

The emission reduction effect of environmental information disclosure: a Chinese city perspective

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Abstract

To address the problem of air pollution caused by industrialization and urbanization, China has issued various types of policies related to environmental protection. However, policies regarding environmental information disclosure have long-term advantages in reducing information asymmetry and improving regulatory efficiency, and are selected as the research objects of this paper. Using the "Environmental Information Disclosure Measures (Trial)" in 2008 as a quasi-natural experiment, our analysis utilizing the difference-in-differences method shows that (1) as the quality of environmental information disclosure increase, the production and emission of sulfur dioxide decrease, and this relationship is robust to different specifications; (2) a possible channel composed of green patents and the pollution source information and treatment information (PITI) disclosure index has a same-direction moderating effect on the reduction of pollutants; and (3) our findings are particularly pronounced in subsamples of large-scale and resource-intensive cities. Overall, this paper reveals micro evidence on the effects of environmental information disclosure policy on the reduction of pollutants, thus providing timely insights for the further improvement and implementation of the policy.

Declarations

1. Ethics approval and consent to participate

Not applicable

2. Consent for publication

Not applicable

3. Availability of data and materials

The datasets generated during the current study are available in the [annual research reports of the IPE, the China City Statistical Yearbook and the China Patent Database] repository, [website of the IPE: <http://www.ipe.org.cn/reports/Reports.aspx?cid=18336&year=0&key=>; website of the China City Statistical Yearbook: <https://data.cnki.net/trade/Yearbook/Single/N2012020070?z=Z007>; website of the China Patent Database: <https://www.cnipa.gov.cn>]

4. Competing interests

The authors declare that they have no competing interests

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Not applicable

6. Authors' contributions

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Introduction

China's industrialization and urbanization are the major sources of air pollution. Air pollution is a serious threat to public health. According to the latest ranking of causes of death of urban residents in China released by the National Health and Family Planning Commission, the death rate from lung diseases caused by air pollution is as high as 20%.

To address the problem of air pollution, the state has implemented three types of policies, including compulsory control, market incentives and environmental information management. However, environmental policy based on environmental information disclosure has significant advantages, including the reduction of information asymmetry between regulatory authorities and objects, and the improvement of the supervision efficiency of the environmental protection department. Therefore, China has issued a series of environmental laws, regulations and policies to protect and regulate environmental information disclosure since 2003. Compared with other policies, the "Environmental Information Disclosure Measures (Trial)"(EIDM) enacted in 2008 was crucial, marking a new stage of environmental information disclosure in China. Based on the EIDM implemented in 2008, the Institute of Public and Environmental Affairs (IPE) and the Natural Resources Defense Council (NRDC) jointly developed a pollution source information and treatment information (PITI) disclosure index at the city level to systematically evaluate the implementation of the disclosure policy by local government departments and related enterprises, and to clarify the baseline of the first year of the EIDM regulation.

Compared with environmental information management policies, there are some disadvantages in the implementation of compulsory control and market incentive policies. The difficulty of a compulsory control policy is the tremendous cost of supervision, especially in determining the marginal cost of emission reduction. Although the market incentive policy represented by trading licences and sewage charges can indirectly alleviate the above shortcomings through market price information, the effectiveness of environmental policies cannot be fully guaranteed due to the incompleteness of the

market and the information asymmetry between the regulatory authorities and firms (Tietenberg, 1998; Sartzetakis et al, 2012). Furthermore, the anti-incentive effects of these two policies are obvious and have been widely debated in the literature (Haupt, 2006; Batina and Galinato, 2017).

In fact, information disclosure has been put forward as a third-generation regulatory instrument (Tietenberg, 1998). Policy related to environmental information disclosure has a strong long-term advantage due to the reduction of information asymmetry and the improvement of regulatory efficiency, and thus has been a relevant concern of policymakers (Cohen and Santhakumar, 2007; Asheim, 2010).

The establishment of the environmental information disclosure system in China followed similar systems in other countries. The establishment of the pollutant discharge and transfer registration system (TRI) established in 1984 in the United States was the earliest and most far-reaching environmental information disclosure policy. Similar environmental information disclosure policies were subsequently implemented by Indonesia and India to address environmental pollution problems. Environmental information disclosure in China has developed substantially since 2003, The "Environmental Information Disclosure Measures (Trial)" that came into effect in 2008 is the main legal basis for environmental information management in China. However, the imperfection of the institutional environment and deficiency of methods, standards and experiences related to disclosure, make it difficult to ensure the effectiveness of the environmental information disclosure. To fill this gap, with the support of the widespread use of information technology, IPE and NRDC have jointly developed the PITI index at the city level to comprehensively and systematically measure the quality of environmental information disclosure after the implementation of the EIDM policy.

It is particularly important to quantify the policy effect of environmental information disclosure for policymakers. However, most related studies are concentrated on enterprises, and the content of disclosures is analysed separately. Surprisingly, little is known about the environmental supervision methods of regulatory authorities. Fortunately, the PITI index, which integrates information from environmental protection departments and enterprises, is a suitable proxy variable to measure the effect of EIDM implementation and is thus selected in this study to examine pollutant reduction.

It is well known that large amounts of energy consumption create a great deal of exhaust gas and dust, which seriously affects the quality of the atmospheric environment and poses a huge threat to public health. The harmful substances emitted directly from pollution sources mainly include sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter. Among these pollutants, sulfur dioxide (SO₂) has been identified as the primary air pollutant in terms of the amount of emissions and the degree of harm it causes. Therefore, the government implemented the "Law of the People's Republic of China on the Prevention and Control of Air Pollution" in 2000, and put the task of reducing SO₂ into the "Five-Year" plan, highlighting the urgency and seriousness of addressing SO₂ pollution. In addition, there are synergistic effects between sulfur dioxide and carbon dioxide in emission reduction policies and technologies because of their similar production sources (Jana et al, 2019; Zhao et al, 2019). Therefore,

taking SO₂ as the focal pollutant in this paper allows us to address the governance of air pollution and low-carbon development simultaneously.

Our identification strategy is based on the quasi-natural experiment of the implementing of the EIDM in 2008 and uses a difference-in-differences (DID) approach to examine the real effect of the policy on the reduction of SO₂ emissions. However, three potential challenges including identifying the causal effects due to selection bias, reverse causality and omitted variable concerns. The cities selected by the IPE and NRDC include cities with a high level of economic development and a high degree of pollution, which will result in the failure of the randomness hypothesis of DID. While the PITI index may shape the behaviour of polluting enterprises due to pressure from the public, the establishment of the PITI index could also stem from the environmental protection behaviour of local regulatory authorities and enterprises. Unobservable regional or firm characteristics related to both sulfur dioxide and the PITI index are left in the residual term of the regression, leading to biased estimations. In an attempt to solve these endogeneity problems, Heckman model and instrumental variable (IV) method were used.

This study makes several contributions to the literature. First, we enrich the literature on the evaluation of environmental information disclosure policy. Using a plausible exogenous policy -the EIDM- we offer obvious evidence that the quality of environmental information disclosure represented by the PITI index leads to the reduction of sulfur dioxide. Second, it makes full use of the advantages of the PITI index, comprehensively quantifying the implementation of the policy from the two dimensions of environmental protection departments and enterprises on the quality of information disclosure, thus complementing previous studies that focus mainly on the effects of relevant policies on the disclosure of enterprise environmental information (Hope, 2003; Delgado-Márquez et al, 2015; Zhang, 2017). Third, we investigate the underlying channel through which the PITI index affects the local emissions of SO₂ and find that green patents play an important role. The rest of the article is organized as follows: section 2 offers a literature review, section 3 describes the institutional background, and section 4 explains the data and basic model and discusses endogeneity problems. Section 5 and 6 are related to robustness and heterogeneity analyses, section 7 describes a mechanism test, and section 8 concludes the paper.

Main Text

Literature review

There is a long history of research on environmental information disclosure systems. The early literature used theoretical models and focused on the impact of environmental information disclosure on enterprise production behavior, consumer welfare and environmental externalities (Gupta, 2008; Evans et al, 2009; Araña and León, 2009; Kallbekken et al, 2010; Oestreich, 2015; Partha et al, 2016). More recently, empirical methods have been applied in efforts to value the more complex effects of environmental information disclosure. The main contents of these studies are to evaluate the effect of policy on emission reduction and determine the reasons for emission reduction.

Information disclosure programs have been shown to achieve some success in pollutant emission reduction, e.g., the US Toxic Release Program (Hamilton, 1995; Helland and Whitford, 2003), Indonesia's Program for Pollution Control, Evaluation, and Rating (García et al, 2009) and India's Green Rating Project (Powers et al, 2011). Moreover, potential emission reduction mechanisms are still under wide discussion, and the related literature verifies them from the perspective of prosocial behaviour, the reduction of information asymmetry, green credit and production technology.

In the age of the rapid development of information technology, the disclosure of information to the public leads to the prosocial behaviour of firms. In particular, the Internet and social media have shortened the distance between the public and the source of information. With growing attention placed on health, the attitude of the public towards an enterprise will depend on whether the enterprise has pollution behaviour—which may weaken the incentives of the firm to increase contaminants due to the risk of reputational damage (Cohen and Santhakumar, 2007; Campa, 2018). Furthermore, the shock of pollution status, the shame of pollution behaviour and the strong legal obligations are also crucial causes of enterprises' prosocial behaviour (Stephan, 2002; Botelho et al, 2005; Wang, 2019).

Information asymmetry is the root of environmental externalities. The new instrument of environmental information disclosure benefits the regulators by potentially reducing the information asymmetry between monitors and producers regarding producers' pollution behaviour, which reduces regulatory costs and improves regulatory efficiency (Chavez and Stranlund, 2008; Elnaboulsi et al, 2015; Belay, 2020). By decreasing the cost of collecting, organizing and disseminating data, the policy of environmental information disclosure also guarantees consumers' interests (Kotchen, 2006; Benneer and Olmstead, 2008). The risk of disclosure may thus subsequently incentivize producers' self-regulation and allow them to access benefits from consumers (Evans et al, 2009; Millock et al, 2012).

Based on the above discussions, however, the policy of environmental information disclosure may lead to a decline in enterprises' willingness to disclose information, and one potential solution to this problem is green credit. In the financial market, the degree and level of information disclosure will affect debt, default and credit scores (Seira et al, 2017, Hu et al, 2018). Green credit is based on environmental information disclosure, which takes the compliance with environmental testing standards, the pollution control effect and ecological protection as the important premises of credit approval to encourage enterprises to establish green credit. Kim and Lyon (2011) argued that the increase in "emission reduction credit" brought by enterprise information disclosure could increase the economic benefits of enterprises. Under the dual stimulation of the economy and politics, the intrinsic motivation for enterprise emission reduction is obvious. Aizawa and Yang (2010) verified the effects of green credit jointly implemented by the Ministry of Environmental Protection, the People's Bank of China and the China Banking Regulatory Commission on the performance of polluting enterprises. Recently, the construction of enterprise green information systems (GIS) has been of great significance for sustainable development. Under this background, the realization and use of GIS, green image and credit have become the competitive advantages for enterprises (Carbderry et al, 2017; Yang et al, 2017).

The core of sustainable development is green production technology. After entering the middle stage of industrialization, the green production efficiency of enterprises declines due to the constraints of energy and the environment. Therefore, the development of technology may be inclined toward clean energy. The purpose of environmental policy is not only to solve the problem of pollution, but also to focus on the transformation of

enterprises' production toward a green production mode. (Greaker and Rosendahl, 2008; Simcoe and Toffel, 2014; Liu et al, 2016). Li and Ouyang (2020) noted that green production technology can be roughly divided into three categories: knowledge stock based on patents, technology absorptive capacity measured by foreign direct investment (FDI) and independent innovation represented by R&D. Among these categories, the number of patents is closely related to environmental policy (Hall and Helmers, 2011; Rubashkina et al, 2015; Franco and Marin, 2017; Albrizio, 2017).

Policy background

The development of environmental information disclosure in China

The tentative reform of the legislation on environmental information disclosure is the "Clean Promotion Act" (CPA). In the period of the reform, the objects of disclosure were only heavily polluting firms, and the contents involved only energy consumption and pollutant indicators, which means that the contents and means of environmental information disclosure were unitary. According to the requirements of the CPA, the list of enterprises that fail to meet the energy consumption control index and key pollutant emission control index must be published in the main media of the region to provide a way for the public to supervise the implementation of cleaner production, however, there are no detailed rules for public supervision.

Thereafter, under the background of a low level of public participation in environmental protection, the "Environmental Impact Assessment Law", which clearly stated that the public's formal participation in the Environmental Impact Assessment (EIA) procedure is regulated in detail to obtain relevant information was enacted. The enthusiasm of the public is not high due to a lack of environmental awareness, resulting in a range of problems, such as laxness in claiming the right to know about environmental information, low participation in hearings in the environmental cases, and insufficient effort to report and expose environmental violations. In 2005, under the guidance of a scientific outlook on development, the State Council issued the "Decision on Implementing the Scientific Outlook on Development and Strengthening Environmental Protection", thereby accelerating the establishment of an environmental information disclosure system.

The implementation of the "Environmental Information Disclosure Measures (Trial)" in 2008 specified the behaviour of regulatory authorities to disclose the information on environmental regulation and the requirements of enterprises to disclose environmental information and protect the rights and interests of citizens, legal persons and other organizations to obtain environmental information, marking a new stage of the full implementation of environmental information disclosure according to Chinese law.

Meanwhile, how to evaluate the implementation of policy using quantitative methods has become a key issue in the implementation of environmental information disclosure systems in China. After the implementation of the EIDM, with support from the IPE and the NRDC, the PITI index at the city level was established to systematically evaluate the implementation of the EIDM by local government departments and enterprises and to clarify the baseline of the first year of information disclosure. The target cities evaluated by the IPE and NRDC are mainly environmental protection cities, and the implementation of the EIDM depends on the characteristics of environmental cities, while cities that are not environmental protection cities suffer from the inefficient implementation of the EIDM due to a lack of a comprehensive environmental management capacity and environmental investment.

The nature of the PITI index

The methodology of the PITI index established in 2008 is noteworthy due to the comprehensiveness of the evaluation objects, the unification of evaluation standards, and the standardization of evaluation processes and scientific evaluation methods, which can generally quantify the effects of EIDM implementation.

In terms of the comprehensiveness of the evaluation objects, the cities evaluated by the PITI index include municipalities directly under the central government, provincial capitals, key environmental protection cities and nonenvironmental protection cities, which are widely distributed in the middle and eastern China. This diversity guarantees the representativeness of the evaluated cities, strengthening the efficiency and effectiveness of the PITI index. In addition, the criteria for selecting evaluation objects were unified and established.

In terms of the unification of evaluation standards, the evaluation was carried out on the basis of the eight "evaluation projects" for each city included in the evaluation object. Each evaluation project was evaluated from four aspects: systematicness, timeliness, integrity and user friendliness, and the publicized information covers not only environmental protection departments but also related polluting enterprises.

The standardization of the evaluation process for PITI occurred in three stages. In stage one, the evaluation standards were formulated. The original work in this stage mainly included the weight setting and modification of sub-evaluation items. First, according to the provisions of laws and regulations and environmental supervision practice, the PITI index compilation group screened out the most important information categories for pollution source supervision, and drafted score weights and evaluation criteria on this basis. Second, to ensure the quality and fairness of the evaluation, the group repeatedly solicited the opinions of experts in environmental protection, statistics and law, revised the evaluation standards repeatedly and finally finalized it. The second stage is the evaluation stage. The evaluation was carried out according to the proposed evaluation criteria on the basis of official network data and information disclosure application. Stage three involved publicizing the valuation results and consulting opinions for modification. The environmental protection departments of the cities evaluated were consulted after the evaluation results were published, and the evaluation results were revised on the basis of this feedback to prevent any omissions in the data collection and to ensure the transparency and fairness of the evaluation process.

The scientific evaluation methods included a sensitivity analysis in setting the evaluation item scores to ensure the objectivity of the evaluations. The purpose of this analysis was to test whether the adjusting scores within a certain range would affect the overall scores and rankings of cities. After analysis, the group provided evidence that the adjustment of score weights had no obvious effect on the overall trends in the rankings.

PITI index disclosure as a solution to urban pollution

The PITI index indicates that the level of environmental information disclosure stipulated by the EIDM may lead to a reduction in urban pollutants; thus, this policy is a particularly useful institutional tool for solving the dilemma between economic growth and environment.

There are four ways in which emissions are reduced: (1) first, the disclosure of the PITI index restricts the behaviour of enterprises. The number of environmental administrative punishment cases has gradually declined in recent years according to the information of the Ministry of Ecological Environment, confirming that an increasing number of enterprises tend to abide by the rules of the EIDM. For example, there were only 124500

national environmental cases involving sanctions in 2019, a 14.23% decrease compared with the previous year; (2) PITI index disclosure reduces the information asymmetry of regulatory departments and improves the efficiency of environmental supervision. The contents of the PITI index related to enterprises focus mainly on pollutant emissions; thus, the regulatory authorities can clearly grasp the emission levels of various industries and enterprises by collecting these data, formulate corresponding policies and introduce relevant technologies for emission reduction (Zhu and Zhang, 2012). (3) Third, the public disclosure of the PITI index promotes public supervision. The public will pay special attention to the environmental information disclosure of regulatory authorities and polluting enterprises due to health considerations, thereby promoting the reduction of pollutant emissions (Cohen and Santhakumar, 2007). (4) Fourth, the disclosure of the PITI index regarding the behaviour of enterprises is conducive to the establishment of firms' environmental credit. The Ministry of Environmental Protection and other departments formulated and issued the "Enterprise Environmental Credit Evaluation Method (Trial)" in 2013, carrying out an environmental credit evaluation of enterprises with large pollutant emissions and high environmental risk; this process clearly clarified that the level of enterprise environmental credit determined the scale of green credit. Therefore, high-pollution enterprises' motivation for emission reduction is stronger than that of low-pollution enterprises.

Data and empirical strategy

Data and variables

To investigate the relationship between the EIDM implementation and the level of air pollution in the region, 286 cities in China were selected as the research objects, and the sample interval was 2003-2018. Taking the EIDM issued by the Ministry of Environmental Protection in 2008 as a quasi-natural experiment, we use the PITI index, which measures the effects of the implementation of the EIDM, as the core explanatory variable to verify the emission reduction effect of PITI index disclosure on urban pollutants.

Our data were obtained from three sources: (1) the city PITI index for individual cities was collected from the annual research reports of the IPE; 113 cities were selected for scoring from 2008 to 2012, and 7 new cities were added from 2013 to 2018. (2) Data on SO₂ levels, as well as data related to the control variables, were obtained from the China City Statistical Yearbook; (3) the regional patent data were collected from the China Patent Database.

In addition, considering the impact of regional characteristics and heterogeneity on pollutant emissions, we added the following control variables to cover cities' characteristics in terms of the economy, energy and technology (Powers, 2011; Zhang, 2019): (1) regional economic performance, defined as the natural logarithm of per capita GDP; (2) the economic structure of the region, measured by the proportion of output value of secondary industry; (3) the energy consumption of the region, defined according to industrial power consumption; (4) the level of technological innovation in the region, measured by the number of invention patents; and (5) the technology absorption level of the region, measured by foreign direct investment (FDI).

The cities selected by the IPE and NRDC are taken as the treatment group, and the other cities are taken as the control group. Descriptive statistics for all variables are shown in Appendix. Panel A of Appendix presents the descriptive statistics for the main variables of interest in our sample. On average, the production and emission level of SO₂ in all samples did not show large differences between the treatment group and control group. The summary statistics for groups in panels B and C are also reported; the observations for the two

groups are similar, and the level of SO₂ production and emissions (in logarithmic form) in the treatment group is higher than that in the control group. Most control variables are also comparable across both groups.

The basic empirical strategy and results

Following Bertrand and Mullainathan (2004), Heyes et al (2019) and Zhang et al (2019), we examine the effect of the EIDM implementation on the level of pollutants emissions using a DID methodology. The basic regression we estimate is as follows:

$$\text{Ln}(\text{SO}_2)_{ct} = \alpha_0 + \alpha_1 \text{PITI}_{ct} + \beta X_{ct} + \gamma_t + \eta_c + \varepsilon_{ct} \quad (1)$$

Where c is the city, t is the time, PITI_{ct} is the score determined by the IPE and NRDC for time t in city c , X_{ct} is a vector of the control variables, ε_{ct} is an error term, α_0 is the intercept, and α_1 is the estimated emission reduction effect. In the regression, we control for year fixed effects γ_t and region fixed effects η_c to eliminate regional and temporal heterogeneity. In addition, robust standard errors are clustered at the city level to eliminate cross-sectional correlation and heteroscedasticity.

To reflect the effects of PITI index disclosure on sulfur dioxide production and emissions, total emissions and per capita emissions, the explained variables are measured by sulfur dioxide production, sulfur dioxide emission, per capita sulfur dioxide production and per capita sulfur dioxide emission, respectively. The regression results are shown in Table 1 based on the above basic model.

Columns (1)-(4) of Table 1 show that the coefficients of the PITI index are significantly negative when controlling for city and year fixed effects, which means that the emission reduction effect of the policy is obvious. Specifically, compared with the cities in the control group, after the implementation of the EIDM in 2008, the production and emissions of sulfur dioxide in these cities were effectively controlled. In addition, we also find that the level of economic development, economic structure, energy consumption and FDI have a strong impact on the regional air pollution, while technological innovation alleviates this phenomenon.

In general, energy consumption is the most important factor of air pollution, compared with economic development and structure. On the one hand, this finding confirms the fact that China's coal power generation accounts for a serious proportion (sulfur dioxide production is generated mainly by the combustion of sulfur-containing coal); on the other hand, it highlights the urgent need to develop clean energy (Leightner, 1999; Shrestha and Marpaung, 2005; Shuddhasattwa et al, 2020).

The use of the number of patents to measure the technological innovation ability of cities is different from using FDI, which reflects cities' technology introduction and absorption ability. Patents for the improvement and optimization of production technology inhibit the emission of sulfur dioxide. However, FDI, which has a strongly negative impact on the environment, promotes the production of SO₂ in the region, providing indirect evidence verifying the "pollution haven" hypothesis (PHH) for China, the hypothesis states that developed countries exploit the lower labour costs and lower environmental standards of developing countries, and transfer their pollution-intensive industries to these countries through FDI (Letchumanan and Kodama, 2000; Eskeland and Harrison, 2003; He, 2006; Lan et al, 2012).

Table1 The effects of PITI index disclosure on SO₂.

	(1)	(2)	(3)	(4)
	-0.00223*	-0.00398***	-0.00252*	-0.00426***
	(0.00134)	(0.00129)	(0.00133)	(0.00130)
	0.00851	-0.134*	0.00615	-0.137*
	(0.0848)	(0.0759)	(0.0836)	(0.0758)
	0.189***	0.123***	0.177***	0.111***
	(0.0419)	(0.0357)	(0.0420)	(0.0354)
	0.000023	0.0106***	0.000441	0.0110***
	(0.00454)	(0.00394)	(0.00441)	(0.00388)
	-0.0167	-0.0498*	-0.0310	-0.0636**
	(0.0290)	(0.0293)	(0.0274)	(0.0301)
	0.0999*	0.0354	0.122**	0.0571
	(0.0516)	(0.0460)	(0.0557)	(0.0509)
Constant	9.027***	10.78***	2.184**	3.928***
	(0.943)	(0.864)	(0.908)	(0.836)
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	3,571	3,586	3,570	3,585
Adj.	0.8412	0.8069	0.8392	0.8095

***,**, * indicate significance of the coefficients at the 1%,5% and 10% level, respectively.

Parallel trend test

The fundamental empirical strategy of this paper is based on the analysis framework of DID. However, the validity of the DID strategy depends on the satisfaction of the parallel trend assumption, that is, the assumption of similar trends in the production and emission of SO₂ during the preshock period for both the treatment and control groups (Houngbedji, 2016; Roth, 2018).

The most direct method for parallel interval testing is the drawing method. The drawing method directly shows the trend of the treatment group and the control group before the implementation of the policy. Fig. 1 shows the parallel trend of the treatment group and the control group through the drawing method. Before the implementation of the EIDM, the trend of the sulfur dioxide emissions of the two groups was identical, and the gap between the two groups was relatively stable. After the implementation of the EIDM in 2008, the gap decreased, although the SO₂ emissions of the treatment group and the control group obviously declined, showing that the parallel trend assumption was satisfied.

Endogeneity

Existing studies have proven that there are three main sources of endogeneity - missing variables, selection bias and reverse causality - all of which violate the assumption that the error term is a spherical disturbance and thus lead to a biased estimation (Manski, 1991; Elwert and Winship, 2014). This section details the endogeneity problems and solutions for the PITI index and SO₂ in terms of the above three aspects.

Omitted variables

There will be substantial errors with regard to missing variables when the missing variables are closely related to the explained variables and the core explanatory variables. In this paper, the selection of control variables is conducted in accordance with the existing literature, which controls the heterogeneity of cities in

terms of the three dimensions of economic development, energy consumption and technological progress, indicating the comprehensiveness of the control variables. In addition, city and year fixed effects are added to control for the influence of unobservable factors. Therefore, all these settings can partly alleviate the problem of missing variables.

Selection bias

Another hypothesis of the DID empirical strategy is the randomness hypothesis, which requires that the selection of samples for the treatment group and control group is random. However, most of the social experiments do not satisfy this hypothesis due to policy limitations, which means that the treatment group and the control group are obviously characterized by artificial selection. Fig.1 shows that there are obvious differences between the evaluation objects (treatment group) and nonevaluation objects (control group) of the PITI index, indicating the existence of selection bias, which needs to be corrected.

In this subsection, Heckman's two-step method is adopted to correct the selection error. In the first step, a probit model is used to estimate the selection probability of the treatment group, and then, the selection deviation between the treatment group and the control group, called the inverse Mills ratio, is calculated. In the second step, the inverse Mills ratio is introduced into the basic model as a control variable. We partially alleviate the estimation bias by controlling for the selection probability of the treatment group according to the theory of the Heckman model. The empirical results are shown in Table 2.

From columns 1 to 4 of Table 2, the PITI coefficients are still significant after adding the inverse Mills ratio, and the problem of sample selection error is more serious for the production of SO₂ than for the emission of SO₂. In columns 1 and 3, the coefficients of the inverse Mills ratio are significant, which indicates that the Heckman method can partially alleviate the problem of sample selection error.

Table 2 Using Heckman model to address selection errors.

	(1)	(2)	(3)	(4)
	-0.00452***	-0.00446***	-0.00467***	-0.00459***
	(0.00133)	(0.00124)	(0.00134)	(0.00128)
	-0.157	-0.155	-0.147	-0.144
	(0.108)	(0.0951)	(0.108)	(0.0960)
	0.181***	0.120***	0.169***	0.108***
	(0.0396)	(0.0349)	(0.0398)	(0.0346)
	0.00212	0.0101***	0.00230	0.0103***
	(0.00462)	(0.00389)	(0.00451)	(0.00382)
	-0.0204	-0.0519*	-0.0346	-0.0652**
	(0.0280)	(0.0285)	(0.0270)	(0.0296)
	0.143***	0.0503	0.163***	0.0701
	(0.0469)	(0.0467)	(0.0513)	(0.0509)
	-0.444***	-0.107	-0.418***	-0.0790
	(0.107)	(0.111)	(0.106)	(0.109)
Constant	10.03***	10.86***	3.105***	3.925***
	(1.056)	(0.971)	(1.031)	(0.957)
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	3,507	3,517	3,506	3,516
Adj.	0.8428	0.8070	0.8395	0.8093

***,**, * indicate significance of the coefficients at the 1%,5%and 10% level, respectively.

Reverse causality

In addition to missing variables and selection errors, the basic model may also have endogeneity problems caused by reverse causality. The root of reverse causality is that the current production and emission of SO₂ may affect the current PITI index. This section attempts to explain and address the problem of reverse causality from two perspectives. First, we start with the specific evaluation content of the PITI index and check the severity of reverse causality in the evaluation content. Then, we use the instrumental variable (IV) method to alleviate the endogeneity problem.

The IPE and NRDC evaluate each city according to eight evaluation projects. The specific evaluation contents are shown in the annual report of IPE. According to the evaluation contents in the reports, the reverse causal relationship between the current production and emission of SO₂ and the current the PITI index is not obvious. The main reasons for this are as follows: 1) the pollutants involved in the evaluation contents of the PITI index include all the pollutants as a whole. However, SO₂ makes up only part of exhaust fumes, that is, it is one of the "three wastes" leading to air pollution. Therefore, the bidirectional causal relationship between the overall pollution and local pollution is not serious. 2) Second, the PITI index aims mainly to evaluate the management ability of the environmental protection department. The score for the information publicity norms and guidelines of the environmental protection departments is 64, while the corresponding score for polluting enterprises is 36. Therefore, we can intuitively conclude that the information disclosure level of environmental protection departments in a region may not directly affect the emission of SO₂ in the region.

However, it is not convincing to discuss the causal relationship between PITI index disclosure and SO₂ emissions based on the evaluation content. Therefore, this section uses the IV method to alleviate the endogeneity problem. To ensure validity, the IVs need to satisfy the hypothesis of correlation and independence, which not only requires the IVs to be related to endogenous variables but also requires that IVs be independent of the disturbance term of the original equation.

Based on these two assumptions, a one-period lag and a two-period lag of the PITI index are selected as the suitable IVs for the current PITI index in this subsection because the PITI index for the previous year and the year before that are related to the PITI for this year, which satisfies the correlation hypothesis, and the production and emission of SO₂ this year may not have an impact on the PITI of the previous two years, indicating that the independence hypothesis is satisfied. The results found using the IV method are shown in Table 3. Table 3 shows that after considering the problem of inverse causality, the disclosure of the PITI index of a region still has an inhibitory effect on the production and emission of sulfur dioxide in the region.

Table 3

Using IV method to address reverse causality.

	(1)	(2)	(3)	(4)
	-0.0110*** (0.00351)	-0.00781** (0.00379)	-0.00998*** (0.00352)	-0.00679* (0.00350)
	-0.234*** (0.0860)	-0.198* (0.120)	-0.212** (0.0830)	-0.175 (0.119)
	0.165*** (0.0374)	0.111** (0.0441)	0.156*** (0.0371)	0.102** (0.0445)
	0.000481 (0.00328)	0.00924** (0.00428)	0.000969 (0.00354)	0.00972** (0.00479)
	-0.0106 (0.0188)	-0.0473*** (0.0181)	-0.0270 (0.0218)	-0.0627*** (0.0209)
	0.125** (0.0625)	0.0385 (0.0460)	0.148* (0.0762)	0.0617 (0.0579)
	-0.619*** (0.113)	-0.199* (0.110)	-0.563*** (0.118)	-0.142 (0.0981)
Constant	12.65*** (0.835)	12.29*** (1.365)	5.799*** (0.810)	5.421*** (1.393)
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	3,481	3,491	3,480	3,490
Adj.	0.8120	0.7765	0.8130	0.7839

***,**, * indicate significance of the coefficients at the 1%,5% and 10% level, respectively.

Identification

Concurrent policies

We exclude the influence of other interference policies in the same period to identify the emission reduction effect of PITI index disclosure in this section. As mentioned in the introduction, the policies related to the prevention and control of SO₂ can be roughly divided into three categories: control of total amounts, market incentives and environmental information management. Concurrent policies refer to the total amount control policies and market incentive policies in the sample range (2003-2018).

The emission control policies relating to SO₂ mainly include the national total emission control plan of pollutants during the " Eleventh Five-Year Plan" period from 2006 to 2010, the national total emission control plan of pollutants during the " Twelfth Five-Year Plan" period from 2011 to 2015 and the emission reduction targets for SO₂ for the "Two Control Zones" implemented in 2010. Market incentive policies have been issued mainly from the perspective of tax and enterprise costs. The most representative of these policies is the "Measures for the Collection and Management of Sewage Charges" implemented in 2003, which is not considered in this section, as the policy did not take place in the sample period.

To eliminate the effect of interference of other policies, we perform the following three identification tests. Concurrent policy variables referring to the " Eleventh Five-Year Plan" (), " Twelfth Five-Year Plan" () and "Two Control Zones" () are introduced into the basic model to check the robustness of the policy effect of the EIDM one by one. The control variables and the inverse Mills ratio are collectively referred to as for simplicity, and the results are listed in Table 4. According to Table 4, after controlling the targets of the "Eleventh Five-Year Plan", the "Twelfth Five-Year Plan" and the "Two Control Zones", the emission reduction effect of the EIDM represented by the PITI index is still significant.

In addition, the emission reduction effects of the "Eleventh Five-Year Plan" target and the "Two Control Zones" target in the sample period are not obvious. There are two possible reasons for this: (1) the coefficients

of the PITI index in our model measure the average policy effects in the sample interval for the treatment group compared with the control group. However, the "Eleventh Five-Year Plan" and "Twelfth Five-Year Plan" were implement only five years, and the targets of these policies included all provinces and cities. Therefore, the short implementation time and the universality of the implementation targets of these two policies may have caused the average emission reduction effect to not be obvious. (2) The compulsory implementation of the "Two Control Zones" policy ended in 2010. However, Fig.1 shows that the SO₂ emissions of the treatment group and the control group were still high in 2010, which may have caused the inapparent effect of the TCZ policy on the sample.

Table 4 Eliminating the interference of concurrent polices.

	(1)	(2)	(3)	(4)
Panel A: Excluding the effect of " Eleventh Five Year Plan"				
	-0.0110***	-0.00814**	-0.00993***	-0.00707**
	(0.00361)	(0.00342)	(0.00367)	(0.00348)
	-0.000131	0.00371	-0.000632	0.00320
	(0.00318)	(0.00300)	(0.00323)	(0.00305)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	3,494	3,504	3,493	3,503
Adj.	0.8120	0.7734	0.8130	0.7815
Panel B: Excluding the effect of " Twelfth Five Year Plan"				
	-0.0118***	-0.00736**	-0.0108***	-0.00634*
	(0.00362)	(0.00343)	(0.00368)	(0.00349)
	-0.00606*	0.00320	-0.00609*	0.00319
	(0.00344)	(0.00318)	(0.00349)	(0.00324)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	3,494	3,504	3,493	3,503
Adj.	0.8154	0.7696	0.8164	0.7782
Panel C: Excluding the effect of "Two Control Zones"				
	-0.0107***	-0.00763**	-0.00954**	-0.00643*
	(0.00381)	(0.00362)	(0.00388)	(0.00368)
	0.0561	-0.00533	0.0806	0.0203
	(0.0529)	(0.0504)	(0.0539)	(0.0514)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	3,494	3,504	3,493	3,503
Adj.	0.8091	0.7767	0.8091	0.7843

***,**, * indicate significance of the coefficients at the 1%,5%and 10% level, respectively.

Placebo test

To corroborate that the policy effect of the EIDM is not due to random chance, we conduct two placebo tests following Bertrand (2004) and Heyes (2019) by creating the year and objects of the policy implementation randomly. Specifically, we check the effectiveness of the synthetic policy variables after artificially assigning the implementation year of the EIDM to the original treatment and control groups. In a similar way, we verify the nonrandomness of the policy effect of the EIDM by incorporating the product of the new scores of the cities selected randomly for evaluation and the EIDM implementation year of 2008 into the regression equation. The

results of the placebo tests shown in Table 5 indicate that the coefficients of the synthetic policy variables are insignificant, meaning that the emission reduction effects of the EIDM are not caused by accidental factors.

Table 5 placebo test.

	(1)	(2)	(3)	(4)
Panel A: Randomly generate the implementation year of the EIDM				
	-0.000336	-0.000944	-0.000413	-0.00102
	(0.00167)	(0.00149)	(0.00168)	(0.00152)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	3,471	3,481	3,470	3,480
Adj.	0.8427	0.8055	0.8376	0.8041
Panel B: Randomly generate the implementation cities of the EIDM				
	0.000511	0.000772	0.000499	0.000761
	(0.000518)	(0.000482)	(0.000538)	(0.000487)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	969	975	968	974
Adj.	0.8279	0.7150	0.8156	0.7576

***,**, * indicate significance of the coefficients at the 1%, 5% and 10% level, respectively.

Sample deletion

One approach to test the robustness of the findings is to delete a portion of the sample according to certain rules and test the significance of the policy effect based on the deleted sample. Generally, there are three ways to perform sample deletion: random sampling, removing extreme values of the samples and deleting samples for other purposes. In this section, the above three methods are used for robustness testing: we randomly select 50% of the samples, remove the 10% most extreme values of the explained variables and delete the samples using propensity score matching (PSM). The PSM method is another way to address sample selection error. It can be seen from Table 6 that through sample deletion for randomness, extreme values and selection error, the emission reduction effect of PITI index disclosure is still significant.

Table 6 Sample deletion.

	(1)	(2)	(3)	(4)
Panel A: Randomly selecting 50% of the samples				
	-0.00460*** (0.00138)	-0.00545*** (0.00143)	-0.00482*** (0.00144)	-0.00561*** (0.00150)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	1,749	1,754	1,748	1,753
Adj.	0.864	0.824	0.864	0.829
Panel B: Removing the extreme value of 10% for the explained variables				
	-0.0110*** (0.00351)	-0.00781** (0.00379)	-0.00998*** (0.00352)	-0.00679* (0.00350)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	3,481	3,491	3,480	3,490
Adj.	0.8120	0.7765	0.8130	0.7839
Panel C: Deleting the samples by PSM				
	-0.00167* (0.000922)	-0.00183* (0.000993)	-0.00174* (0.000903)	-0.00189* (0.000921)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	2,009	2,008	2,009	2,008
Adj.	0.7961	0.6983	0.8271	0.7663

Note: Among these three ways, the procedure of PSM is complicated because it involves the calculation of propensity value, score matching, balance test after matching, calculation of Average effect of the Treatment on the Treated (ATT) and sensitivity analysis. Balance test after matching is the key point for ensuring that there is no statistical difference between the matched treatment group and the control group before the implementation of the policy. After a series of tests, we find that PSM significantly reduces the sample selection bias, and the average bias is reduced from 0.9328 to 0.1807. Standard errors clustered at the city level are reported in parentheses. ***, **, * indicate significance at the 1%, 5% and 10% levels respectively.

Policy effects of long-term and short-term

Fig.1 shows that the production and emission of SO₂ in both the treatment group and the control group did not decrease significantly after the implementation of the EIDM in 2008. However, the EIDM has had an obvious emission reduction effect since 2012, indicating that the EIDM has had different long-term and short-term effects. In fact, distinguishing the long-term and short-term effects of the EIDM has great guiding significance for policy makers and provides evidence of the trend in the policy effect.

Therefore, the whole sample period is divided into different time periods to identify the long-term and short-term emission reduction effects of the EIDM. Choosing the time node of policy implementation in 2008 as the centre and taking three years, five years and ten years as the radii, three time periods are determined: 2005-2010, 2003-2012 and 2003-2017. The regression results based on three subsamples time periods are shown in Table 7. Panel A of the Table 7 shows that the emission reduction effect of the EIDM from 2005 to 2010 is insignificant, indicating that the short-term effect of the policy is not obvious. However, the EIDM plays a strong role in reducing the generation of SO₂ but has no impact on the emissions from 2003 to 2010, according to Panel B. Moreover, the EIDM effectively inhibits the production and emission of SO₂ in the later period, showing that the long-term effect of the policy is notable. One possible explanation for the different long-term and short-term

policy effects is that it is difficult to improve and enhance public monitoring and the efficiency of EIDM supervision in the short term, indicating the need for the long-term implementation of the EIDM.

Table 7 Long-term and short-term effects.

	(1)	(2)	(3)	(4)
Panel A: Short-term effect of the EIDM in 2005-2010				
	-0.00250 (0.00347)	0.00245 (0.00293)	-0.00297 (0.00427)	0.00198 (0.00358)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	1,555	1,555	1,555	1,555
Adj.	0.9107	0.9342	0.9135	0.9366
Panel B: Medium and long-term effect of the EIDM in 2003-2012				
	-0.00752* (0.00422)	-0.00371 (0.00392)	-0.00729* (0.00431)	-0.00349 (0.00383)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	2,547	2,552	2,547	2,552
Adj.	0.8479	0.8623	0.8556	0.8704
Panel C: Long-term effect of the EIDM in 2003-2017				
	-0.0110*** (0.00351)	-0.00781** (0.00379)	-0.00998*** (0.00352)	-0.00679* (0.00350)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	3,481	3,491	3,480	3,490
Adj.	0.8120	0.7765	0.8130	0.7839

***, **, * indicate significance at the 1%, 5% and 10% levels respectively.

Heterogeneity analysis

City size

As mentioned above, the disclosure of the urban PITI index produced as a result of the implementation of the EIDM in 2008 can significantly reduce the production and emission of SO₂ at the city level. However, the urban scale affects the heterogeneity of the emission reduction effects of the policy. Reeve and Scott (2013) and Rainald and Takatoshi (2018) stressed that the pollution of large cities was more serious than that of small cities due to the high level of population density, obvious industrial agglomeration effect, and the tremendous energy consumption of large cities. Pressures in term of the population, resources and the environment also restrict the behaviours of polluting enterprises as the urban scale increase (Han et al, 2016). Therefore, we can hypothesize that the effect of the EIDM may vary depending on city size.

In this section, cities are divided into small and medium-sized cities (with a population of less than 1 million), large cities (with a population between 1 million and 3 million) and mega cities (with a population of more than 3 million), according to the "Standards on Adjusting the Division of City Size" issued by the State Council in 2014. The results of subsample regression are shown in Table 8. Panel A of Table 8 shows that the disclosure of environmental information in the PITI index has no significant impact on the production and emission of SO₂ in small and medium-sized cities, which might be caused by low awareness of this information disclosure and the poor execution of the EIDM. However, the disclosure of the PITI index could effectively control local air pollution in large cities, which is consistent with the basic conclusion of the effectiveness of

the EIDM and illustrates that the EIDM is a good governance tool for the local environmental protection departments. In addition, the comparison of Panel B and C shows that PITI index disclosure only has a certain inhibitory effect on the emission of SO₂ in megacities, which are characterized by a high level of environmental governance and green innovation.

Table 8 Heterogeneity analysis - the size of city

	(1)	(2)	(3)	(4)
Panel A: small and medium-sized cities				
	-0.00381 (0.00474)	0.00354 (0.00698)	-0.00447 (0.00492)	0.00287 (0.00648)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	1,124	1,127	1,124	1,127
Adj.	0.8592	0.7865	0.8624	0.7869
Panel B: large cities				
	-0.0222*** (0.00529)	-0.0140*** (0.00479)	-0.0211*** (0.00507)	-0.0129*** (0.00466)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	1,020	1,021	1,020	1,021
Adj.	0.6839	0.6836	0.6720	0.6847
Panel C: mega cities				
	-0.00610* (0.00335)	-0.0112** (0.00534)	-0.00396 (0.00394)	-0.00891* (0.00468)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	1,230	1,236	1,229	1,235
Adj.	0.8242	0.7238	0.8172	0.7185

***, **, * indicate significance at the 1%, 5% and 10% levels respectively.

Cities' resource endowment

Resource-based cities are a crucial strategic basis for the sustainable and healthy development of China's economy. However, resource-intensive cities facing the dilemma of high development intensity and a low level of comprehensive utilization of resources have to bear the problem of environmental pollution. The resource endowment of a region determines the regional energy structure and then has an impact on the local environment. For example, air pollution in coal-intensive cities is very serious due to the combustion of sulfur coal. Therefore, the difference in urban resource endowment might lead to heterogeneity in the effects of the EIDM policy.

In 2013, the State Council issued a notice on "Printing and Distributing the National Sustainable Development Plan for Resource-based Cities (2013-2020)", which determined a list of 108 national resource cities. The regression results for this subsample of cities are shown in Table 9. Compared with Panel A and B of Table 9, it is concluded that the PITI index, which is used to measure the level of environmental information disclosure, has a more obvious effect on the emission reduction of resource-based cities, especially on the emission of SO₂. A possible reason for this effect is that the characteristics of the low cost of energy use and the high intensity of energy consumption in resource-based cities might lead to serious pollution problems. Specifically, the disclosure of environmental information through the PITI index accelerates the flow of

information in the context of strong environmental awareness among local residents, causing the public to engage in strong supervision of polluting enterprises and environmental protection departments, thus indirectly alleviating pollution.

Table 9 Heterogeneity analysis - resource endowment of city

	(1)	(2)	(3)	(4)
Panel A: Resource-based cities				
	-0.0106*** (0.00252)	-0.0135*** (0.00413)	-0.00980*** (0.00262)	-0.0127*** (0.00428)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	1,325	1,325	1,325	1,325
Adj.	0.8634	0.7294	0.8543	0.7884
Panel B: non resource-based cities				
	-0.0142** (0.00556)	-0.00467 (0.00449)	-0.0132** (0.00592)	-0.00358 (0.00384)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	2,156	2,166	2,155	2,165
Adj.	0.8124	0.7281	0.8012	0.7125

***, **, * indicate significance at the 1%, 5% and 10% levels respectively.

Potential mechanisms

Thus far, we have shown that the implementation of the EIDM significantly reduces the production and emission of SO₂ at the region level. In this subsection, we investigate the underlying mechanisms behind of our findings. According to the previous analysis, environmental information disclosure due to the EIDM can ameliorate the air quality of the region by improving the regulatory efficiency of environmental protection departments and promoting the achievement of green production, particularly upgrades and transformations of the traditional mode of production for polluting enterprises. However, the improvement of the regulatory efficiency of regulatory authorities is difficult to quantify, enterprises' green production levels can be measured by their green patents. Therefore, this section takes green patents as the starting point of the mechanism analysis.

Green patents are different from patents in general. The classification of green patents in China is based on the list of green patents issued by the World Intellectual Property Organization (WIPO) in 2010 and include seven categories: transportation, waste management, energy conservation, alternative energy production, administrative supervision and design, agriculture and forestry, and nuclear power. It can be seen from the above classification that green patents mainly involve green production, energy conservation and administrative supervision and have a certain degree of similarity with the evaluation content of the PITI index. Therefore, this section takes the level of green patents in the region as a moderating variable for the PITI index to determine the channel by which the EIDM leads to emission reduction.

Regarding relationship between green patents, innovation and environmental pollution, most of the existing literature verifies the relationship between green technology and pollution from the perspective of the energy structure, energy density and investment related to energy (Wurlod et al, 2018; Ng and Zheng, 2018; Yan et al, 2020). Based on the above research, we add the multiplication term and decentralized interaction term of

regional green patents and the PITI index into the basic model to verify the effectiveness of using green patents as the moderator. The regression results are shown in Table 10. Panel A and Panel B of Table 10 show that the interaction between PITI index and green patent index has an auxiliary emission reduction effect on the emission of SO₂, which indicates that the disclosure of environmental information in the PITI index may lead to an increase in green patents for enterprises, encourage heavily polluting enterprises to control the discharge of pollutants, eventually reducing SO₂ emissions in the region.

Table 10 Mechanism analysis-Taking green patent as moderating variable.

	(1)	(2)	(3)	(4)
Panel A: Decentralized processing of cross multiply items				
	-0.00441***	-0.00299**	-0.00449***	-0.00272*
	(0.00161)	(0.00152)	(0.00162)	(0.00165)
	-0.000794	-0.0139*	-0.00157	-0.0146*
	(0.00786)	(0.00734)	(0.00823)	(0.00795)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	3,507	3,517	3,506	3,585
Adj.	0.8428	0.8070	0.8395	0.8093
Panel B: Centralized processing of cross multiply items				
	-0.00448***	-0.00422***	-0.00463***	-0.00435***
	(0.00134)	(0.00126)	(0.00135)	(0.00131)
	-0.000794	-0.0139*	-0.00157	-0.0146*
	(0.00786)	(0.00734)	(0.00823)	(0.00766)
	YES	YES	YES	YES
City Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES
Observations	3,507	3,517	3,506	3,516
Adj.	0.8429	0.8077	0.8395	0.8098

***, **, * indicate significance at the 1%, 5% and 10% levels respectively.

Conclusion

Based on the quasi-natural experiment of the “Environmental Information Disclosure Measures (Trial)” implemented in 2008, this paper used a DID methodology to investigate the effects of PITI index disclosure on the reduction of SO₂ emissions in cities. We find that (1) a large PITI index with larger number, which represents a higher level of environmental information disclosure, has a certain inhibitory effect on the production and emission of SO₂ in the region; (2) the emission reduction effect of the EIDM remains obvious after excluding other concurrent policies related to SO₂; (3) in the discussion of potential mechanisms, we find that regional green patents have a moderating effect in the same direction as the emission reduction effect of PITI index disclosure; and (4) the emission reduction effect is greater in cities characterized by a large scale and resource intensity. Overall, our research reveals the micro evidence of the effects of the EIDM policy on the reduction of SO₂ and provides timely insights for the further improvement and implementation of the policy.

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Figures

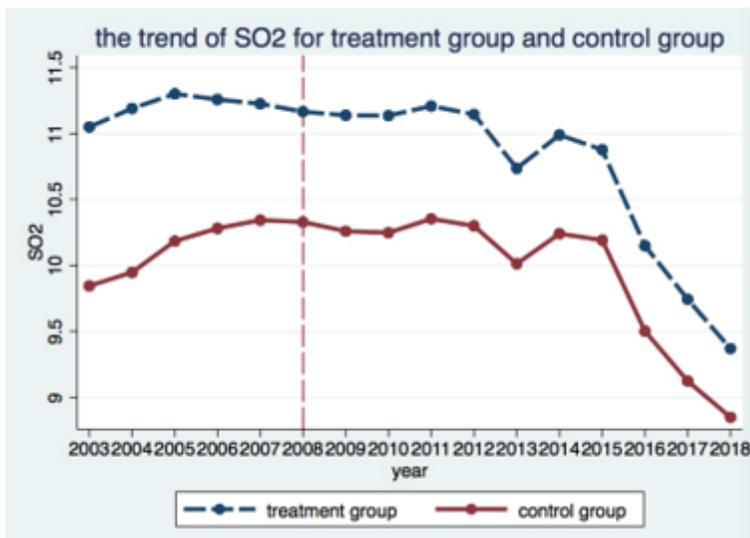


Figure 1

Parallel trend test

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