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Article

Does Environmental Information Disclosure Reduce PM_{2.5} Emissions? Evidence from Chinese Prefecture-Level Cities

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Abstract: As an important means of regulating pollution emissions, environmental regulation is crucial for reducing urban PM_{2.5}. However, previous studies have mainly focused on the emission reduction effect of formal environmental regulations and neglected the role played by informal environmental regulations represented by environmental information disclosure. We employed a multiperiod difference-in-differences (DID) model to assess the effectiveness of EID policies in mitigating PM_{2.5} emissions and to investigate their abatement mechanism by focusing on green innovation and industrial structure. The findings indicate that the implementation of EID policies significantly reduces PM_{2.5} emissions. Mechanism tests reveal that EID promotes PM_{2.5} reductions by fostering green innovation and upgrading industrial structure. In addition, the impact of EID policy is more marked in resource-based cities and those located in interior regions. This study contributes to the reduction in urban haze emissions in China, offering empirical evidence and policy recommendations for the further implementation of environmental information disclosure.

Keywords: environmental information disclosure; PM_{2.5} emissions; prefecture-level cities; multiperiod DID model; mediating effect; heterogeneous effect



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1. Introduction

China's economy has been in a period of rapid development since its reform and opening up. As a result of years of reckless economic growth, the environment has been damaged, and haze pollution has become a particularly worrying problem. According to the *National Ecological Quality Profile* promulgated by China's Ministry of Ecology and Environment, the national ambient air quality compliance rate in cities across the country was 46.6% in 2019, an increase of 25% from 21.6% in 2015. Data from the *2019 China Ecological Environment Status Bulletin* show that the PM_{2.5} concentration in 337 cities at the prefecture and above levels across the country was 36 µg/m³, unchanged from the previous year, with 46.6% of all cities meeting the environmental air quality standard [1]. In 2019, these 337 cities together had 452 days of severe pollution, 183 days fewer than in 2018, and 1666 days of heavy pollution, 88 days more than in 2018. On 78.8% of the days with severe or worse pollution, PM_{2.5} was the main pollutant [2]. These data indicate that the sources of PM_{2.5} pollution remain a top target in China's air pollution management efforts.

In response, the Chinese government prioritized this issue by issuing a series of measures to reduce PM_{2.5} concentrations, such as the *Air Pollution Prevention and Control Law*, the *Air Pollution Prevention and Control Action Plan*, and the *Ambient Air Quality Standards*. One key measure, the *2013 Air Pollution Prevention and Control Action Plan*, is considered one of the most ambitious environmental policies in China's history. It has significantly curbed haze pollution but at a considerable cost. Taken together, these policies and regulations have helped to improve China's air quality, but progress remains insufficient.

The sustained effectiveness of the air pollution control measures led by the Chinese government is hampered by information asymmetry between local governments and polluting enterprises, leading to frequent instances of enterprises evading environmental supervision [3]. The effectiveness of environmental governance can be determined by a robust EID system that facilitates joint governance by the government, corporations, and the public. EID enhances public awareness of environmental protection, motivates government oversight, establishes internal and external mechanisms for environmental supervision, resolves information asymmetry in pollution control processes, and improves regional pollution control performances. According to the theory of signal transmission, credible, comprehensive, transparent, and high-quality environmental information is needed for effective governmental pollution prevention and control [4].

Present studies on Chinese environmental protection policies and their effects on PM_{2.5} reductions tend to focus on the implementation of governmental environmental regulations, such as establishing regulatory frameworks [5], environmental protection supervision [6], and environmental justice [7,8], and on the level of market regulation, like environmental taxes [9], subsidies [10], and emissions trading [11], for pollution prevention and control. However, less research has examined the impact of pollution disclosure on reducing PM_{2.5} emissions in urban areas. Among the limited empirical studies exploring pollution governance through environmental information disclosure, the Pollution Information Transparency Index is commonly employed to measure the level of urban environmental transparency [12,13]. It should be noted that such evaluation indexes, derived from comprehensive index system calculations, often face issues of subjectivity, limited comprehensiveness, and timeliness [14]. Additionally, most cities that have been selected for evaluation are national key cities for environmental protection, leading to potential selection bias and skewed evaluation results [15].

The Chinese government is gradually establishing and improving its environmental information disclosure regime. In 2007, the State Environmental Protection Administration promulgated the *Environmental Information Disclosure Measures (for Trial Implementation)*, which came into effect on 1 May 2008. This marked the initial construction of China's environmental information disclosure system. By collecting panel data on 256 prefecture-level cities from 2005 to 2021, we constructed a quasi-natural experiment using the multiperiod DID method to investigate the EID effect on PM_{2.5} governance. We found that (1) EID can significantly reduce PM_{2.5} emissions; (2) EID indirectly contributes to the reduction in PM_{2.5} by increasing green innovation and upgrading industrial structures; and (3) the impact of EID on PM_{2.5} is more significant in resource-based and interior cities.

The key contributions of this study are in the following areas: First, existing research on PM_{2.5} pollution control and reduction predominantly concentrate on command-and-control regulations or market-based incentives, with few studies addressing public-participation-driven environmental regulation. This study centers on the Public Disclosure of Environmental Information (Trial), China's first official regulation on environmental information disclosure, which aims to promote public participation in the environmental protection. Doing so further expands the scope of research on China's environmental protection policies.

Second, from a methodological perspective, this study adopts a city-year sample selection and employs a DID model to assess the influence of EID policies on urban PM_{2.5} emissions. This method categorizes prefecture-level cities into the treatment or control group based on whether they have implemented EID policies, allowing for both horizontal comparisons between cities implementing the policy and those that did not, as well as vertical comparisons of cities before and after policy implementation. The DID approach mitigates the effect of external factors on PM_{2.5} emissions before and after policy implementation and effectively addresses the endogeneity issue between EID and PM_{2.5} emissions. This method enables a more precise identification of the net influence of EID policies on urban PM_{2.5} emissions.

Finally, this study highlights the significance of green innovation and industrial structure in shaping the linkage between EID and urban PM_{2.5} emissions. By organizing theoretical insights, we construct a conceptual framework that links EID, green innovation, industrial structure, and urban PM_{2.5} emissions. This framework offers a new perspective for understanding how EID influences urban PM_{2.5} emissions.

The rest of the study is structured in the following way: Section 2 reviews the policy background of EID; Section 3 reviews the relevant literature and presents the hypotheses; Section 4 outlines the model, data, and variables; Section 5 presents the results of the empirical analysis; and Section 6 discusses the conclusions and provides policy recommendations.

2. Policy Background

The high-energy-consumption, low-efficiency development pattern has promoted the rapid development of China's economy over the past decades. However, it has also led to serious environmental pollution problems, particularly air pollution, which have raised social concerns. High concentrations of PM_{2.5} in the air can severely degrade air quality and endanger human health [16]. In response to haze pollution, the Chinese government has adopted several environmental regulatory measures, resulting in various outcomes. EID is increasingly valued by governments and enterprises as a new means of environmental regulation in the context of economic development and improving living standards to further deepen environmental governance and promote economic transformation and transparency with regard to the environmental situation. On 8 February 2007, the Chinese government launched the Environmental Information Disclosure Measures (Trial), which mandates both government and enterprise environmental information disclosure. These measures aim to promote the construction of an EID system.

EID is widely practiced globally. Historically, EID first emerged in the form of legislation, stipulating the items to be disclosed by law and ensuring citizens' right to know [17]. In the US, for instance, the 1986 *Environmental Protection and Consumer Protection Act (EPCRA)* requires its manufacturers to disclose annually to the public the amount of toxic chemicals they released into the environment. This disclosure system is administered by the US Environmental Protection Agency (EPA) and has been attributed to a 46% reduction in toxic emissions over an 11-year period [18]. Practice has proven that the EID system meets governmental needs for environmental regulation and guarantees citizens' right to environmental information. It helps maintain social justice, protect and promote rational use of the environment and resources, coordinate the relationship between humans and nature, and, ultimately, achieve sustainable development.

As for specific measures of EID, the "Measures" made the following provisions: in terms of government information disclosure, environmental protection departments should take the initiative to disclose environmental protection laws and regulations, environmental quality conditions, the allocation of total emissions of major pollutants and their implementation, the issuance of emission permits, the quantitative assessment results of comprehensive urban environmental improvement, and pollutant emissions that exceed the standard list of polluting enterprises. In terms of corporate information disclosure, it implements a combination of voluntary and mandatory disclosure. It encourages enterprises to voluntarily disclose the total annual consumption of resources; the type, quantity, concentration, and destination of pollutants emitted by enterprises; the treatment and disposal of their production waste; and the recycling and recovery of their waste. Specific enterprises should also disclose the names of main pollutants, emission methods, and emission concentrations and totals, as well as instances where standards and total limits have been exceeded. In addition to the disclosure of content, it also includes manners and procedures to ensure the implementation of the EID system. This policy marked the initial establishment of China's EID system. It promotes China's transition from the traditional government-led system to a more transparent system of environmental governance.

Since the enactment of the EID policy in 2007, the quantifiable evaluation of its implementation has been a key issue in the further development of EID practice in China.

Since 2008, environmental information on 113 key cities related to environmental protection has been published annually, evaluating the following eight items: “information on daily exceedance of standards and violation records of pollution sources”, “information on centralized remediation of pollution sources”, “information on clean production audits”, “information on the overall evaluation of the environmental behavior of enterprises”, “information on letters, visits, and complaints from the public on environmental issues or pollution by enterprises and the results of their treatment as verified by investigation”, “information on the acceptance of environmental impact assessment documents of construction projects and the results of environmental protection acceptance of completed construction projects”, “information on sewage charges”, and “information on public disclosure upon application”.

3. Literature Review and Theoretical Hypotheses

3.1. Literature Review

The literature closely related to our study focuses primarily on the following two key areas: (1) relationships between environmental regulation and pollution and (2) environmental information disclosure.

3.1.1. Environmental Regulations and Pollution Emissions

Environmental regulation can be categorized into the following two types: formal and informal regulation [19]. Formal environmental regulation involves government use of administrative measures to guide enterprise production and operational practices, aiming to achieve both sustainable development and environmental protection [20]. In contrast, informal environmental regulation refers to constraints imposed by stakeholders through public opinion and emissions monitoring, aiming to motivate enterprises to reduce pollution emissions [21].

The linkage between formal environmental regulation and environmental pollution is a prominent issue in academia, but there is still no consensus among researchers about their relationship. One viewpoint argues that formal environmental regulation facilitates pollution reduction. Properly designed environmental regulations compel high-energy-consuming, high-pollution enterprises to invest in technological innovation and adopt advanced pollution control technologies, ultimately reducing emissions [22,23]. The second view posits that formal environmental regulation may increase pollutant emissions, creating a “green paradox” [24]. Strictly enforced regulations raise the compliance costs for high-pollution, high-emission firms, crowding out funds for technological innovation. In pursuit of profit maximization, firms may even increase emissions by expanding production to maintain profitability [25]. A third perspective suggests that the relevance between formal environmental regulation and pollution emissions is not linear. Wang and Zhang (2022) [26] found that formal environmental regulation has a reverse U-shaped link with urban CO₂ emissions, as follows: initially, regulation increases emissions, but after the inflection point, regulation reduces emissions.

The effect of informal environmental regulation on pollution reduction has received increasing attention from researchers in recent years. Most scholars agree that informal environmental regulation is crucial for reducing pollution [27–29]. Mechanistically, Shen et al. (2023) [30] found that informal environmental regulation reduces regional CO₂ mainly through upgrading the industrial structure and substituting renewable energy. Cui and Cao (2024) [31] identified three channels—media environmental concern, corporate green innovation, and government environmental governance—through which informal environmental regulation reduces urban PM_{2.5} pollution. Liu et al. (2023) [32] noted that public concern, as an informal form of environmental regulation, reduces PM_{2.5} emissions by enhancing pollution detection. Furthermore, some researchers suggest that the link between informal environmental regulation and pollution is not simply linear but follows a reversed U-shaped curve [33].

3.1.2. Environmental Information Disclosure

Environmental pollution control requires collaboration among multiple stakeholders, and an EID policy serves as a governance tool that engages stakeholders, such as the government, corporations, and citizens. Existing research on the EID policy concentrates mainly on the following two dimensions: determinants and consequences.

Environmental information disclosure can be influenced by a range of factors. Lv et al. (2024) [34] show that establishing regional environmental courts can improve corporate environmental disclosure. New media monitoring and environmental information uncertainty were found to encourage corporate information disclosure by Zhang and Xiang (2024) [35]. Chen et al. (2024) [36] empirically confirm that investor attention dampens EID behavior in high-tech firms in China. Zhang et al. (2024) [37] argue that online media pressure and a robust internal control system can enhance corporate environmental information disclosure. Big data technology can improve the quality of corporate EID and tackle the challenge of misinformation according to Zhang et al. (2024) [38]. Wei et al. (2024) [39] found that management ownership is positively correlated with environmental disclosure.

The implementation of environmental information disclosure has varying effects at different levels. At the regional level, Yu and Jin (2022) [40] found that environmental information disclosure significantly enhances public environmental awareness in urban areas, with this effect increasing as EID expands. Pan et al. (2023) [41] argued that the enforcement of the EID policy contributed to the inflow of FDI into China's pilot cities, creating a siphoning effect. Wang et al. (2024) [42] found that the EID policy notably increased carbon total factor productivity in Chinese pilot cities, whereas Guo and Xu (2024) [43] demonstrated that the EID policy fosters urban economic growth by attracting talent capital. At the firm-level, Guo et al. (2023) [44] found that EID significantly reduces the financialization of nonfinancial firms by facilitating R&D investment, whereas Feng et al. (2024) [45] demonstrated that EID stimulates green innovation by reducing information asymmetry and alleviating financial constraints. Tan and Liu (2024) [46] argued that EID promotes corporate environmental performance, though this effect is weakened by analysts and media reports.

Various types of environmental regulations influence pollution emissions through different mechanisms and directions. In contrast to command-and-control or market-based environmental regulations, informal environmental regulations, such as environmental information disclosure policies, which encourage public participation, are gaining increasing importance. This study examines the impacts and mechanisms of EID on PM2.5 emissions, contributing to the growing literature on this topic.

3.2. Theoretical Hypothesis

3.2.1. Direct Effect Analysis

In 2008, the Environmental Information Disclosure Measures (Trial) came into effect in China. It required both the government and firms to disclose environmental information. At the government level, it is necessary to disclose to the public the environmental quality, allocation, and implementation of total emissions targets of major pollutants, issuance of emission licenses, and quantitative evaluation results of comprehensive urban environmental improvement in cities. At the firm level, enterprises are encouraged to voluntarily disclose environmental information, including the total annual consumption of resources and the type, amount, concentration, and destination of pollutants emitted. The procedures for disclosure also made provisions for using the government website, bulletins, press conferences, newspapers, radio, television, and other means to facilitate timely public access to environmental information. Thus, the environment can be improved and PM2.5 can be reduced through the following three aspects: government, enterprises, and the public.

First, EID imposes requirements on government actions. Under the governmental target responsibility assessment system, the government is guided by environmental management goals and administrative responsibilities, forming an incentive and constraint mechanism [47]. To complete the performance assessment, the government will take en-

environmental problems seriously, thus promoting the reduction in PM2.5 concentrations. Second, enterprises' pollution information is much more transparent under the EID system. On the one hand, as the main emitters, enterprises will face increased production costs and reduced profits due to sewage charges. On the other hand, companies with excessive emissions will be listed as serious polluters, negatively impacting their reputation, leading to decreased investor confidence and reduced consumer demand for their products [48]. On the basis of stakeholder theory, enterprises must meet the requirements of different stakeholders, including the government, the public, investors, and environmental organizations. EID enables enterprises to address these concerns, thereby enhancing their reputation and market value [49]. To avoid negative consequences, companies take steps to reduce pollutants, thereby effectively controlling PM2.5 emissions. As EID progresses, the transparency of environmental information continues to improve. This increased transparency facilitates public access to environmental information, fostering societal oversight that holds both the government and enterprises accountable [50], ultimately improving environmental quality and reducing PM2.5 emissions. Therefore, we propose the following Hypothesis 1:

H1. *EID helps directly reduce PM2.5 emissions.*

3.2.2. Impact Mechanism Analysis

In general, EID promotes green innovation (GI) [51] and industrial structure (IS) upgrading [52], both of which have been identified as critical factors influencing pollution emissions [53,54]. Thus, this article primarily explores the mechanisms through which EID affects PM2.5 emissions across cities, focusing on the roles of green innovation and industrial structure.

(1) Green innovation effect

EID can stimulate innovation in various ways. It can reduce the cost of innovation through government incentives, lowering the threshold for firms to innovate and providing a better environment for innovation. It can also increase social media attention, enhancing social reputation [55] and attracting capital market stakeholders to push enterprises toward green innovation. A higher level of EID can reduce information asymmetry, lower investment risks, promote corporate financing, and provide more financial support for green innovation [56]. Environmentally sensitive consumer groups are also attracted to the high-quality environmental information revealed by firms [57]. These consumers tend to prefer environmentally friendly products, prompting companies to optimize production lines, improve production processes, develop more environmentally friendly products, and achieve more green innovations [58].

Green innovation plays a crucial role in achieving green development goals, encompassing both green and innovative attributes. The primary objective of green innovation must be environmental protection [59]. At the macro level, green innovation promotes the optimization and upgrading of energy structures, thereby reducing air pollutant emissions and PM2.5 concentrations [60]. At the firm level, green technological innovation encompasses advancements in production processes and governance [61]. The former focuses on green upgrades in production processes to maximize resource efficiency and reduce total pollutants, whereas the latter enhances pollution control technologies and treatment facilities to improve regional air quality and lower PM2.5 levels. Therefore, we propose the following Hypothesis 2:

H2. *EID drives green innovation and, thus, reduces PM2.5.*

(2) Industrial structure effect

The EID policies reduce the share of heavy industry in a city's GDP, facilitating the optimization and upgrading of urban industries. First, as the EID policy is carried out, pilot cities release detailed emission reduction methods and targets. They optimize industrial layouts by promoting pollution reduction, accelerating the elimination of outdated

production capacities in heavily polluting sectors, like electricity, steel, petrochemicals, and mining, and closing, merging, or upgrading the technology of polluting enterprises for energy efficiency and environmental protection [62]. Second, the policy raises environmental access thresholds, making the approval of new or expanded high-emission enterprises, such as steel mills, thermal power plants, and cement plants, more stringent, which further expedite the removal of outdated production capacities in the region [63]. Finally, the policy increases local government support for cleaner production and provides incentives for enterprises to develop environmentally friendly industries, thus promoting the orderly optimization and upgrading industrial structure by increasing the share of cleaner industries in the region [64].

Given that different industries vary in their levels of resource consumption and environmental damage, industrial upgrading reduces PM2.5 emissions by lowering pollutant emissions. Although industrial restructuring appears to involve changes in the proportion of each industry, it fundamentally reflects shifts in energy utilization and efficiency across industries. The secondary industry is dominated by energy-intensive heavy industries characterized by high resource consumption, low technological advancement, and inefficient development. As the proportion of the secondary industry in a city grows, resource consumption rises significantly, resulting in higher urban pollutant emissions. In contrast, the tertiary industry, which is dominated by the production and service sectors, is less reliant on fossil resources. An increase in the tertiary sector's share of a city's GDP reduces fossil energy demand and lowers pollutant emissions. Therefore, we propose the following Hypothesis 3:

H3. *EID drives industrial structure upgrading to reduce PM2.5.*

Based on the above theoretical analysis, the mechanism of EID on PM2.5 is shown in Figure 1.

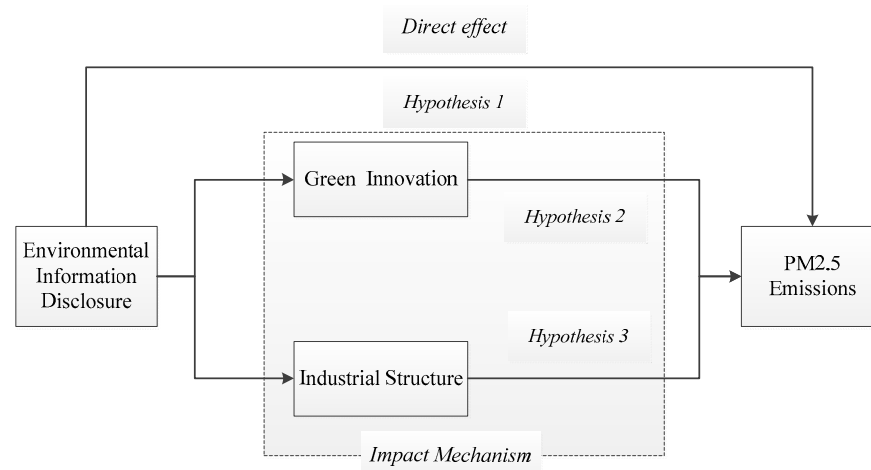


Figure 1. Influencing mechanism of EID on PM2.5 reduction.

4. Methodology and Dataset

4.1. Methodology

4.1.1. DID Method

The difference-in-differences (DID) method is a commonly used method of causal inference that is primarily used to evaluate the influence of an event or policy [65]. The basic principle is to infer the causal effect of an intervention by comparison of changes in the experimental and control groups before and after the intervention. In the first step, a control group with a trend similar to that of the experimental group before the intervention is selected to ensure that the trends of the two groups before the intervention are parallel.

In the second step, the causal effect of the intervention was calculated by comparing the changes in the experimental and control groups before and after the intervention.

In 2008, the Public Environmental Research Center and the Natural Resources Defense Council jointly published the Pollutant Information Disclosure Index for 113 cities in China. This number expanded to 120 cities in 2013. To examine the effect of EID on PM2.5 in 256 Chinese prefecture-level cities, a quasi-natural experiment was constructed. The 116 cities (excluding the four municipalities directly under the Central Government) served as the experimental group, and the remaining 140 cities served as the control group. Since the time points of the policies were inconsistent, the net effect of EID on PM2.5 was assessed using a multiperiod DID approach. The model was set up as follows:

$$PM2.5_{it} = \alpha_0 + \alpha_1 did_{it} + \sum \alpha_j Controls_{jit} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

In the above equation, i and t denote city and year, respectively. $PM2.5_{it}$ denotes the PM2.5 concentration, and did_{it} indicates whether the city is included in the assessment of EID, taking 1 for the experimental group and 0 for the control group. The coefficient α_1 represents the net effect of EID on PM2.5 emissions, which is the focus of this study. $Controls$ represent a set of control variables affecting PM2.5. α_j denotes the coefficient of the control variable. μ_i and γ_t represent city- and time-fixed effects, respectively. ε_{it} is the random disturbance term.

4.1.2. Intermediary Effect Model

The regression results above confirm that EID can significantly reduce PM2.5, but what is the path of this influence? This study investigates the impact mechanism by constructing a two-step mediating effects model, with the first step being Equation (1) and the second step being the equation shown below:

$$M_{it} = \lambda_0 + \lambda_1 did_{it} + \sum \alpha_j Controls_{jit} + \mu_i + \gamma_t + \varepsilon_{it} \quad (2)$$

In the above equation, M is the mediating variable. The influencing mechanism was tested in terms of both the level of green innovation and industrial structure.

4.2. Data and Variables

The dataset used in this study consisted of a panel of prefecture-level cities in China, covering the years 2005–2021. The data are taken from the *Chinese Urban Statistical Yearbook 2022*. It is important to note that Beijing, Shanghai, Tianjin, and Chongqing are provincial-level administrative units with significantly higher political statuses than typical prefecture-level cities; thus, these four cities were excluded from the sample. Additionally, some cities were dropped due to lack of data. As a result, the final sample consists of 256 cities.

4.2.1. Dependent Variable

As the explained variable, Chinese officials only started ground-based monitoring of PM2.5 in some key cities in 2013, which means the data are unable to meet the needs of our study. In addition, the data obtained from ground-based monitoring are point-source data, which are difficult to use to measure the whole picture of PM2.5 emissions in the whole city [66,67]. Fortunately, Chinese PM2.5 data could be obtained from the Dalhousie Atmospheric Composition Analysis Group (Canada) and are based on global satellite monitoring of PM2.5 pollution [68]. The raster data of annual average concentrations were processed and measured with prefecture-level cities in China as the basic units.

4.2.2. Independent Variable

Since the element of “information” is hard to quantify and has its own endogeneity problem, this study chooses whether prefecture-level cities are included in the evaluation of EID (did) as the independent variable. Out of the 116 cities in the experimental group, 109 began to disclose information in 2008, whereas the remaining 7 began to disclose

information in 2013. If environmental information is disclosed in the current year, the value is 1; otherwise, the value is 0.

4.2.3. Control Variables

(1) Fixed-asset investment (FAX). FAX influences multiple aspects of national economic growth and serves as a key tool for adjusting the economic structure and optimizing productivity distribution [69]. Over the long term, fixed-asset investment lays a robust material and technological foundation for economic development, directly impacting PM2.5 emissions by phasing out outdated production methods and enhancing the production structure. At present, there are two main methods of measuring fixed asset investment: fixed asset investment per capita and fixed asset investment as a proportion of GDP. Consideration of the latter measurement method can, to a certain extent, reflect the pattern and strategy of local economic development. Changes in this indicator can reflect adjustments in the economic structure and changes in the direction of development, which are crucial to sustainable economic development. Therefore, the ratio of urban fixed-asset investment to GDP (Unit: %) is used to measure the level of fixed-asset investment [70].

(2) Foreign direct investment (FDI). Currently, scholars have not reached a consensus on the influence of FDI on PM2.5 emissions. The pollution haven hypothesis posits that developed countries use FDI to relocate polluting production activities to developing countries, leading the latter to bear the environmental pollution consequences [71]. In contrast, the pollution halo hypothesis argues that FDI introduces advanced technology and valuable production management expertise to the host country, thereby reducing its PM2.5 emissions [72]. There are two indicators of FDI in the City Statistical Yearbook, namely, number of projects for contracted foreign direct investment and amount of foreign capital actually utilized. The latter can more truly reflect the amount of foreign direct investment absorbed by the city. This study uses the proportion of amount of foreign capital actually utilized to GDP (Unit: %) as the indicator of the FDI level [73].

(3) Urbanization (Urb). Urb is a key factor influencing PM2.5 emissions. On the one hand, as urbanization progresses, a large portion of the rural population migrates to cities, increasing the demand for resources and energy that, in turn, exacerbates PM2.5 emissions in urban zones [74]. On the other hand, the expansion of urban areas attracts skilled professionals, enterprises, and research institutions, leading to the dissemination of knowledge, information, and technology, which promote technological advancement and help mitigate urban haze pollution [6]. There are three main methods for measuring urbanization: the urban population ratio method, the built-up area ratio method, and the construction of comprehensive indicators method. Considering that people are the core of urbanization, this article adopts population urbanization, which refers to the proportion of urban population to total population (Unit: %), to measure the level of urbanization [75].

(4) Fiscal Decentralization (FD). FD is an additional factor influencing PM2.5 emissions. Under the perspective of fiscal decentralization, local governments have an obvious information advantage and can formulate haze management policies that are in line with the economic development of their jurisdictions, so as to internalize the costs and benefits of management and improve the efficiency of PM2.5 emission reduction. There are two main measurement methods in existing studies: a revenue and expenditure perspective, which uses revenue decentralization and expenditure decentralization indicators to measure the degree of fiscal decentralization, and a self-sufficiency perspective, which measures the degree of fiscal decentralization by using the ratio of local general public budget revenues to local general public budget expenditures. The fiscal self-sufficiency perspective can fully capture the financial autonomy of cities in reducing PM2.5 emissions, because this paper finally chooses this method to measure the degree of fiscal decentralization (Unit: %) of cities [76].

(5) Economic development (ED). The level of economic development is one of the most important causes of urban PM2.5, but scholars have not yet reached a consensus on the relationship between the two. On the one hand, the higher the level of economic

development of a city, the more importance it attaches to the protection of the ecological environment, and thus it will take a variety of measures to reduce urban PM2.5 emissions [77]. On the other hand, economic growth will consume a large amount of fossil energy, which will emit more PM2.5 [78]. GDP and per capita GDP (PGDP) are often used to measure the level of economic development of a region; GDP is the total amount of economic activity in a region, while PGDP is treated per capita through the GDP total, which better reflects the average level of the region's economy and the quality of life of its people. We borrow from Jiang et al. (2022) [79] and use PGDP (Unit: CNY 10,000 /person) to measure the level of economic development.

4.2.4. Intermediate Variables

(1) Green innovation. Green innovation was measured by two types of indicators: green patent applications or green patent grants. Considering that green patents took a long time to go through from application to grant, the lag phenomenon was more obvious. This study used the number of green patent applications (Unit: 10,000 items) to measure green innovation [51]. Data were sourced from the patent database of the State Intellectual Property Office. Green patents were identified using the "Green Patent List", released by the World Intellectual Property Organization, in 2010, and the green patents of each city are aggregated from micro-level data of the listed companies.

(2) Industrial structure. The industrial structure serves as an important intermediary factor in the linkage between environmental information disclosure and urban PM2.5 emissions. Industries are the main driving force of and important support for the economic development of cities. Among the three industries, the secondary industry includes the chemical, electric power, and iron and steel industries, which are key sectors for fossil energy consumption, and the pollutants emitted during their production processes are the main cause of PM2.5 emissions. Following the measurement approach of Feng et al. (2021) [47], industrial structure was quantified by the secondary industry value-added share of GDP (Unit: %).

5. Results

5.1. Baseline Regression Analysis

5.1.1. Descriptive Statistics

Table 1 presents the descriptive statistics of the main variables. The range of urban PM2.5 emissions spans from 11.637 $\mu\text{g}/\text{m}^3$ to 108.955 $\mu\text{g}/\text{m}^3$, indicating significant disparities in emission levels across different cities. In addition, some cities face severe PM2.5 emission issues that require urgent attention. Additionally, the average PM2.5 emission level in these cities is 43.827 $\mu\text{g}/\text{m}^3$, significantly exceeding the national concentration limit of 15 $\mu\text{g}/\text{m}^3$ and the secondary limit of 35 $\mu\text{g}/\text{m}^3$, as per the ambient air quality standards. This indicates that China's prefecture-level cities are struggling to control PM2.5 emissions, with substantial room for improvement.

Table 1. Descriptive statistics for the variables.

Variables	N	Mean	SD	Min	Max
PM2.5	4352	43.827	15.603	11.637	108.955
did	4352	0.320	0.467	0	1
FAX	4352	0.754	0.332	0.090	2.860
FDI	4352	0.018	0.020	0	0.229
Urb	4352	0.514	0.164	0.120	1
FD	4352	0.465	0.223	0.0260	1.256
ED	4352	10.418	0.751	4.595	13.056

Table 1. Cont.

Variables	N	Mean	SD	Min	Max
GI	4352	0.023	0.074	0	1.375
IS	4352	0.469	0.107	0.107	0.859

Note: The minimum value of the variable FDI is not 0; however, it is displayed as 0 because it cannot be represented with 3 decimal places in the table.

5.1.2. Baseline Results

Table 2 presents the results of the baseline regression. The Hausman test results indicate a fixed-effects model is appropriate for estimating the panel data. Both column (1) and column (2) account for year- and city-fixed effects. Column (1) does not control for characteristic city variables, and the coefficient of *did* is -1.245 , significant at the 1% level, indicating that EID contributes to the reduction in PM2.5. Column (2) includes city characteristic variables, and the estimated results show that the significant impact remains unchanged. In column (2), the coefficient of the *did* is -1.586 , also significant at the 1% level. This indicates that if a city discloses environmental information, PM2.5 emissions will decrease by $1.586 \mu\text{g}/\text{m}^3$. This finding confirms the hypothesis of the previous study.

Table 2. Results of benchmark regression analysis.

Variable	Explained Variable: PM2.5	
	(1)	(2)
<i>did</i>	-1.245^{***} (0.303)	-1.586^{***} (0.308)
FAX		-1.517^{***} (0.356)
FDI		-16.717^{***} (5.815)
Urb		-4.254^{***} (1.253)
FD		-5.824^{***} (1.046)
ED		-0.483 (0.378)
City FE	Yes	Yes
Year FE	Yes	Yes
Constant	44.226^{***} (0.115)	55.711^{***} (3.684)
N	4352	4352
R ²	0.936	0.938

Note: *** indicate significance levels of 1%. The values in parentheses are the robust standard error of regression coefficient.

Pollution management requires the joint efforts of different stakeholders, and EID is a management tool that involves the participation of multiple stakeholders, including government, enterprises, and citizens. EID has a positive impact on PM2.5 management for several reasons. First, with the disclosure of pollution information, enterprises, as the main emitters, are monitored by the government and the public. To avoid severe administrative penalties and pressure from public opinion, enterprises are motivated to invest in reducing pollution emissions by improving technology. Second, information gaps and uncertainties are core problems of pollution management, and disclosing environmental information significantly reduces the concealment and nonreporting of pollution. Third, increased disclosure of environmental information satisfies the public's right to know, and public participation has been shown to help improve environmental efficiency.

5.1.3. Parallel Trend Test

The parallel trend test is a precondition for using the difference-in-differences method. This presupposes that the experimental and control groups satisfy the parallel development assumption before the policy is implemented. This means that we need to examine how the

experimental and control groups differ before the policy is implemented. Only when they are similar enough can the reliability of the experimental results be guaranteed. Changes in trends in the three years before and the eight years after EID implementation are examined in this study. The results of the parallel trend test are shown in Figure 2. Prior to the EID implementation, the experimental and control groups exhibited consistent trends with no significant differences. Following the policy's enactment, the experimental group experienced a significant reduction in PM_{2.5} concentration compared to the control group. This confirms that the sample passed the parallel trend test, indicating the EID policy as a crucial factor in reducing PM_{2.5} emissions.

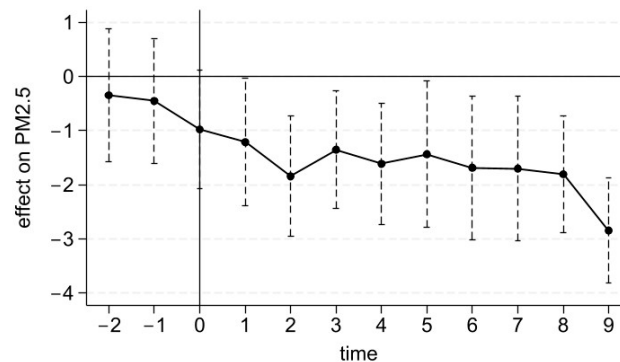


Figure 2. Parallel trend test results. Note: As a result of the two policy shocks in 2008 and 2013, there are limited data for periods 8 to 3 before policy implementation and periods 10 to 13 after policy implementation. To facilitate the analysis, the data from periods 8 to 4, prior to the policy's implementation, were combined with the 3rd period, whereas the data from periods 10 to 13, after the policy's implementation, were grouped with the 9th period. Additionally, the third period, before the policy's implementation, was used as the baseline period to derive the results presented above.

5.2. Analysis of Impact Mechanism

Building on the theoretical analysis and the model's construction in the previous section, this section explores the policy's mechanism through the following two key dimensions: green innovation and industrial structure.

5.2.1. Mechanistic Test for Green Innovation

Green innovation was incorporated as a mediating variable in the regression model, and the results are presented in Table 3. The results of the benchmark regression in the second column are consistent with the results in the last column of Table 2. Building on this, green innovation is included as a mediating variable. In addition, the results are shown in the third column of Table 3. The regression coefficient between EID and GI is 0.037, passing the 1% significance level, indicating that the enforcement of EID policy strongly promotes urban green innovation. This demonstrates that green innovation partially mediates the effect of EID on PM_{2.5}. These regression results conclude that EID impacts PM_{2.5} through the mediation of green innovation, confirming Hypothesis 2.

EID fosters green innovation by enhancing cities' competitiveness in green development and stimulating green innovation vitality. Public disclosure of environmental information exerts pressure on both local governments and companies. Governments, aiming to preserve their reputation, adopt targeted policies to address environmental issues. Similarly, companies must safeguard their social image and business interests, prompting them to pursue green technological innovation for sustainable development.

Green innovation has a crucial role to play in environmental protection. Du and Wang (2022) [49] provide both theoretical and empirical evidence for the role of green innovation in mitigating haze pollution. In the production stage, green innovation enhances energy efficiency, facilitating the shift from fossil fuels to clean energy, thereby reducing emissions. In the treatment stage, green innovation supports the management and storage of emissions.

Overall, EID has bolstered firms' innovation performance and contributed to reducing PM2.5 emissions.

Table 3. Mechanism test.

Variable	PM2.5	Intermediate Variables	
		GI	IS
did	−1.586 *** (0.308)	0.037 *** (0.004)	−0.025 *** (0.003)
controls	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	55.711 *** (3.684)	0.140 *** (0.039)	−0.766 *** (0.174)
N	4352	4352	4352
R ²	0.938	0.610	0.877

Note: *** indicate significance levels of 1%. The values in parentheses are the robust standard error of regression coefficient.

5.2.2. Mechanistic Test for Industrial Structure

The mediating effect of industrial structure in the linkage between EID and urban PM2.5 emissions was further investigated, as reported in the fourth column of Table 3. The regression coefficient between EID and industrial structure is -0.025 , which is significant at the 1% level, suggesting that EID notably reduces the secondary industry's share of national economies. Optimizing the industrial structure can be seen in the falling share of secondary industries and the rising share of tertiary-level industries in the national economy. The EID policy mitigates PM2.5 emissions by promoting industrial structure optimization, thus confirming Hypothesis 3.

The EID policy increases public awareness of environmental pollution, diminishes the positive perception of heavily polluting enterprises among urban residents, and discourages investment in and financing of such enterprises, ultimately reducing their economic profitability. In line with the capital's profit-maximizing motive, social resources in the market flow toward higher-profit enterprises, causing high energy-consuming and high-polluting industries to exit market competition, thereby decreasing the share of secondary industries in the national economy and driving industrial structure rationalization. As the industrial structure gradually optimizes, overall city pollution decreases, leading to improved control over PM2.5 emissions.

5.3. Heterogeneous Effects

The samples selected for this study encompass cities with diverse characteristics, reflecting significant variations in PM2.5 emissions. Given the variations in resource endowments and geographical locations across these cities, it is essential to examine the heterogeneity in the impact of EID policies on urban PM2.5 emissions.

5.3.1. Heterogeneity Test Based on Resource Endowment

Resource endowment refers to the diverse production factors available in a region. Significant differences in mineral resources across cities can influence their economic development models and, in turn, impact pollution emissions. The *National Sustainable Development Plan for Resource-Based Cities (2013–2020)*, issued by the State Council, classifies cities as resource-based cities (RBCs) or non-resource-based cities (Non-RBCs). RBCs and Non-RBCs in China exhibit significant differences in industrial structures. Currently, heavy industries that predominantly consume fossil fuels are concentrated in RBCs, where pollution issues are more severe, potentially making these cities more responsive to environmental information disclosure policies. This study defines resource endowment as a

dummy variable, assigning a value of 1 to RBCs and 0 to Non-RBCs [80,81]. Among the 256 prefecture-level cities analyzed in this study, 107 are RBCs and 149 are Non-RBCs.

The regression results are displayed in columns 2 and 3 of Table 4. The regression coefficient between EID and PM2.5 emissions in resource-based cities is -3.105 , passing the test at the 1% significance level, whereas in Non-RBCs, the coefficient is -0.328 and does not pass the significance test. This suggests that EID significantly reduces PM2.5 emissions in RBCs, but this effect is not verified in Non-RBCs. One potential explanation is that residents of resource-based cities are more aware of environmental pollution due to long-term exposure to haze, which directly affects their health. When the EID policy is implemented, pollution information is quickly disseminated and captures the attention of urban residents, creating strong public pressure that motivates local governments and enterprises to actively address environmental problems and reduce PM2.5 emissions. In contrast, residents of non-resource-based cities are less sensitive to publicly disclosed pollution information, which explains why EID has not yet shown a significant inhibitory effect on PM2.5 emissions in these cities.

Table 4. Heterogeneous effects results.

Variable	Explained Variable: PM2.5			
	RBCs	Non-RBCs	CACs	IACs
did	-3.105^{***} (0.508)	-0.328 (0.382)	-0.489 (0.396)	-1.928^{***} (0.430)
Controls	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Constant	49.349^{***} (5.735)	63.908^{***} (6.075)	25.150^{***} (6.765)	83.850^{***} (8.463)
N	1819	2533	1819	2533
R ²	0.936	0.942	0.953	0.930

Note: *** indicate significance levels of 1%. The values in parentheses are the robust standard error of regression coefficient.

5.3.2. Heterogeneity Test Based on Urban Geographic Location

Considering China's vastness, significant differences in climate and economic development across regions may influence the impact of the EID policy on PM2.5 emissions. Thus, following existing research practices [82,83], the 256 sample cities were categorized into the following two groups based on geographic location: coastal area cities (CACs) and inland area cities (IACs). CACs were assigned a value of 1, and IACs were assigned a value of 0. The effects of EID on PM2.5 emissions across cities in different geographic locations were explored.

The results are displayed in the fourth and fifth columns of Table 4. The regression coefficients of EID on PM2.5 emissions in IACs is -1.928 , passing the test at the 1% significance level, whereas in CACs, the coefficient is -0.489 and does not pass the significance test. This suggests that EID significantly reduces PM2.5 emissions in IACs, but this effect is not verified in CACs. IACs have lower levels of economic development and less established EID systems compared to coastal cities. Thus, the implementation of EID policy in inland cities can more effectively reduce PM2.5 emissions. In contrast, CACs are more economically developed, and environmental protection policies in these areas are more comprehensive, resulting in a less significant effect of environmental information disclosure.

5.4. Robustness Tests

To ensure the reliability of the conclusions, this section includes several robustness tests.

(1) Placebo test

To avoid spurious regression due to confounding policies and omitted variables, we employed an indirect placebo test. The basic premise is to construct virtual "treat" and

“post” variables to replace the actual “treat” and “post”, generating a false estimate, β' . The resulting placebo test results after 500 repetitions are presented in Figure 3. These test results show that the estimator, β' , follows an approximate normal distribution with a mean coefficient of 0, which is distinctly different from the baseline regression coefficient. This outcome aligns with the expected results of the placebo test.

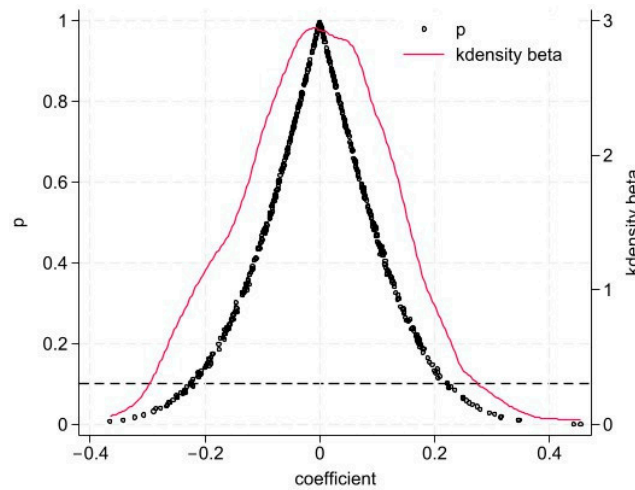


Figure 3. Placebo test results.

(2) Shortened sample period test

To identify the sensitivity of EID to temporal changes, we conducted a regression after shortening the sample period to 2006–2015. Meanwhile, other conditions remained unchanged. Column 2 in Table 5 indicates the regression results. We found that after shortening the sample period, the estimated coefficient is -0.896 , significant at the 1% significance level. Compared to the baseline regression, the overall results did not change much, although the significance decreased. The results above show that changing the sample period affects the regression results, but our results are still noticeably negative. This further confirms the robustness of the results.

Table 5. Results of the robustness test.

Variable	Explained Variable: PM2.5		
	Shortened Period	Excluding Singular Values	Excluding Other Policy
did	-0.896^{***} (0.274)	-1.633^{***} (0.274)	-1.659^{***} (0.341)
Controls	YES	YES	YES
City FE	YES	YES	YES
Year FE	YES	YES	YES
Constant	60.003^{***} (4.049)	54.797^{***} (4.384)	70.638^{***} (5.093)
N	2,816	4352	3388
R ²	0.959	0.939	0.940

Note: *** indicate significance levels 1%. The values in parentheses are the robust standard error of regression coefficient.

(3) Excluding singular values

Samples often contain individual data points that deviate from expectation, commonly referred to as outliers. If outliers are combined with normal data during econometric regression, the accuracy of the regression results may be compromised. To alleviate the effects of outliers, we shrunk the quartiles at 1% and 99% of the explained variable. The

regression coefficient of EID on PM2.5 is -1.633 , which is negative and statistically notable at the 1% level, which verifies the reliability of the basic findings.

(4) Excluding other policies

Policy enforcement is inevitably affected by other policies, which may affect the accuracy of the results. To promote the Chinese economy's green transformation, the National Development and Reform Commission launched low-carbon city pilot projects in 2010 and expanded them further in 2012 and 2017. To eliminate the potential interference of these low-carbon city pilot policies with this study's findings, we categorized low-carbon pilot cities by implementation batch and re-ran the regression analysis. As reported in the fourth column of Table 5, the regression coefficient for EID remains negative, confirming the robustness of the baseline regression results.

(5) PSM-DID test

As most of the cities disclosing environmental information are key cities for environmental protection, the public list may have been selected from more polluted local cities. This nonrandom grouping makes it difficult to eliminate the interference of confounding variables and may lead to systematic bias. To overcome the systematic differences and reduce the fitting bias of the DID method, we used propensity score matching methods. First, we used logit regression to impute the propensity scores, with the control variables as the characteristic variables. Second, we used three methods, namely, 1:3 and 1:5 caliper nearest neighbor matching and kernel matching, to match the control group of cities affected by environmental information disclosure policies. Finally, we re-applied the DID method to estimate the net impact of EID on PM2.5. PSM can largely resolve the systematic bias of observable covariates, and DID can eliminate the effects of unobserved variables that are constant over time or change simultaneously over time. Combining these two methods can better detect the effects of external shocks. Table 6 displays the regression results after using PSM. Overall, we found that the net effect coefficients are all significantly negative, passing the 5% significance level tests. The above results do not alter the conclusion of the benchmark regression, so the robustness test is passed.

Table 6. The results of PSM-DID tests.

Variable	Explained Variable: PM2.5		
	1:3	1:5	Kernel Matching
did	-2.154^{***} (0.678)	-1.893^{***} (0.779)	-2.343^{**} (0.926)
Controls	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	57.006^{***} (6.879)	58.403^{***} (6.980)	58.552^{***} (7.092)
N	1893	1809	1734
R ²	0.939	0.936	0.935

Note: **, and ***, respectively, indicate significance levels of 5%, and 1%. The values in parentheses are the robust standard error of regression coefficient.

6. Conclusions and Policy Implications

The environmental information disclosure policy, as an institutional arrangement involving various stakeholders such as the government, corporations, and citizens, represents a new model of pollution management, wherein multiple parties coordinate to jointly reduce PM2.5 emissions. This study used China's 2007 Environmental Information Disclosure (Trial) policy as a quasi-natural experiment and applied a multiperiod DID model to empirically examine the net effect of EID on urban PM2.5 emissions, its underlying mechanisms, and the heterogeneity of its impact across cities with varying resources and geographic locations. The study's results indicate that, first, EID significantly reduces

urban PM_{2.5} emissions, and this conclusion remains robust after the parallel trend test and various robustness checks. Second, green innovation and industrial structure upgrades acted as key mediating channels through which EID reduces urban PM_{2.5} emissions. Third, regarding urban resource endowment heterogeneity, EID significantly reduces PM_{2.5} emissions in resource-based cities, whereas the effect is not significant in non-resource-based cities. From the perspective of geographic location, EID reduces PM_{2.5} emissions in inland area cities and is not as effective in coastal area cities.

The following policy suggestions emerge from the findings of the above research. First, it is essential to further enhance the environmental information disclosure system. This includes expanding the scope and content of EID, formulating unified disclosure standards and formats, facilitating convenient access to environmental information for all stakeholders, establishing environmental pollution reporting channels, and encouraging public participation in the identification and management of environmental pollution. Second, regarding the mediating channels of EID that affect urban PM_{2.5} emissions, the government should provide subsidies and tax breaks to encourage enterprises to increase R&D expenditures for green innovation; in addition, it should promote the closure and transformation of outdated production capacities, accelerate the development of green energy and energy-saving environmental protection industries, and optimize and upgrade the industrial structure through the gradual conversion of old and new kinetic energy. Finally, it is important to establish a differentiated assessment mechanism for the disclosure of urban environmental information and to implement policy incentives for resource-based and inland cities that demonstrate significant reductions in pollution, thereby further motivating these regions to reduce PM_{2.5} emissions.

This study examines the role of EID in pollution reductions at the city level, finding that EID effectively inhibits urban PM_{2.5} emissions. However, this study acknowledges certain research limitations and outlines directions for future research. On the one hand, this paper focuses on PM_{2.5} as a representative of pollution emission to explore the pollution reduction effect of EID. However, it should be pointed out that the daily production and life in the city will not only produce PM_{2.5}, but also emit a large amount of carbon dioxide. The synergistic effect of pollution reduction and carbon reduction is an effective way to promote the green transformation of economic and social development. Therefore, the next step will be to explore the role of EID policy from the perspective of the synergy of pollution reduction and carbon reduction, which is an important role in further expanding the research field of EID and practicing urban green development. On the other hand, as the primary contributors to pollution emissions and the focal subjects of pollution management, it is crucial to investigate the impact of EID policies on enterprises and their pollution emissions to better understand the effectiveness of these policies. However, because of existing statistical standards, data related to enterprise-level pollution emissions, such as carbon emissions, sulfur dioxide, and PM, are currently unavailable. As micro-statistical data continue to improve, future studies on the impact of EID on corporate emissions at the enterprise level could significantly enrich this field.

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