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**Working Paper**

## Digital monitoring technology and air quality: Evidence from the People's Republic of China

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# DIGITAL MONITORING TECHNOLOGY AND AIR QUALITY

## EVIDENCE FROM THE PEOPLE'S REPUBLIC OF CHINA

*Pinghan Liang, Yadi Liu, and Shu Tian*

**NO. 788**

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Pinghan Liang, Yadi Liu, and Shu Tian

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## ABSTRACT

Since the early 21st century, air quality concerns in the People's Republic of China (PRC) have garnered significant attention from both the public authorities and society. This study investigates the effects of digital environmental monitoring technology on air pollution. Specifically, we explore the data from government procurement of digital environmental monitoring technologies over the 2014–2019 period. The baseline results indicate that on average, each additional environmental contract per 100,000 residents signed by governments is associated with an 8-percentage point reduction in city PM<sub>2.5</sub> levels. This effect arises from more accurate pollutant identification, which strengthens enforcement of environmental regulations, facilitating any necessary transition and, where applicable, orderly exit of heavily polluting enterprises, and fosters green innovation. Further, this effect exhibits regional variation in the extent of environmental concern and the level of information disclosure. The results suggest that technology-driven environmental governance, supported by public engagement and policy frameworks, plays a crucial role in enhancing air quality in the PRC.

**Keywords:** digital environmental monitoring, PM<sub>2.5</sub>, public monitoring, information disclosure

**JEL codes:** O18, O33, Q50

## 1. INTRODUCTION

There is increasing interest from the public, city administrators, and regulators in air quality, as safe, clean air is essential for cities and communities to thrive (Smith and Doe 2020). In 2010, the People's Republic of China (PRC) became the world's second-largest economy; however, this growth came at a significant environmental cost. Regions such as Beijing, Tianjin, and Hebei Province have frequently suffered from severe smog, with air pollution levels reaching hazardous levels. These alarming indicators have prompted the PRC government to continuously prioritize environmental issues, implementing a series of policy reforms and technological advancements aimed at environmental improvement.

In 2013, the PRC government announced an investment of CNY1.7 trillion (\$277 billion) over the next 5 years to combat the dangerous and rapidly worsening air pollution resulting from the PRC's rapid economic growth (Wu 2013). This initiative includes actively leveraging digital technologies to enhance environmental governance efficiency, as demonstrated by the widespread implementation of digital environmental monitoring systems in urban areas (Schlæger and Zhou 2019). Digital technology offers unique advantages in predicting pollution level changes and tracking dispersion pathways. This technology addresses the principal-agent information asymmetry between the government and polluters. By providing real-time, transparent data, it reduces uncertainty and effectively lowers pollution levels. Despite the numerous advantages of digital monitoring technology and its growing role in environmental governance in the PRC, the impact of digital monitoring technology on air pollution management remains insufficiently understood and warrants further investigation.

We obtained environmental monitoring procurement contracts from the Chinese Government Procurement Network for the years 2014–2019, matched them with cities based on the addresses of the purchasing parties to examine the impact of government digital monitoring technology on city PM<sub>2.5</sub> levels. The baseline regression results indicate that, on average, each additional environmental contract per 100,000 residents corresponds to an estimated 8%

reduction in PM<sub>2.5</sub> levels. This effect arises from more accurate pollutant identification, which strengthens governmental enforcement of environmental regulations, expedites the exit of heavily polluting enterprises, and fosters green innovation.

First, our research directly broadens and supplements discussions on environmental monitoring technology within the context of the PRC's digitalization (Jin et al. 2020, Schlæge and Zhou 2019, Hao 2018), emphasizing the significance of technology-aided decision-making. Traditional environmental governance frameworks, such as market-based regulations, have positively impacted environmental governance (Mao and Wang 2016, Zhang et al. 2019). However, they often exhibit temporal delays. Our findings indicate that digital monitoring technology significantly enhances the efficiency of air pollution regulation, with its impact strongly correlated to the density of monitoring devices—a relationship confirmed within industrial parks (Huang et al. 2019). We extend this conclusion to city level, finding that higher levels of digital monitoring infrastructure effectively reduce overall air pollution. This finding carries substantial implications for other facets of the PRC's environmental governance, suggesting that intensified monitoring efforts can support broader environmental improvement goals.

Second, some studies have discussed the impact of environmental monitoring stations under central government regulation on air quality. On the one hand, monitoring stations have improved air quality, but this effect appears to be localized (Yang et al. 2024; He et al. 2020). On the other hand, environmental monitoring stations signify a shift in environmental monitoring authority, and the increase in digitalization and information disclosure reduces the potential for local data manipulation (Greenstone et al. 2022). Reported air pollution concentrations showed an immediate increase following the establishment of monitoring stations. This also motivated local government officials to address environmental pollution. No studies, to the best of our knowledge, have explored how local governments react to urban air quality when data regulation authority is transferred upwards. This issue is critical because increased information disclosure not only elevates public and government awareness of environmental pollution but also forces

local governments to adopt more efficient pollution control measures in response to public demands. Consequently, the expansion of the air monitoring network through the procurement of advanced digital monitoring technologies becomes a key strategy for local governments. Our study reveals that cities with higher levels of environmental information disclosure experience a significantly greater reduction in air pollution because of the impact of digital monitoring.

Lastly, our research underscores that technology, while offering numerous governance benefits, cannot independently resolve complex environmental issues. Digital monitoring technology serves primarily as an information provider in air pollution management; however, its effectiveness depends on integration within a broader systemic governance framework. On the one hand, Greenstone et al. (2022) indicate an immediate and lasting increase of reported air pollution level after the introduction of automated monitoring of air quality. Yang et al. (2024) show that local governments' strategic response to the automated monitors may limit the enforcement of environmental regulation. On the other hand, Buntaine et al. (2024) show that citizen participation via social media could improve use of the real-time emission information and strengthen environmental governance. Hence, tangible governance outcomes are achieved only when environmental issues garner substantial attention from both governments and the public. This indicates that, although technology supplies essential tools and platforms for governance, meaningful change arises through collaborative engagement between technology and key social forces, including government, industry, and the public.

The structure of this report is as follows: Section 2 reviews the relevant background; Section 3 details the methodologies employed in this study; Section 4 presents the findings and discussion; and Section 5 concludes with a summary of key insights and policy recommendations.

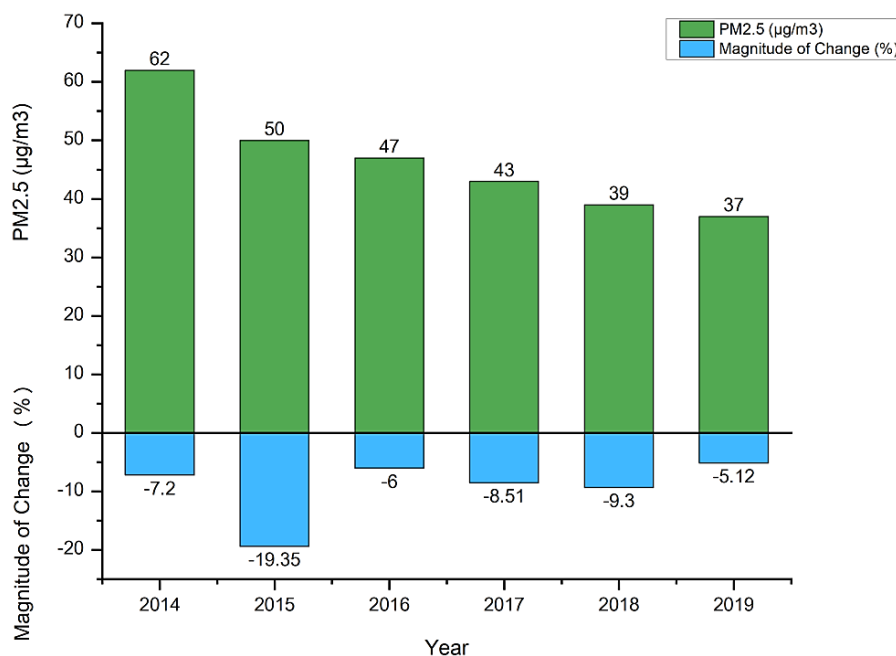
## **2. INSTITUTIONAL BACKGROUND AND DEVELOPMENT OF ENVIRONMENTAL MONITORING TECHNOLOGY**

### **2.1 Air Pollution and Digital Transformation**

Air pollution, a critical global environmental challenge, particularly affects developing countries, disrupting the Earth's temperature balance, diminishing biodiversity, and exacerbating respiratory diseases (Chakraborty and Lee 2019; Syed, Folz, and Ali 2023), and potentially reducing labor productivity (He, Liu, and Salvo 2019). In recent years, the PRC has taken active measures to reduce air pollution and has made notable progress (Fig.1), from the perspective of PM<sub>2.5</sub> concentrations, there has been a sustained annual reduction in overall pollution levels across the CPPRR, indicating a trend of improvement in air quality over time. The government initiated this effort in 2013 with the "Air Pollution Prevention and Control Action Plan," which launched a nationwide campaign to tackle air pollution and emphasized the use of digital monitoring methods to strengthen air quality supervision.

In the era of smart cities, digital technology offers new opportunities for environmental governance. In fields such as traffic management and public safety, digital transformation has shown positive results (Westerman et al. 2014; Hollis 2019, Ardabili et al. 2023). Technologies such as big data, cloud computing, internet of things (IoT), and artificial intelligence (AI), with their real-time data collection, powerful data processing, and predictive capabilities, can analyze data patterns in conjunction with variables such as weather conditions, traffic density, and industrial emissions, enabling accurate pollution forecasting and preemptive policy measures, better respond to rapidly changing environmental conditions and policy needs (Shen 2018, Aggestam and Mangalagiu 2020). Currently, environmental monitoring technology has been widely applied in soil detection (Wilson 2012), water quality testing (Chen et al. 2018), and air quality monitoring (Ma et al. 2014, Van et al. 2015). Empirical evidence from Western countries shows that environmental monitoring and enforcement activities provide a significant deterrent effect, reducing both violations and emissions (Gray and Shimshack 2011).

**Figure 1. National Average PM2.5 Concentration and Changes**



Note: Figure 1 illustrates the annual variation in PM2.5 concentrations in the PRC from 2014 to 2019. The data is sourced from the Ministry of Ecology and Environment of the PRC. The 2014 data represents the PM2.5 concentration in 74 cities where the new standards were implemented, while the remaining green bars reflect the national annual average PM2.5 concentrations. The blue bars indicate the year-on-year changes (%) in PM2.5 concentrations.

Source: Authors' calculations.

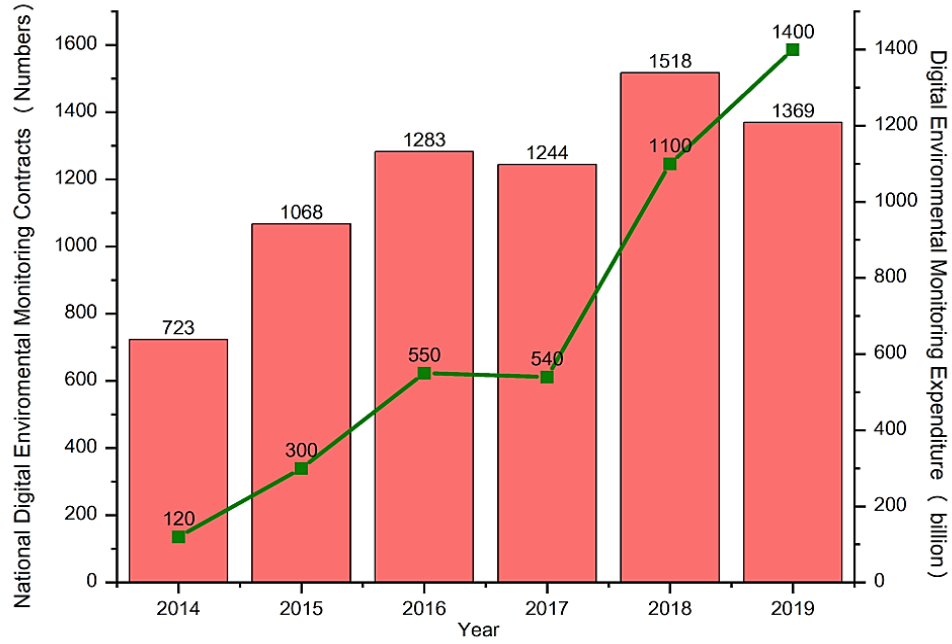
## 2.2 Policy Background and Status of Environmental Digital Monitoring

To meet urban environmental management needs, the PRC established its air monitoring network in the mid-1970s, adopting a “government-led, market-participated” model. Historically, local governments maintained control over data collection, and monitoring technology limitations—especially prior to 2012—led to widespread concerns regarding the reliability of the PRC’s air quality data (Tang, Wang, and Yi 2023; Greenstone et al. 2022). In response, following the 18th National Congress, the PRC started to switch to the high-quality development model that integrates economic growth with environmental protection, and the central government initiated significant measures to combat air pollution. subsequent policy frameworks, such as the “Ecological Environment Monitoring Network Construction Plan” (2015) and the “13th Five-Year

Plan for Ecological Environmental Protection” (2016), collectively emphasized the establishment of a comprehensive and interconnected environmental monitoring system that integrates technological innovation from both public and private sectors. The nationwide campaign that underscored digital monitoring methods to bolster air quality oversight. These efforts included the establishment of an environmental monitoring network, comprising central government-established monitoring stations and environmental monitoring equipment independently procured by local governments. The monitoring station network was fully operational by early 2015. This new system enabled hourly and daily air quality reporting to the central government, reducing previous issues of data delays and omissions and incentivizing local governments to prioritize urban environmental issues. Local governments have increasingly procured environmental monitoring equipment from technologically advanced companies through open tenders. The density of these devices is closely aligned with population and industrial distribution, allowing for targeted monitoring. By continuously tracking environmental pollutant concentrations, these devices gather extensive environmental data, which is then transmitted via wireless or wired connections to a centralized cloud platform for comprehensive management and analysis. Leveraging IoT technology, the equipment enables real-time environmental monitoring and alert functions (Perry et al. 2022), providing essential data support for environmental protection agencies to respond promptly and effectively.

Our analysis of government procurement contracts and expenditure on environmental monitoring reveals a significant national development trend in environmental monitoring technology (Fig. 2). The bar heights illustrate a steady increase in contract numbers, starting from 723 in 2014 and reaching a peak of 1,518 in 2019, suggesting intensified efforts in environmental monitoring. Overall, Expenditures on digital environmental monitoring have exhibited a consistent upward trend over the years. This shift indicates that the government is increasingly employing digital technologies to enhance its capabilities in pollution detection, data collection, and regulatory enforcement.

**Figure 2. National Environmental Monitoring Development**



Note: Figure 2 shows the development of national environmental monitoring from 2014 to 2019. The bar chart represents the annual number of national environmental monitoring contracts, and the line chart shows the trend of digital environmental monitoring expenditure. The left Y-axis represents the scale of environmental monitoring contract procurement quantity, while the right Y-axis represents the scale of environmental monitoring expenditure.

Source: Authors' calculations.

### 3. DATA AND METHODOLOGY

#### 3.1 Empirical Model

This study conducts an empirical examination of the impact of digital monitoring technologies on air pollution, based on data from 283 prefecture-level cities and above in the PRC over a 6-year period from 2014 to 2019. The estimation specification is the following:

$$\ln(Pollution_{i,t}) = \beta_1 + \beta_2 \times Environmental\ Monitoring_{i,t} + \delta Control_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t} \quad (1)$$

where for city  $i$  and year  $t$ ,  $\ln(Pollution_{i,t})$  refers to the level of PM2.5(log) in the city.  $Environmental\ Monitoring_{i,t}$  the numbers of environmental monitoring contracts per 100,000 people in city  $i$  and year  $t$ . Controls represents a set of control variables, including weather factors, as well as social and economic factors in city  $i$ .  $\mu_i$  is an urban fixed effect to absorb all unique regional

characteristics that do not change over time, such as cultural differences, and  $\gamma_t$  is a year fixed effect to capture the effects of unobservable variables that change over time, such as policy changes.  $\varepsilon_{i,t}$  is a random error term.

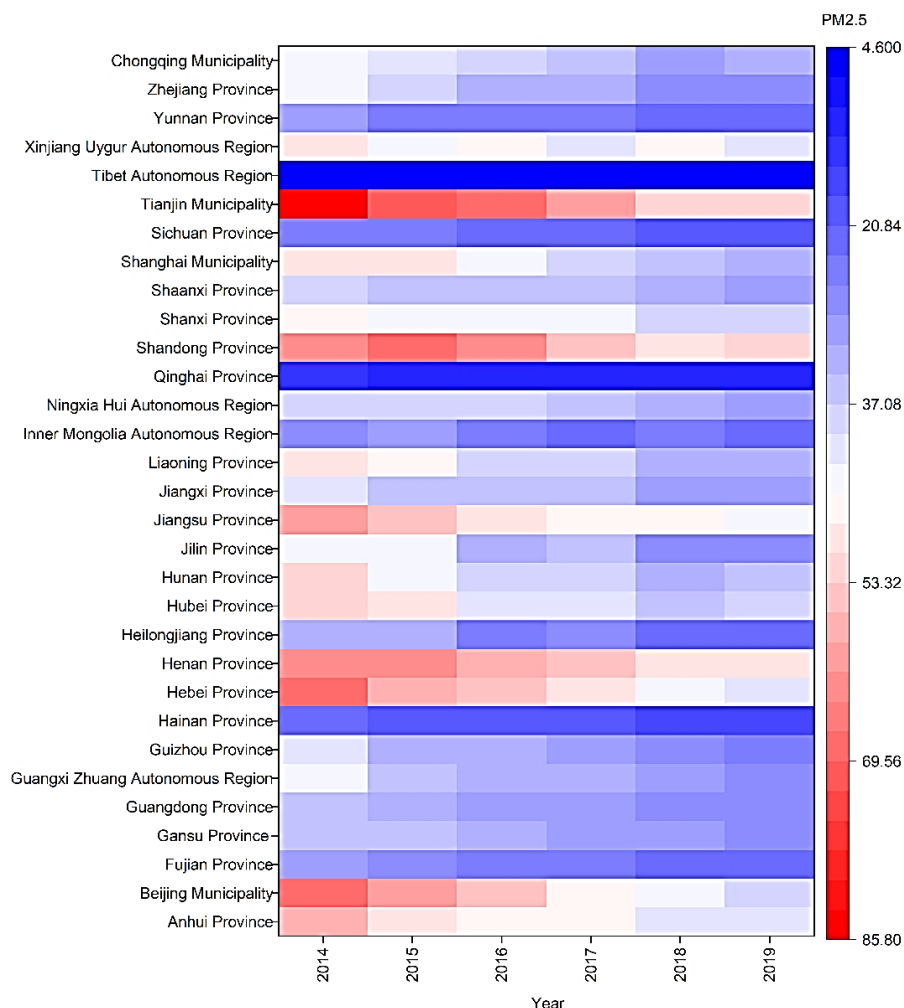
### 3.2 Variables and Data Source

Environmental monitoring contracts. The information related environmental monitoring technology mainly comes from the procurement winning announcements of Chinese Government Procurement Network (ccgp.gov.cn). The government's environmental monitoring procurement behavior reflects its efforts towards environmental protection. Since the upload rate of procurement announcements has been high only since 2014, this study extracts procurement announcements for environmental monitoring equipment purchased by municipal environmental protection departments from 2014 to 2019. The amounts and addresses for each contract are determined using a combination of a semi-supervised deep learning algorithm (NER) and manual verification. These addresses are then matched with city-level data based on the supplier's address information. To mitigate the influence of variables such as brand reputation, market price fluctuations, city economic conditions, and government budgets on contract amounts, we utilize a standardized measure based on contract quantity to evaluate digital environmental monitoring at the city level. Specifically, digital environmental monitoring density is assessed by calculating the number of contracts per 100,000 residents in each city. This approach allows for a consistent and comparable metric across different urban contexts.

**Air Quality.** Urban air quality is measured using annual PM2.5 levels, a key indicator officially recognized for monitoring air pollution in the PRC. PM2.5 is a typical product of various urban pollution sources and is strongly associated with human health risks (Mao et al. 2024). In February 2012, the PRC incorporated PM2.5 into its official urban air quality monitoring framework. To assess annual average PM2.5 concentrations for cities from 2014 to 2019, we utilized globally sourced, ground-based PM2.5 grid data, calibrated by Washington University in St. Louis using geographically weighted regression (GWR). Fig. 3 presents the average PM2.5 concentrations

across the PRC's provincial regions from 2014 to 2019. Higher concentrations are observed in the Beijing-Tianjin-Hebei region and in provinces such as Henan, Anhui, and Shandong, whereas relatively lower levels are found in western regions. Overall, PM2.5 concentrations demonstrate a gradual declining trend across all regions of the PRC over the observed period.

**Figure 3.** PM2.5 in Provincial-Level Regions of the People's Republic of China from 2014 to 2019



Note: This chart illustrates the annual average PM2.5 concentrations across provincial-level regions of the PRC from 2014 to 2019. The X-axis represents the years, while the Y-axis lists the region names. Regions are color-coded, with red indicating higher PM2.5 concentrations and blue indicating lower concentrations.

Source: Authors' calculations.

**Control variables.** We consider other relevant factors from two dimensions. The weather characteristics and socioeconomic features of cities. The city's annual average precipitation, temperature, and air circulation coefficient are critical weather factors that significantly influence the dispersion and deposition levels of pollutants (Mao et al. 2020). On the socioeconomic side, the “Environmental Kuznets Curve” has been widely verified, indicating that the level of urban economic development often shows an inverted “U” shaped nonlinear relationship with environmental pollution (Grossman and Krueger 1995). Additionally, urbanization and industrial structure are also critical factors influencing urban pollution levels (Wang et al. 2022; Shahbaz, Lean, and Shabbir 2012). The descriptive statistics for all variables used in the study are presented in Table 1.

**Table 1.** Descriptive Statistics

Variable names	N	Mean	Std.Dev.	Min	Max
<b>Panel A: Main variables</b>					
Env_Digital_Contract	1,046	7.15	11.12	2	172
Env_Contract_100k	961	0.27	0.27	0.01	2.79
Digital Monitoring Values (ten thousand)	961	84.87	65.10	0.027	12,800
Env_Trans_Contract_100k	1,187	0.31	0.28	0.01	2.96
PM2.5 ( $\mu\text{g}/\text{m}^3$ )	1,323	45.96	18.62	9	135
<b>Panel B: Weather, City economic and social characteristics</b>					
ln(GDP) (billion)	1,393	7.48	0.93	5.03	10.55
ln(GDP) <sup>2</sup> (billion)	1,393	56.77	14.40	25.31	111.29
Sec_ind_ratio (%)	1,334	44.45	9.64	16.16	59.40
Ter_ind_ratio (%)	1,398	43.80	9.24	19.76	83.52
Urbanization (%)	1,340	57.42	13.91	6.49	100
Annual Average Precipitation	1,398	1,174.65	597.42	54.72	3,081.46
Annual Average Temperature	1,398	14.40	5.61	-2.38	28.10
Air Circulation Coefficient	1,398	1,261.547	557.63	263.58	4913.83
<b>Panel C: Instrumental Mechanism and Heterogeneity characteristics</b>					
Environmental administrative penalty (number)	1,308	302.57	751.15	2	11232
Polluting Firm (number)	1,136	6.99	10.27	0	92
Smog Search Index	1,371	62.58	55.94	0.62	439.34
Environmental Term Frequency	1,393	0.24	0.014	0.01	0.09

*Continued on the next page*

Variable names	N	Mean	Std.Dev.	Min	Max
Information Disclosure (PITI)	589	3.89	0.30	2.74	4.41
Low-carbon city pilot (dummy)	1,398	0.42	0.49	0.00	1.00
Carbon emission trading pilot (dummy)	1,398	0.15	0.36	0.00	1.00
Joint Green Patents	1,130	2.67	3.80	1	15

Source: Authors' calculations.

## 4. RESULTS

### 4.1 Baseline Results

Table 2 presents the baseline regression results. In Column (1), we do not control for fixed effects or other influencing factors, and the regression coefficient indicates that an additional environmental monitoring procurement contract per 100,000 people corresponds to a 27% reduction in PM2.5 (log) concentration. Column (2) displays the regression results with city and year fixed effects included. In Column (3), we further incorporate city-level economic and social characteristics, while Column (4) shows the final regression results with additional weather factors included. We find that the procurement of digital environmental monitoring technology consistently and significantly reduces urban PM2.5 concentrations. The regression results in Column (4) reveal that, holding other factors constant, an additional environmental monitoring contract per 100,000 people is associated with an 8% reduction in PM2.5 (log) concentration, highlighting the importance of including control variables.

This result reflects the effectiveness of digital monitoring technology in air pollution management, improving air quality through “monitoring” and “forecasting.” First, digital monitoring technology can significantly enhance the accuracy of pollutant source identification within the detection scope. These data enable governments and regulatory agencies to quickly detect pollution sources and take corresponding remedial actions. Second, digital monitoring, combined with machine learning, can analyze and forecast pollution, which greatly reduces the occurrence of high emissions and severe pollution events.

**Table 2.** Baseline Estimation

	ln (PM2.5)	ln (PM2.5)	ln (PM2.5)	ln (PM2.5)
	(1)	(2)	(3)	(4)
Environment Monitoring	-0.273*** (0.039)	-0.089*** (0.023)	-0.082*** (0.023)	-0.075** (0.022)
Economic and social characteristic variables	NO	NO	YES	YES
Weather characteristic variables	NO	NO	NO	YES
Time FE	NO	YES	YES	YES
City FE	NO	YES	YES	YES
N	922	922	882	882
adj. R-sq	0.0648	0.587	0.668	0.673

Note: This table presents the baseline regression results of the model. Environment Monitoring is our dependent variable, representing the number of contracts per 100,000 people, while ln(PM2.5) represents the logarithms of the annual average PM2.5 in the city. The regression coefficients are estimated using the OLS model. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ ; Standard errors in parentheses are clustered at the city level.

Source: Authors' calculations.

## 4.2 Robustness Analyses

We conducted a series of regressions to examine the robustness of our main results. Firstly, we excluded the effects of municipalities (Column 1), as their higher administrative levels differ in resource allocation and environmental governance compared to regular cities, making the results more generalizable. Secondly, pilot environmental policies, such as low-carbon cities or carbon emission trading pilots, could cause biases in pollution levels and the effectiveness of monitoring technology, so we also controlled for this influence (Column 2). The PRC is also a major emitter of sulfur dioxide (SO<sub>2</sub>), thus we replaced the dependent variable with city-level SO<sub>2</sub> concentration (Column 3) to examine the impact of digital monitoring technology on other air pollutants. We found that for every additional digital monitoring contract per 100,000 people, the SO<sub>2</sub> level decreases by 15%. This finding suggests that digital monitoring technology exerts a greater influence on SO<sub>2</sub> than on PM2.5. This is likely because environmental monitoring technologies primarily target large-scale, high-emission sources, such as coal power plants and steel mills, which are major contributors to SO<sub>2</sub> emissions.

Additionally, since digital monitoring equipment has a certain durability period, previously installed equipment may continue to exert influence. We thus measured urban digital environmental monitoring intensity using the cumulative number of environmental monitoring contracts (Column 4). Since the industrial sector is a significant source of PM<sub>2.5</sub> emissions, we also calculated the ratio of contract numbers to the share of industrial output in GDP, providing a measure of digital monitoring intensity within the industrial sector (Column 5). Further, as transportation is also a significant source of pollution, we included traffic monitoring in the analysis of air pollution (Column 6). Our coefficient of interest remains significant and slightly larger, suggesting that, beyond its role in identifying traffic violations and managing congestion, traffic monitoring has a spillover effect in pollution control (Column 7). We also replaced the explanatory variable with urban digital monitoring procurement expenditure to re-measure the intensity of digital monitoring technology implementation. While the coefficient of interest is slightly smaller in magnitude and significance than when measured by contract numbers, the significance of all robustness test results consistently indicates the stable suppressive effect of digital environmental monitoring technology on air pollution.

**Table 3. Robustness Check**

	Excluding municipalities	Incorporate Policy Pilot	ln(SO <sub>2</sub> )	Cumulative Contracts	EnvMonit_SecInd	Env_trans_contract_100k	Digital Monitoring values
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Environment Monitoring	-0.075*** (0.022)	-0.073*** (0.021)	-0.158*** (0.041)				
ln(Env_cumulative Contracts)				-0.043** (0.018)			
Sec_contracts					-0.021** (0.010)		
Env_trans_contract_100k						-0.081** (0.029)	
Digital Monitoring values							-0.007* (0.004)
Low-carbon city pilot							
Carbon emission trading pilot	NO	YES	NO	NO	NO	NO	NO
Control variables	YES	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES	YES
N	873	882	882	1517	882	1089	882
adj. R-sq	0.673	0.674	0.780	0.408	0.676	0.592	0.530

Note: This table presents the seven robustness tests mentioned. We used OLS estimation to conduct a series of regressions to examine the robustness of our main results. \* $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ ; Standard errors in parentheses are clustered at the city level.

Source: Authors' calculations.

### 4.3 Endogeneity Analysis

We employ a two-stage regression with instrumental variables to address potential endogeneity issues in this study. Drawing on the approach by Atkin (2013), we construct a supply shock:

$$\varphi_{i,2014} = \frac{Contract_{city_{i,2014}}}{\sum_{i \in I} Contract_{city_{i,2014}}} \quad (2)$$

$$IV_{i,t} = \ln(\varphi_{i,2014} \times \sum_{i \in I} Contract_{city_{i,t}}) \quad (3)$$

Here,  $\varphi_{i,2014}$  represents the proportion of digital environmental monitoring contracts in a given city to the total digital environmental monitoring contracts in the province at the initial sample period, which measures the region's responsiveness to market opportunities in digital monitoring development. Therefore, the interaction between  $\varphi_{i,2014}$  and the total number of contracts within the province at each time period reflects market-driven shocks in digital monitoring development. As shown in Table 4, the F-statistics are greater than 10. The result indicates that, after controlling for market shocks, the effect of digital monitoring technology on PM2.5 suppression is more pronounced (with a coefficient of -0.28). This partly suggests that market responsiveness and external shocks play a more significant role in the promotion of technology than simple policy-driven efforts.

**Table 4. Results for Endogeneity Test**

	IV estimation
	(1)
	Second-stage regression
Environment Monitoring	-0.28 *
	(0.160)
Economic and social characteristic variables	YES
Weather characteristic variables	YES
Time FE	YES
City FE	YES
	First-stage regression
Industry shock_IV	0.143 ***
	(0.013)
Control variables	YES
Time FE	YES
City FE	YES
F-stat.	114.35
N	877

Note: This table presents the regression results estimated using provincial public security monitoring contracts as the IV variable. The model includes a total of 1,021 samples, and the regression coefficients were obtained using 2SLS estimation. In all models, control variables, year fixed effects, and city fixed effects are fully controlled. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ ; Standard errors in parentheses are clustered at the city level.

Source: Authors' calculations.

#### 4.4 Mechanism Analysis

Digital technology serves primarily as a tool for data analysis and decision support, rather than directly reducing pollutant concentrations. Its impact is most evident in its indirect role, where it enhances governance efficiency by facilitating information flow and strengthening decision-making. As shown in Column (1), environmental monitoring technology significantly improves the identification of pollution cases; the coefficient indicates that each additional environmental monitoring procurement contract per 100,000 people is associated with a 46% increase in environment administrative penalty cases identified by the government. This finding indicates that procuring digital monitoring technology significantly enhances transparency in both information disclosure and regulatory enforcement. By reducing information asymmetry in the principal-agent relationship between polluting enterprises and the government, digital monitoring strengthens accountability (Liu, Uchida, and Bao 2024).

The increased risk of regulatory scrutiny directly compels enterprises to adopt more advanced environmentally friendly technologies in their production and management processes. To further investigate this effect, we examined the impact of digital environmental technology on

different types of enterprises, finding that heavily polluting firms are most affected. As indicated in Column (2), each additional environmental monitoring procurement contract per 100,000 people is associated with a 73.3% reduction in the number of heavily polluting enterprises in a city. Tiantian et al. (2024) observed similar trends, noting that increased regulatory intensity has driven the systematic elimination of outdated production capacities in the industrial sector, including government-led closures of small, heavily polluting factories. This outcome is largely because of the substantial compliance costs associated with adopting advanced clean technologies, which pose particular challenges for pollution-intensive industries (Zhang and Li 2023).

On the other hand, the Porter Hypothesis posits that stricter environmental regulations ultimately enhance corporate green performance and competitiveness (Zhang et al. 2024, Cohen and Tubb 2017). To explore this, we examined the impact of adopting digital environmental monitoring technology on the green patents co-invented by enterprises in the city. The regression results in Column (3) indicate that digital monitoring technology accelerates waste utilization and reduces energy consumption, leading to “innovation compensation.”

**Table 5. Results for Mechanism Analysis**

	Administrative penalty(log)	Polluting Firm(log)	Joint Green Patents(log)
	(1)	(2)	(3)
Environment Monitoring	0.463** (0.226)	-0.733* (0.374)	0.378** (0.152)
Economic and social characteristic variables	YES	YES	YES
Weather characteristic variables	YES	YES	YES
Time FE	YES	YES	YES
City FE	YES	YES	YES
N	715	773	704
adj. R-sq	0.041	0.361	0.110

Note: The table records three possible mechanisms through which digital environmental monitoring technology affects urban PM2.5 levels. Column (1) represents the impact of environmental monitoring technology on the number of urban environmental protection cases; Column (2) shows the impact of environmental monitoring technology on the number of heavily polluting enterprises in the city; Column (3) represents the impact of environmental monitoring technology on the number of green patents in the city. In all models, control variables, year fixed effects, and city fixed effects are fully controlled. \* $p < 0.1$ , \*\* $p < 0.05$ , \*\*\* $p < 0.01$ ; Standard errors in parentheses are clustered at the city level.

Source: Authors' calculations.

## 4.5 Heterogeneity Analysis

### 4.5.1 Public Interest and Government Attention

As previously outlined, digital environmental monitoring technology functions primarily as an “information provider,” while the government, enterprises, and individuals act as the actual “users” of this data. Increased attention to air quality data often reflects higher expectations for the environment, and the supervisory pressure resulting from this heightened awareness is more likely to translate into actual pollution control decisions, driving environmental improvement.

Our analysis focuses on the effects of public and governmental attention on environmental pollution. Public interest is measured using the Baidu Search Index, whereas government attention is assessed through the frequency of environmentally related terms in government work reports—a widely adopted approach in environmental regulation studies (Tu et al. 2024, Chen and Chen 2018). Based on median values, both attention metrics are categorized into high and low groups. The regression results are presented in Table 6.

In regions with higher public environmental concern, an additional procurement contract per 100,000 people leads to a 10% reduction in PM<sub>2.5</sub> levels (Column 1). This result underscores the importance of public influence in environmental governance. As public concern for the environment increases, governments are likely to face greater regulatory pressure, leading to stricter pollution control measures (Wang and Jia 2021, Wang and Cao 2024).

Similarly, in regions with higher levels of government environmental concern, each additional environmental monitoring procurement contract per 100,000 residents corresponds to a 9% reduction in PM<sub>2.5</sub> levels (Column 3). Comparing these coefficients shows that public attention exerts a stronger environmental impact than government concern. This can be attributed to sustained public attention, which typically fosters stronger social oversight and environmental feedback, thereby enhancing pollution control effectiveness. However, in areas with lower levels of public and government environmental concern, we do not observe a significant impact of digital environmental monitoring on pollution control. This result highlights the synergy between

technology and human behavior (i.e., social attention and government decision-making), highlighting the conditions and dependencies for technology to achieve effective outcomes.

**Table 6.** Impact on Public Interest and Government Attention

	High_public interest	Low_public interest	High_government attention	Low_government attention
	(1)	(2)	(3)	(4)
Environment Monitoring	-0.103** (0.033)	-0.038 (0.031)	-0.088** (0.027)	-0.051 (0.030)
Economic and social characteristic variables	YES	YES	YES	YES
Weather characteristic variables	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
<i>P</i> -value of inter-group difference coefficient	0.050**		0.049**	
<i>N</i>	606	276	483	399
<i>adj. R</i> -sq	0.742	0.655	0.770	0.661

Note: This table shows the heterogeneity of the impact of digital environmental monitoring technology on PM2.5 under public and government environmental concern, with the median used as the grouping standard. Columns (1)–(2) represent the heterogeneity of public environmental interest on urban PM2.5, while Columns (3)–(4) represent the heterogeneity of government environmental concern. We used a two-sided t-test to examine the significance of differences between coefficients across different groups. In all models, control variables, year fixed effects, and city fixed effects are fully controlled. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ ; Standard errors in parentheses are clustered at the city level.

Source: Authors' calculations.

#### 4.5.2 Environmental Information Disclosure

Public interest in environmental information is predicated on the accessibility and transparency of environmental data. We use the Pollution Information Transparency Index (PITI) to measure the level of environmental information disclosure in PRC cities, with core evaluation content including the disclosure of enterprise emissions information, environmental regulatory transparency, air quality information, and public participation. Because of data availability, we obtained the environmental information disclosure index for 120 cities from 2014 to 2018.

The regression results are shown in Table 7. In regions with higher levels of environmental information disclosure, each additional environmental monitoring procurement contract per

100,000 residents corresponds to a 7% reduction in PM2.5 levels (Column (1)). This finding underscores the critical role of information disclosure in effective environmental governance. A lack of transparent environmental data can encourage lax production practices among enterprises and foster rent-seeking behavior among government officials. Enhanced transparency, however, directly restricts opportunities for officials to benefit from concealing information, thereby reinforcing public oversight and bolstering government accountability (Wei and He 2022, Chen et al. 2022). We further present our baseline regression coefficients, heterogeneity by attention level, and information disclosure through coefficient visualization (Fig. 4).

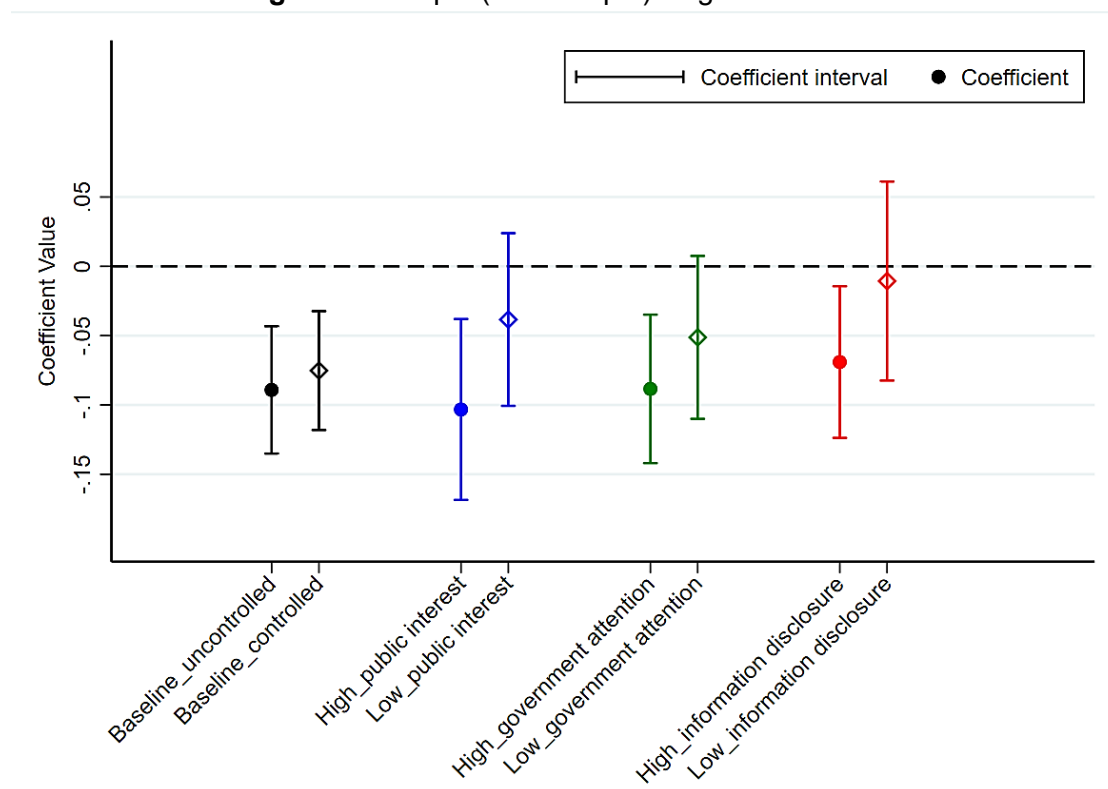
**Table 7.** Impact on Information Disclosure

	ln(PM2.5)	
	(1)	(2)
	High information disclosure	Low information disclosure
Environment Monitoring	-0.069** (0.028)	-0.011 (0.036)
Economic and social characteristic variables	YES	YES
Weather characteristic variables	YES	YES
Time FE	YES	YES
City FE	YES	YES
P-value of inter-group difference coefficient	0.093*	
N	403	340
adj. R-sq	0.677	0.761

Note: This table shows the impact of digital environmental monitoring on PM2.5 under the heterogeneity of information disclosure. We used a two-sided t-test to examine the significance of differences between coefficients across different groups. In all models, control variables, year fixed effects, and city fixed effects are fully controlled. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ ; Standard errors in parentheses are clustered at the city level.

Source: Authors' calculations.

**Figure 4. Sample (sub-sample) Regression Coefficients Plot**



Note: Figure 4 documents OLS-estimated regression coefficients. From left to right, the black capped lines represent baseline regression results without and with control variables, respectively. The last three groups are divided by median values: blue capped lines show regression results for high and low public interest groups; green capped lines for high and low government attention groups; and red capped lines for high and low levels of information disclosure.

Source: Authors' calculations.

### 4.5.3 Regional Characteristic Heterogeneity

This section examines the heterogeneous effects of digital environmental monitoring on air pollution across varying regional characteristics. Cities are grouped based on geographic location (coastal vs. inland) and population size (large vs. small-medium). The regression results are shown in Table 8. The findings indicate significant regional differences: digital environmental monitoring is notably more effective in reducing air pollution in inland and small-medium cities. This variation can be attributed to two main factors. First, industrial structure differences create disparities in baseline pollution levels; coastal and large cities tend to be service-oriented, while inland and small-medium cities are more dependent on manufacturing and other high-pollution industries, which places greater pressure on pollution control. Second, pollution control resources

vary across regions; coastal areas, being more economically developed, have access to a broader array of pollution control measures, whereas digital environmental monitoring offers an efficient, cost-effective solution particularly suited to inland and smaller cities.

**Table 8.** Impact on Regional Characteristics

	ln(PM2.5)		ln(PM2.5)	
	Coastal city	Inland city	Large city	Mid-sized and small city
	(1)	(2)	(3)	(4)
Environment Monitoring	-0.054** (0.024)	-0.089*** (0.031)	0.038 (0.055)	-0.069** (0.028)
Economic and social characteristic variables	YES	YES	YES	YES
Weather characteristic variables	YES	YES	YES	YES
Time FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
P-value of inter-group difference coefficient	0.093*		0.037**	
N	434	448	613	269
adj. R-sq	0.782	0.643	0.659	0.767

Note: This table shows the impact of digital environmental monitoring on PM2.5 under the heterogeneity of Regional Characteristics. Columns (1)–(2) represent the heterogeneity of Regional location, while Columns (3)–(4) represent the heterogeneity of city scale. We used a two-sided t-test to examine the significance of differences between coefficients across different groups. In all models, control variables, year fixed effects, and city fixed effects are fully controlled. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ ; Standard errors in parentheses are clustered at the city level.

Source: Authors' calculations.

## 5. CONCLUSION AND POLICY RECOMMENDATIONS

Our report underscores the pivotal role of digital environmental monitoring technologies in enhancing air quality in urban areas of the PRC. By deploying a comprehensive empirical analysis utilizing data from various cities over the period from 2014 to 2019, we have identified significant reductions in PM2.5 level associated with increases in environmental monitoring procurement contracts. This correlation highlights the efficacy of digital technologies in pollution control, facilitated by their capacity to provide real-time, accurate data which enhances regulatory compliance and facilitates timely governmental action.

Our mechanism analysis and heterogeneity in attention both emphasize the importance of placing digital technology within a broader governance framework. Technology provides a platform for governance, but real change occurs through the synergy between technology and social forces. Enhanced environmental information disclosure strengthens local governments' environmental enforcement capabilities but also exerts pressure on enterprises. Consequently, our paper provides new, comprehensive evidence supporting the "Porter Hypothesis." Environmental monitoring technology reduces overall air pollution levels; however, its impact on enterprises is twofold. Digital technology increases regulatory intensity, benefiting all businesses by improving environmental standards, while many heavily polluting enterprises may fail to offset productivity declines from regulation with technological innovation and thus may exit the market (Diederich 2016). For technologically advanced firms, however, environmental regulations have indeed enhanced their environmental, social, and governance (ESG) performance (Xu et al. 2024, Luo et al. 2024). We recommend that policymakers tailor environmental regulations to account for industry-specific differences, ensuring that regulations promote green innovation without imposing excessive burdens on specific sectors. Offering financial incentives for cleaner technologies, supporting R&D in green innovations, and enforcing strict environmental monitoring can encourage companies to adopt sustainable practices.

Our findings are relevant for other developing countries facing pollution challenges. First, the environmental benefits of digital technology are clear, and governments should increase investment in digital environmental monitoring, particularly in air quality monitoring, data analysis, and regulatory enforcement. Second, strengthening environmental education for society is also crucial to fostering positive interactions among the government, businesses, and the public in driving environmental governance. Regions with higher engagement and proactive environmental stances tend to see more pronounced benefits from these technologies, underscoring the importance of sustained public awareness and government commitment as essential complements to technological solutions in combating pollution. Finally, both the government and enterprises should adopt region-specific policies. The government can promote green finance,

facilitate industry-academic collaboration, and encourage firms to develop green technologies and expand market share. For polluting enterprises, the government should offer support for technological upgrades or establish a structured market exit mechanism.

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## Digital Monitoring Technology and Air Quality

*Evidence from the People's Republic of China*

This paper empirically investigates the impact of digital environmental monitoring technologies on air quality in the People's Republic of China using public procurement data. The findings show that following the adoption of digital environmental monitoring technology: (i) city-level PM2.5 concentrations exhibit a sizeable reduction, (ii) regulatory enforcement improves and heavily polluting firms exit more, (iii) green innovation is enhanced through more accurate pollutant identification, and (iv) the effectiveness of these technologies depends on the extent of information disclosure and public participation.

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