132)	
L.Ep × *L*.Er × *L*.Pub2		0.634
		(0.407)
Year/Region	Y	Y
Control variables	Y	Y
_cons	25.138***	30.452***
	(2.802)	(2.467)
N	999	999
Adj-R^2	0.354	0.361

Note: *, **, and *** are significant at the 10 %, 5 %, and 1 % levels respectively.

5. Further analysis

The level of economic development is the cornerstone of the effectiveness of PM governance. under different levels of economic development, there may also be significant nonlinear characteristics in the governance effect of Pub on PM. Therefore, this study further explores the threshold characteristics of the marginal emission reduction effect of Pub on PM from the perspective of different economic development levels, which aims to provide empirical evidence for the in-depth expansion and improvement of the research system.

The empirical results are shown in Table 7. The Pub1 on PM has only a single threshold effect, while Pub2 on PM has a dual threshold effect. Specifically, column (1) shows that when Pgdp below the threshold (Pgdp≤10.2765), the estimated coefficient of Pub1 is 0.206, which is significantly positive at the 1 % level; When the Pgdp above the threshold (Pgdp>10.2765), the estimated coefficient of Pub1 is −0.084, which is significantly negative at the 1 % level. This suggests that Pub1 have shifted from contributing to air pollution towards inhibiting it with the rapid economic growth.

Upon investigating its root cause, during the low-economic-development phase, the public, with limited environmental quality demands and scarce channels to voice environmental concerns, faces local governments that, under performance-assessment pressure, often perfunctorily handle their environmental protection appeals, thus triggering frequent "government-enterprise collusion". Apparently, polluting firms are punished and environmental regulations seem tightened, yet in reality, to support local industries or attract pollution - intensive businesses, the government weakens environmental standards and governance via subsidies and tax breaks, worsening air pollution. However, as the economy advances, people increasingly value their quality of life and health. In recent years, the public's awareness of climate change and air-pollution hazards has grown, along with their environmental consciousness. Moreover, digital technology has diversified public channels for expressing environmental concerns and cut information - acquisition costs, so the emission-reduction impact of Pub on PM is gradually emerging.

The results in column (2) show that the level of economic development can be divided into three intervals, low economic development interval (Pgdp≤10.7094), middle economic development (10.7094<Pgdp≤11.1769) and higher economic development interval (Pgdp>11.1769). With economic development levels raising, the effect of Pub2 on PM is gradually weakening. Specifically speaking, in the low

Table 7
Results of threshold regression estimation.

	(1) PM	(2) PM
L.Pub1(Pgdp≤10.2765)	0.206***	
	(0.072)	
L.Pub1(Pgdp>10.2765)	−0.084***	
	(0.023)	
L.Pub2(Pgdp≤10.7094)		−0.049***
		(0.012)
L.Pub2(10.7094<Pgdp≤11.1769)		−0.022**
		(0.009)
L.Pub2(Pgdp>11.1769)		−0.005
		(0.007)
Year/Region	Y	Y
Control variables	Y	Y
_cons	82.024***	84.943***
	(15.466)	(16.370)
N	2412	2412
adj. R^2	0.752	0.755

Note: *, **, and *** are significant at the 10 %, 5 %, and 1 % levels respectively.

economic development interval, the estimated coefficient of Pub1 is −0.049, which is significantly positive at the 1 % level, In the high economic development interval, the estimated coefficient of Pub2 is −0.005, which is not significant. Initially, low-economic development, accompanied by rapid industrialization and urbanization, heightens air pollution. Pub2 prompts government intervention in PM control, leading to significant improvement. However, with economic growth, Pub2′s positive impact on PM fades. This is because in the new media-dominated environment of higher-level economies, although Pub2-related information spreads widely, it is overly complex and hard to verify. The flood of information distracts government departments, preventing them from quickly identifying and focusing on crucial PM-control information. Overall, Pub2 is more effective than Pub1 in emission reduction at low-economic levels, while the opposite is true at high-economic levels, as the government's environmental governance system matures, better integrating Pub1 into existing professional processes and supervision mechanisms. **H3 was confirmed.**

6. Conclusion and policy recommendations

With the continuous refinement of the environmental participation system and the rapid evolution of new media technology, the integration of "bottom-up" Pub has emerged as a pivotal driver in PM. This study, grounded in the panel data of 268 prefecture-level cities in China from 2011 to 2020, comprehensively deploys the double fixed-effects model, moderating effects model, and threshold effects model. It systematically probes into the differential impacts and economic threshold characteristics of Pub on PM under WA, Er and Ep. Main findings are as follows: (1) Pub1 exhibits a pronounced emission-reduction effect on PM, while Pub2′s significant impact on PM is confined in resource-based cities. A battery of robustness tests validates this conclusion. (2) In resource-based cities, WA demonstrates a negative substitution effect on Pub1. Conversely, Er and Ep exerts a positive moderating effect on Pub1, indicating a potential for cooperation in strengthening the emission reduction effect of Pub1 on PM. (3) Further analysis reveals that, Pub1 and Pub2 manifest distinct threshold effects on PM under the different Pgdp. Pub1 follows a single-threshold pattern, shifting from an initial increase to a subsequent decrease in PM, while Pub2 exhibits a double-threshold characteristic of diminishing marginal emission-reduction benefits. Based on these findings, the following policy recommendations are proposed:

(1) Deepen the public environmental participation mechanism

Firstly, cultivating public responsibility. Establish a comprehensive responsibility cultivation framework for Pub. Through systematic environmental education and outreach, ensure public awareness and fulfillment of responsibilities in all phases of PM, from pre-planning to mid-supervision and post-evaluation. Secondly, driving new media integration. Harness advanced information technologies like the Internet and big data to seamlessly integrate new media platforms with Pub. Develop user-friendly online platforms, such as virtual council halls and real-time negotiation forums, to widen participation avenues and enhance user experience, enabling unhindered public involvement in air pollution management decision-making and oversight. Thirdly, leveraging public opinion. Capitalize on the influence of public opinion to prompt enterprises to internalize pollution costs. By mobilizing public scrutiny and pressure on polluting enterprises, encourage proactive adoption of environmental protection measures and production process optimization, thereby enhancing overall air pollution management effectiveness.

(2) Enhance the adaptability of government policy tools

Firstly, strengthening government regulation. The central government must not only up the inspection frequency but also deepen and broaden their scope in the resource-based city. For instance, conduct targeted inspections in areas with chronic environmental problems or high-risk industries. Develop a comprehensive evaluation system for local government environmental law-enforcement, covering both procedural compliance and actual environmental quality improvement. Regularly disclose inspection results to the public, applying public pressure on local governments to ensure fair, standardized, and efficient environmental law-enforcement. Secondly, strengthening media monitoring. Bolster public opinion monitoring on social media platforms such as Weibo. Employ big data analytics to precisely identify public environmental concerns and promptly address potential environmental risks, thereby optimizing public participation in environmental affairs via new media. Thirdly, Fostering public-government interaction. Leverage social media's dissemination prowess to innovate environmental knowledge dissemination. Use engaging and accessible means to raise public environmental awareness. Implement reward-based reporting systems and public consultation initiatives to encourage public-government environmental information exchange, thereby enhancing public participation enthusiasm.

(3) Improve the collaborative governance mechanism in accordance with local conditions.

Firstly, in the underdeveloped city, governments should institute a refined complaint classification and guidance mechanism and streamline complaint handling and feedback processes. Set up dedicated environmental protection hotlines and user-friendly online platforms, leveraging information technology to expedite handling and response times. Secondly, in developed city, constructing the hierarchical and multifunctional new media interaction platforms, such as official environmental protection WeChat and Weibo accounts, equipped with convenient pollution reporting portals and real-time online consultation services. Utilize digital tools to boost public participation convenience and depth. Thirdly, promoting regional collaboration. Strengthen inter-city cooperation and refine the inter-city environmental protection coordination mechanism. Regularly organize experience-sharing sessions among environmental protection departments, public representatives, and new media operators from resource-based and non-resource-based cities. For cross-regional pollution transfer issues, establish a permanent inter - city environmental protection coordination body to jointly formulate effective governance strategies and enhance regional air pollution management efficacy.

This research offers a crucial reference for refining the air pollution management framework and policy system. At the policy-making level, it empowers the government to accurately identify key aspects of Pub in PM, formulate more effective policies, and foster a virtuous cycle among WA, Ep, Er and Pub. In practical applications, it provides clear guidance for central governments and local relevant departments to optimize environmental governance processes and enhance efficiency. Socially, it heightens public awareness of their role in PM, spurring broader and deeper public engagement. Through strategic public participation guidance, it aims to establish a collaborative governance model involving the government enterprises and public.

CRediT authorship contribution statement

Pingping Ma: Writing – original draft, Methodology, Data curation. **Ming Zhang:** Writing – original draft, Methodology, Formal analysis, Conceptualization. **Yan Song:** Writing – review & editing.

Declaration of competing interest

Ming Zhang reports financial support was provided by National Natural Science Foundation of China. If there are other authors, they 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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Appendix 1

Robustness tests based on Eq. (1).

	PM		PM	
	(1)	(2)	(3)	(4)
L.Pub1	−0.064***		−0.102***	
	(0.022)		(0.025)	
L.Pub2		−0.007		−0.015
		(0.006)		(0.013)
Ind	10.631***	10.437***	9.376***	9.397***
	(3.788)	(3.804)	(3.333)	(3.390)
Pgdp	−4.333***	−4.430***	0.595	0.343
	(1.128)	(1.130)	(1.264)	(1.279)
Fin	−20.604***	−19.675***	−13.799**	−12.454*
	(5.563)	(5.565)	(6.444)	(6.574)
Inv	−0.000	−0.004**	−0.000	−0.006***
	(0.002)	(0.002)	(0.002)	(0.002)
Den	−6.143**	−6.791**	7.020**	6.145*
	(2.736)	(2.782)	(3.307)	(3.472)
Open	−8.005***	−7.618***	−5.198**	−4.773**
	(2.239)	(2.179)	(2.126)	(2.113)
Year/Region	Y	Y	Y	Y
Control variables	Y	Y	Y	Y
cons	131.509***	135.185***	3.373	10.684
	(22.700)	(22.884)	(26.495)	(27.377)
N	2412	2412	1608	1608
Adj-R^2	0.758	0.757	0.736	0.731

Note: *, **, and *** are significant at the 10 %, 5 %, and 1 % levels respectively.

Appendix 2

The results of the threshold effect test.

	F-value	P-value	10 %	5 %	1 %
Single	90.26	0.0000***	19.7642	23.1357	31.8983
Double	16.61	0.1230	17.9574	21.1631	26.5355
Three	15.24	0.3770	25.1855	28.4761	37.2060

Data availability

The data that has been used is confidential.

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