Low-carbon governance, fiscal decentralization and sulfur dioxide emissions: Evidence from a quasi-experiment with Chinese heavy pollution enterprises

Ping Guo
Hunan University
Jin Li (ljin0502@hnu.edu.cn)
Hunan University https://orcid.org/0000-0003-4526-9786
Jinsong Kuang
Hunan University of Technology and Business
Yifei Zhu
Hunan University of Technology and Business
Renrui Xiao
Hunan University
Donghao Duan
Hunan University
Baocong Huang
Hunan University

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Author names

Ping Guo,Jin Li, Jinsong Kuang,Renrui Xiao,Baocong Huang,Donghao Duan, Yifei Zhu

Affiliations

School of Economics and Trade, Hunan University, Changsha 410205, Hunan,China

Ping Guo, Jin Li, Renrui Xiao & Donghao Duan

School of Economics and Trade, Hunan University of Technology and Business, Changsha 410205,Hunan,China

Jinsong Kuang & Yifei Zhu

School of Public Administration, Hunan University, Changsha 410205, Hunan,China

Baocong Huang

Corresponding author

Jin Li telephone:15898529150; email address: ljin0502@hnu.edu.cn

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Abstract

This paper investigates the effects of enterprise environmental governance under low-carbon pilot policies in China with a difference in differences (DID) design. In examining the development of these policies, we focus on exploring their effects on sulfur dioxide emissions of heavily polluting enterprises based on prefectural city- and firm-level data from 2003-2014. Overall, the policies significantly increased enterprise SO_2 emissions, and the underlying reason being that investments in CO_2 control crowded out investment in SO_2 control in enterprises in low-carbon pilot regions. We also find that the implementation of low-carbon pilot policies resulted in greater SO_2 emissions from state-owned enterprises and enterprises in western regions than from non-state-owned enterprises and those in eastern regions. It is further found that fiscal decentralization and the associated mediating effect of market segmentation promote enterprises' CO_2 control and inhibit their SO_2 control. This study helps us re-examine the overall environmental effects of low-carbon policies and has implications for the revision and improvement of environmental governance policies in developing countries.

Keywords: Low-carbon pilot city;Fiscal decentralization;SO_2; DID; Sulfur dioxide treatment input; Heavy pollution enterprises

1. Introduction

With rapid economic development, air pollution caused by industrial production in China has become increasingly serious (Hao et al. 2018; Mujtaba and Shahzad 2021), with air pollution problems caused by emissions of carbon dioxide (CO_2) and sulfur dioxide (SO_2) becoming a particular focus of attention (Zhang et al. 2020). Poor air quality can lead to major public health and welfare problems (WHO 2016). Many cities around the world have constructed low-emission zones as an important measure to enhance urban competitiveness, reduce greenhouse emissions, decrease air pollution, and improve the resident well-being. In terms of academic research, scholars outside China have extensively investigated the role of low-emission zones in pollution governance (Ellison et al. 2013; Wolff 2014; Gehrsitz 2017). Ellison et al. (2013) explored the relationship between air quality in low-emission zones and that of surrounding regions before and after policy implementation and assessed the impact of low-emission policies implemented in London on regional air quality. Wolff (2014) assessed the impact of low-emission area policies implemented in Europe on regional air quality by using a difference-in-differences (DID) design to determine the treatment effects across regions and over time. Gehrsitz (2017) also used DID to investigate the effect of low-emission zone policies implemented in Germany on air quality and infant mortality. All of the above studies found that low-emission policies significantly improved air quality in the regions where the policies were implemented.

To improve air quality and control environmental pollution, the Chinese government has also developed and implemented a series of environmental governance measures, with the Low-Carbon Pilot Policy (LCPC) being one of the most important institutional arrangements. In July 2010, the Chinese government issued a notice on the first round of low-carbon provincial and municipal pilot programs and areas, including Guangdong, Guiyang and 13 other provinces and cities. In November 2012, the "Notice on the Second Batch of Low-Carbon Provincial and Municipal Pilots" was issued, covering 29 provinces and cities such as Hainan and Zhenjiang. Numerous studies have shown that the LCPC has significantly reduced CO_2 emissions (Lin et al. 2014; Dai and Cao 2015; Feng et al. 2021; Hong et al. 2021). However, whether this policy can reduce emissions of SO_2 and gases other than CO_2 and improve overall environmental management is still an important issue of study that has not yet attracted active attention in academia.

Research literature focusing on the impact of the LCPC on SO_2 emissions is still scant. As a comprehensive environmental regulatory tool, the LCPC differs from traditional single environmental regulations in that its goal is to achieve emission reductions of CO_2, SO_2 and other pollutant gases (Tan et al. 2017; Chen et al. 2021) but it requires greater reductions of CO_2 than of SO_2. Song et al. (2019) used single-period DID to analyze the relationship between the LCPC and urban air pollution in China and found that the LCPC reduced the air pollution index (API)[1] of pilot cities by fostering upgrades and innovation in the industrial structure. However, Peng et al. (2020) found that the LCPC has no significant effect on SO_2 emissions in small and medium-sized cities and megacities based on a single-period DID.

It can be seen that the depth and breadth of the existing literature is far from adequate in terms of the mechanisms whereby the LCPC impacts SO_2 emissions. The LCPC places environmental regulatory pressure on enterprises in pilot regions and increases their actual pollution emission costs (Chen et al. 2021). Regional governments attach much more importance to CO_2 than SO_2 emission reductions (Feng et al. 2021). On the one hand, enterprises may invest in technology and equipment to reduce CO_2 and SO_2 emissions. On the other hand, to maximize profit and meet the higher CO_2 reduction targets, enterprises may increase their capital investment in CO_2 governance, which may crowd out funds for governance of other polluting gases such as SO_2 and result in an

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[1] The urban API includes a combined assessment of $PM_{10}, SO2, NO_2$, etc.

increase in enterprise emissions of these pollutants.

In addition, most of the existing literature evaluates the effects of the LCPC by using single-period DID designs, which may suffer from endogeneity problems. Specifically, the LCPC has been implemented in rounds, and samples covering different periods have different characteristics, such as differences in economic development levels. These variables may affect SO_2 emissions, and their omission could bias the estimation results obtained.

Therefore, to examine the development of the LCPC, this paper uses data on prefecture-level cities and enterprises in China from 2003 to 2014 and applies a multiperiod DID to investigate the relationship between the LCPC and SO_2 emissions. It attempts to explore the following core issues: Does the LCPC curb SO_2[2] emissions from heavily polluting enterprises? What are the mechanisms whereby SO_2 emissions from heavy polluters are affected? Answering the above questions will help clarify the relationship between low-carbon policies and pollution emissions and help us re-examine the overall environmental governance effects of the LCPC.

The potential contributions of this paper relate mainly to the following three aspects.

First, in terms of the research perspective, this paper focuses on assessing the impact of the LCPC on SO_2 emissions from heavy polluters, complementing previous studies on China that have focused on the role of the LCPC in reducing CO_2 emissions. Previous studies have found that the LCPC can effectively reduce CO_2 emissions (Song et al. 2018), but the impact on SO_2 emissions remains to be verified. Moreover, this paper enriches and complements the research on the impact of the LCPC on cleaner production in heavily polluting enterprises. In particular, most of the literature on the impact of low-carbon policies on regional air quality has focused on

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[2] It would be preferable to examine the impacts on more than one pollutant. However, for industrial pollution, the central government of China previously focused on only SO_2 among air pollutants and chemical oxygen demand (COD) for water pollution.

developed countries, and few studies have focused on China, the largest developing country. Therefore, this quasinatural experimental study of the LCPC based on a sample of Chinese firms is innovative, providing new empirical evidence for developing countries and complementing existing studies.

Second, from a data and methodological perspective, one of the challenges commonly faced in existing literature evaluating environmental policy effects is endogeneity problems. Due to the late start of environmental policies in China and data limitations, there is less literature examining the effects of environmental remediation that effectively addresses these endogeneity problems. Thus, this paper uses a multiperiod DID approach based on firm-level pollution data for the period 2003-2014 and takes the LCPC as a quasinatural experiment to better alleviate endogeneity problems and data limitations, providing new empirical and methodological ideas for related studies.

Third, the mechanism by which the LCPC affects the SO_2 emissions of heavy polluters is explored. The mechanism analysis finds that the LCPC has a crowding-out effect on financial investment for the treatment of SO_2. This decrease in investment in SO_2 control causes an increase in SO_2 emissions. Moreover, existing studies suggest that the LCPC can influence the environmental investment decisions of enterprises (Guo et al. 2020 Xu and Cui 2020; Ji et al. 2021); however, whether the LCPC influences the SO_2 emissions of heavy polluters has not been demonstrated. Therefore, we test the mechanism with a moderating effect model. Our findings suggest that the LCPC increases financial investment in the treatment of CO_2 and crowds out investment in the treatment of SO_2, which in turn increases SO_2 emissions among heavily polluting enterprises.

The remainder of this paper is structured as follows: The second part introduces the LCPC with respect to its formulation, implementation background and potential effect mechanism. The third part presents the data used in the empirical study and sets up an econometric regression model to implement the identification strategy. The fourth part reports the analysis of the empirical results and conducts robustness and mechanism tests. The fifth part offers a heterogeneity analysis. The sixth part presents further discussion from the perspective of fiscal decentralization, and the seventh part offers the conclusion and policy implications.

2. Policy background and research hypotheses

2.1. China's low-carbon pilot policy (LCPC)

The economic development of China's prefecture-level cities has been accompanied by a yearly increase in greenhouse gas and pollution emissions. In this context, to control emissions of greenhouse and polluting gases, China has successively introduced a series of energy conservation and emission reduction policies. In 2010, the National Development and Reform Commission issued the "Notice on the Piloting of Low-Carbon Provinces and Low-Carbon Cities" and successively selected pilot provinces and cities. The pilots were initiated to promote scientific and technological innovation, upgrade growth patterns, and develop green industries (Liu and Qin 2016). The first round of pilots was implemented from 2010, with 13 provinces and cities selected, including Guangdong, Liaoning, Hubei, Shaanxi, Yunnan, Tianjin, Chongqing, Xiamen, Shenzhen, Hangzhou, Nanchang, Guiyang, and Baoding. The second round of pilots was implemented from 2013, covering 29 provinces and cities[3] including Hainan Province, Beijing and Shanghai. In addition, 28 other cities were selected for the third round of low-carbon pilots in 2017.

Overall, the LCPC has achieved positive results in reducing CO_2 emissions (Song et al. 2018), but there

[3] Beijing, Shanghai, Hainan, Shijiazhuang, Qinhuangdao, Jincheng, Hulunbeier, Jilin, Daxinganling, Suzhou, Huaian, Zhenjiang, Ningbo, Wenzhou, Chizhou, Nanping, Jingdezhen, Ganzhou, Qingdao, Jiyuan, Wuhan, Guangzhou, Guilin, Guangyuan, Zunyi, Kunming, Yan'an, Jinchang, and Urumuqi.

are some institutional weaknesses, especially the lack of a clear definition of low-carbon pilot areas, an effective evaluation system and comprehensive development goals and the implementation of multiple parallel programs that confuse the process (Khanna et al. 2014). In turn, local governments lack awareness over the progress of the low-carbon economic transition and clarity surrounding the concepts of energy conservation and a circular, low-carbon, sustainable economy. This irrational design and consequent implementation problems lead to distortions in resource allocation and efficiency losses, which can easily lead to a green paradox (Sinn 2008).

At the pilot region level, the LCPC imposes clear CO_2 emission reduction requirements (Feng et al. 2021) but advocates only voluntary reductions in other emissions such as SO_2 (Song et al. 2021). Although most pilot regions use a combination of three regulatory tools, namely, mandates, market tools and voluntary initiatives, to pursue policies (Wang et al. 2015), the specific implementation process uses mainly mandates (Xu and Cui 2020): for example, shutdowns of enterprises violating CO_2 emission standards, setting of mandatory CO_2 emission intensity targets per unit of GDP, and delegation of CO_2 emission control to lower levels of government and enterprises (Song et al. 2021). In addition, government officials in the pilot regions generally regard the central government's assessment targets for CO_2 emission reduction as their top priority because compliance affects their personal careers. In addition, they pay no attention to emissions other than those targeted for assessment unless they become components of the higher-level assessment (Qi 2013; NDRC 2014). As a result, the intensity of CO_2 emission control may be greater than that of SO_2 emission control in low-carbon pilot regions in China.

For enterprises, as rational economic agents, the optimal choice in complying with the LCPC is to increase their investment in CO_2 treatment. This inevitably requires significant financial support, forcing enterprises to redirect their environmental funds to reducing CO_2 emissions. However, many enterprises in heavily polluting industries have limited environmental protection expenditures because of financial and technological constraints

(Liu et al. 2021, and enterprises may reconfigure these expenditures in the presence of regulation. This may make it difficult to increase capital investment in the treatment of SO_2 in line with increases in enterprise production. Thus, the implementation of the LCPC and increase in investment in CO_2 control is likely to be accompanied by a crowding-out effect on investment in SO_2 control, with SO_2 emissions among heavy polluters in pilot areas correspondingly increasing.

2.2. Research hypotheses

Drawing on the framework of Berman and Bui (2001) and Liu et al. (2021), we construct a production function that includes "quasi-fixed" input factors, calculate firms' pollution emissions, and then introduce environmental regulations into the pollutant function. In particular, according to Brown and Christensen (1980), "quasi-fixed" input factors can be determined by exogenous constraints. As the main tool for the LCPC, the command-and-control policy requires firms to meet emission standards by a deadline, and firms must invest more in CO_2 emission control in the short term or have their operations suspended or even shut down. Therefore, we consider the pollutant treatment inputs for LCPC compliance to be "quasi-fixed" input elements.

Assume that a cost-minimizing heavy polluter operates in a perfectly competitive market. The capital quantity *k* is the sum of the "quasi-fixed" input z(z= z_c+z_s) and the fixed input *u*. The production function has the following form:

$$q = f(u, l, z_c, z_s) \quad (1)$$

where *q* is the output, l is the labor input, and z_c, z_s are the CO_2 treatment input the SO_2 treatment input of the LCPC, which we consider "quasi-fixed" input factors. We use a linear equation to approximate:

$$q = \eta + \alpha u + \beta l + \tau（z_c + z_s） \quad (2)$$

Referring to the Levinson (2009) approach, total emissions of pollutants E are assumed to be:

$$E=v*q \tag{3}$$

In the above equation, v is the pollutant pollution emission intensity, and q is the output. Equation (2) brought into equation (3) gives:

$$E = v\eta + v\alpha u + v\beta l + v\tau\,(z_c + z_s) \tag{4}$$

Referring to Li and Peng (2013), we can simplify the effect of environmental regulation (R) on pollution emissions as:

$$E = \delta + \mu R \tag{5}$$

The impact of environmental regulation (R) on pollution emissions is achieved through the following mechanisms:

$$\frac{dE}{dR} = v\alpha\frac{du}{dR} + v\beta\frac{dl}{dR} + v\tau\frac{dz_c}{dR} + v\tau\frac{dz_s}{dR} \tag{6}$$

The input factor market is assumed to be perfectly competitive, so any change in environmental regulation will not affect factors l and u. In addition, the pollutant emission intensity is determined by the firms' emission reduction technology and emission reduction equipment, which are not affected by the environmental regulation in the short run. Therefore, the first and second terms in equation (6) are dropped, leaving the third and fourth terms. These terms reflect the impact of the LCPC on the "quasi-fixed" CO_2 and SO_2 treatment inputs, respectively. Because the LCPC regulates CO_2 more strongly than SO_2 emissions, i.e., $dR_c > dR_s$, $dz_c > dz_s$. Becase z= z_c+z_s, in the case of z remaining unchanged, enterprises can only control the "quasi-fixed" SO_2 treatment inputs (z_s, i.e., SO_2 governance input) by crowding out "quasi-fixed" CO_2 treatment inputs.

Therefore, with z(z= z_c+z_s) held constant, $z_c > 0$ and $z_s < 0$. Hence, $\frac{dz_c}{dR}>0$ and $\frac{dz_s}{dR}<0$.

In addition, it has been shown (Copeland and Taylor 2013) that dE/dz>0, so that we can derive $\frac{dE_C}{dR} > 0$ and $\frac{dE_S}{dR} < 0$. It is clear that the LCPC has a crowding-out effect on the "quasi-fixed" SO_2 control inputs. If the "quasi-fixed" SO_2 control input is reduced, SO_2 emissions increase. Based on this, this paper proposes the following.

Hypothesis 1: Low-carbon pilot policies aggravate SO_2 emissions by heavy polluters.

Hypothesis 2: Low-carbon pilot policies increase CO_2 inputs and inhibit SO_2 inputs among heavy polluters.

In addition, in China's low-carbon pilot regions, financial support is an important institutional arrangement for CO_2 governance. The low-carbon planning programs of the pilot regions have proposed various low-carbon financial policies to reduce CO_2 emissions, including special funds for low-carbon development; industry subsidies, preferential loans with reduced interest rates, and specific loan funding arrangements for CO_2 reduction; and low-carbon tax exemptions. These financial policies can increase investment in low-carbon projects and direct more capital to low-carbon industries and production processes by allocating capital among different types of industries, thus alleviating the financing constraints that enterprises may face and helping them reduce their CO_2 emissions (Wang et al. 2019). This low-carbon finance policy focuses on management of CO_2 emissions and requires enterprises to meet certain treatment input requirements for CO_2 reduction. However, the LCPC does not set out a financial support policy for reducing SO_2 emissions; thus, enterprises in high-pollution industries are more willing to invest in governance to meet CO_2 emission standards and to complete the tasks assigned by local governments but less willing to invest in governance of SO_2 and other pollutants, which may exacerbate SO_2 emissions. Accordingly, this paper proposes the following.

Hypothesis 3: Low-carbon pilot policies related to financing lead heavy polluters to increase their CO_2

treatment inputs and inhibit SO_2 treatment inputs through a crowding-out effect on SO_2 reduction inputs.

3. Data and empirical strategy

3.1. Data sources

To comprehensively examine the impact of the LCPC on the SO_2 emissions of heavily polluting enterprises and its influence mechanism, this paper integrates multiple sets of statistical data and finally integrates them to construct a comprehensive database including Chinese industrial enterprise data, enterprise pollution data, and municipal-level statistics. The details are as follows.

First, we use data on Chinese industrial enterprises. The data come from the National Bureau of Statistics, covering all industrial enterprises above a certain size. This database contains basic information such as the enterprise name, legal person code, enterprise address and many financial indicators such as total assets and sales. This database, which offers the advantages of a large sample size and rich information, has been widely used in recent studies. Referring to Brandt et al. (2012, 2017) and others, the following processing was performed on the database of industrial enterprises before matching: (1) enterprises with duplicate legal person codes were eliminated; (2) enterprises whose data do not comply with general accounting standards (e.g., had current assets exceeding total assets, net fixed assets greater than total assets, or a missing number of employees) were eliminated; (3) enterprises with missing key indicators were eliminated; (4) the 4-digit industry codes from 1998-2014 were standardized according to the industry cross-reference table published by the National Bureau of Statistics; (5) a cross-year panel was constructed through the method of sequential matching; and (6) enterprises with a large number of missing data were removed.

Second, we use Chinese industrial enterprises' pollution data. The China Environmental Statistics Database (CESD) offers the most detailed environmental statistics available in China, covering the whole country, and is considered to be the most comprehensive and reliable environmental microeconomic database in the country (Zhang et al. 2018). The Ministry of Environmental Protection (MEP) has established an environmental information system covering all major emission sources. However, the CESD has long been confidential and was only recently made available to researchers (Chen et al. 2018a). Each company self-reports data on a seasonal basis, which is then compiled by the MEP. Local environmental protection agencies (EPAs) confirm the data quality through unannounced inspections and other monitoring activities. The local EPA then generates a final report that is sent to the provincial EPA. After review and approval, the certification information is sent to the MEP. National and provincial environmental authorities often review local EPAs' statistical work via a variety of methods, including random spot checks. If problems are found, on-site inspections are conducted when necessary. Higher-level governments also directly conduct flight inspections, cross-checks, and on-site verifications of enterprise pollution emissions. The CESD is the most comprehensive environmental set of microdata in China, covering approximately 85% of annual emissions of major pollutants (e.g., SO_2 and COD). The CESD contains basic enterprise information (e.g., enterprise name, legal person code (Chen et al. 2018b), district code and industry code), pollution emissions, environmental equipment (e.g., number of exhaust gas treatment facilities and wastewater treatment facilities), and other environmental information of the enterprise (e.g., pollutant removal, treatment capacity, and operating costs of abatement facilities). For our empirical analysis, we use CESD information on SO_2 emissions, number of SO_2 exhaust treatment facilities (Cole and Elliott 2007), statistical year, ownership type, area code, and industry code.

In terms of other data, we use the annual municipal statistics produced by the National Bureau of Statistics of China and the China City Statistical Yearbook, covering the main socioeconomic statistics of 289 municipalities.

Given that the most recent data from the China industrial enterprise database are available only through 2014, the sample period for this study ends in 2014, and the first- and second-round pilot municipalities are selected as the treatment group. We exclude the third round of pilot cities from our study analysis because they are still in the initial stage of the policy implementation and have limited data available. At the enterprise level, data on SO_2 emissions, nitrogen oxide emissions, the number of CO_2 and other waste gas treatment facilities, and the number of SO_2 waste gas treatment facilities of heavily polluting enterprises were obtained from the CESD, and other data were obtained from the China Industrial Enterprises Database. At the city level, city data were obtained from the China City Statistical Yearbook for previous years. This paper matches the CESD, China industrial enterprise database and prefecture-level city data based on the legal person code, enterprise name and enterprise location. In this paper, only heavily polluting enterprises are retained in the industry screening. To mitigate the influence of outliers on our results, we winsorize all continuous variables at the 1st and 99th percentiles.

3.2. Model specification

The question explored in this paper is the effect of the LCPC on SO_2 emissions from heavy polluters. To address the endogeneity problems commonly faced in the literature, this paper constructs a multiperiod double-difference model using the LCPC as a quasinatural experiment, divides the study population into a treatment group (areas where the policy has been implemented) and a control group (areas where the policy has not been implemented), and removes the time trend. The net effect of the policy implementation is identified by differentiating the time trend before and after policy implementation and the difference between the treatment and control groups to isolate the policy effect from the influence of time-varying and unobservable factors. This method has been widely used in existing policy studies (Song et al. 2019). In this paper, the provinces and cities included in the scope of the first two rounds of low-carbon pilot projects are used as the treatment group, and the remaining provinces and cities are used as the control group to quantitatively assess the effect of LCPC implementation on SO_2 emissions from heavily polluting enterprises. The specific model settings are as follows:

$$\ln(SO_2)_{it} = \beta_1 + \beta_2 DID_{it} + \beta_5 Z + \mu_i + \mu_t + \varepsilon_{it} \tag{7}$$

$post_{it}$ is used to distinguish the years before and after the low-carbon pilot, where $post_{it}$=0 means the year before the pilot and $post_{it}$=1 the year after the pilot; $treat_{it}$=1 indicates areas where the policy has been implemented and $treat_{it}$=0 areas where the policy has not implemented; and DID_{it} is the interaction term between $treat_{it}$ and $post_{it}$, which takes the values 0 or 1. If firm *i* belongs to the low-carbon pilot region in year *t*, DID_{it} is assigned a value of 1 in that year and each year after, and 0 otherwise. β_2 is the focus of the paper: if the coefficient is significantly positive, it indicates that the LCPC increases SO_2 emissions in the treatment group. This indicates that the LCPC significantly increases the SO_2 emissions of heavily polluting enterprises. *Z* represents enterprise and geographical control variables; μ_i represents enterprise fixed effects, μ_t year fixed effects, and ε_{it} the random error term. In the model, $\ln(SO_2)_{it}$ represents the logarithm of SO_2 emissions from enterprise *i* in year *t*.

3.3. Variable selection

3.3.1. Dependent variable

SO_2 emissions ($\ln SO_2$). Drawing on Liu et al. (2021), we use enterprise SO_2 emissions for this indicator. SO_2 most intuitively reflects the enterprise exhaust emission problem and is quantifiable and representative. In the robustness check, this paper also uses nitrogen oxide emission data from the Chinese industrial enterprise database as the explanatory variable to ensure the robustness of the benchmark analysis.

3.3.2. Independent variable

LCPC treatment (*DID*). The key independent variable is the dummy variable *DID*, obtained based on the list of low-carbon cities in the “Notice on Conducting the Pilot Program of Low-Carbon Provinces and Cities” and the time of program establishment.

3.3.3. Control variables

Control variables (Z). Considering that other factors at the enterprise and municipal levels may have potential effects on the SO_2 emissions of heavy polluters, we select a series of enterprise economic characteristics and municipal-level influencing factors as control variables in this paper. (i) Enterprise size (*lnsize*). It has been shown in the literature that larger enterprises make more stable governance investments to meet environmental protection standards for the sustainability of their development (Li and Zheng 2016; Bu et al. 2020). In this paper, the logarithm of total firm capital at the end of the year is used to measure the firm size. (ii) Firm age (*age*). The age of a firm usually represents its maturity, and studies have shown that more mature firms tend to have stronger operational capabilities (Huang et al. 2021). In this paper, the number of years that a firm has been in business since its inception is used to measure firm age. (iii) Firm performance–related variables. Drawing on Cai et al. (2019), this paper controls for both firm capital intensity (*capital*) and firm profit (*profit*) to account for the influence of factors such as firm performance. Capital intensity is expressed as the ratio of the firm's fixed assets to total assets; corporate profit is expressed as the logarithm of the firm's total profit. (iv) Relevant variables at the city level. To account for the possible effects of regional openness, the economic development level and industrial structure changes at the city level on the SO_2 emissions of heavily polluting enterprises (Yu and Zhang 2017; Jin and Shen 2018), this paper controls for foreign investment share (*lncityfdi*), per capita GDP (*lnpgdp*) and industrial structure (*lndustry*). The foreign investment share is the ratio of the total output value of foreign-invested industrial enterprises to the total industrial output value of the region, GDP per capita is the logarithm of GDP per capita at the city level, and the industrial structure is expressed as the share of the secondary industry in GDP at the city level.

Table 1 shows the summary statistics of the main variables used (sample size, mean, standard deviation, minimum and maximum values). Panel A of Table 1 shows the descriptive statistics for the complete sample. Panels B and C of Table 2 show descriptive statistics for the main variables for the treatment and control groups, respectively. On average, approximately 49.34% of the company-year observations are covered by the LCPC during our sample period.

Table 1. Descriptive statistics

	(1)	(2)	(3)	(4)	(5)
VARIABLES	N	mean	sd	min	max
Panel A: Descriptive statistics of full sample					
age	535,515	11.58	9.455	2	39
capital	535,140	0.339	0.234	0	0.784
profit	388,003	8.174	2.046	4.369	11.72
lnsize	535,140	11.10	1.517	8.654	14.09
lncityfdi	527,549	0.192	0.173	0.0111	0.580
lnpgdp	534,762	10.36	0.698	9.046	11.49
lndustry	535,095	3.943	0.147	3.630	4.170
$\ln SO_2$	390,788	7.217	3.837	0.177	12.72
Panel B: Descriptive statistics of treatment group					
age	264,298	12.12	9.514	2	39
capital	264,021	0.334	0.232	0	0.784
profit	188,909	8.235	2.071	4.369	11.72
lnsize	264,021	11.21	1.520	8.654	14.09
lncityfdi	262,098	0.254	0.191	0.0111	0.580
lnpgdp	263,950	10.52	0.704	9.046	11.49
lndustry	263,856	3.934	0.146	3.630	4.170
$\ln SO_2$	185,984	7.134	3.847	0.177	12.72
Panel C: Descriptive statistics of control group					

age	271,217	11.05	9.366	2	39
capital	271,119	0.345	0.235	0	0.784
profit	199,094	8.116	2.021	4.369	11.72
lnsize	271,119	10.99	1.506	8.654	14.09
lncityfdi	265,451	0.131	0.125	0.0111	0.545
lnpgdp	270,812	10.20	0.654	9.046	11.49
lndustry	271,239	3.951	0.147	3.630	4.170
lnSO_2	204,804	7.293	3.827	0.177	12.72

Note: Continuous variables are winsorized at 1% and 99%.

4. Results

4.1. Main results

The results of the baseline regression of the effect of the LCPC on SO_2 emissions are shown in Table 2. $lnSO_2$ is the explanatory variable. Column (1) shows that the coefficient of the core explanatory variable is 0.08 and significant at the 1% confidence level after we add only the core explanatory variable *DID* and the two-way year and region fixed effects, indicating that the low-carbon pilot reform increases the SO_2 emissions of heavily polluting enterprises in the jurisdiction by 8%. The coefficient of the core explanatory variable is 0.138 and significant at the 1% confidence level after we add the firm-level control variables (firm size, age, capital intensity, and profit) in column (2), indicating that the low-carbon pilot reform increases the SO_2 emissions of heavily polluting firms in the jurisdiction by 13.8% after the firm-level variables are controlled for. Column (3) further controls for three indicators reflecting regional economic development (the foreign investment share, GDP per capita and industrial structure of prefecture-level cities), and the coefficient of the core explanatory variable is 0.143 and significant at the 1% confidence level, indicating that the low-carbon pilot reform increases SO_2 emissions among heavily polluting enterprises in the jurisdiction by 14.3% after firm- and prefecture-level variables are controlled for. Overall, this indicates that the LCPC is significantly and positively related to the SO_2 emissions of heavily polluting enterprises, indicating that hypothesis 1 is valid.

Table 2. Baseline results

	(1)	(2)	(3)
DID	0.080***	0.138***	0.143***
	(0.010)	(0.013)	(0.013)
scale_ass		0.105***	0.103***
		(0.007)	(0.007)
profit		0.015***	0.014***
		(0.003)	(0.003)
capital		-0.001	-0.001
		(0.019)	(0.019)
age		0.001	0.001
		(0.001)	(0.001)
lncityfdi			0.447***
			(0.087)
lncityrjgdp			0.032
			(0.026)
lncitycyjg			-0.022
			(0.054)
Constant	10.050***	8.785***	8.533***
	(0.009)	(0.072)	(0.266)
Year FE	YES	YES	YES
Observations	233600	167569	164488
R squared	0.888	0.891	0.892

Notes: This table reports regression coefficients and robust standard errors (clustered within cities and robust to heteroskedasticity) in parentheses for the full sample regression results. Continuous variables are winsorized at 1% and 99%. Firm-year fixed effects are included in the regression estimations. ***, **, and * represent significance levels of 1, 5, and 10%, respectively. These notes apply to all subsequent tables.

4.2. Robustness checks

4.2.1. Parallel trend hypothesis and dynamic test

An important assumption required for the policy assessment using the multiperiod double-difference method is that the time trends of the treatment and control groups would have been the same in the absence of the policy shock, and thus, a parallel trend test of this assumption is required. For this purpose, we set up the following econometric model:

$$ln\,(SO_2)_{it} = \alpha + \beta_2 DID_{it}^{-4} + \beta_3 DID_{it}^{-3} + \cdots + \beta_9 DID_{it}^{4}$$

$$+\gamma Z + \mu_i + \mu_t + \varepsilon_{it} \tag{8}$$

In the model, $DID_{it}^{\pm j}$ is a series of dummy variables, DID_{it}^{-j} takes the value of 1 when the treatment group is in year *j* before the low-carbon pilot reform, and DID_{it}^{+j} takes the value of 1 when it is in year *j* after the low-carbon pilot reform; otherwise, $DID_{it}^{\pm j}$ takes the value of 0. We take the year before the low-carbon pilot reform as the reference category for the coefficient of $DID_{it}^{\pm j}$ in the regression. This coefficient indicates whether there is a significant difference in the trend of SO_2 emissions between the treatment and control groups of enterprises in year *j* before and after the low-carbon pilot reform in comparison with this difference in the control group. To represent the estimation results visually, we present the trend of the coefficient of $DID_{it}^{\pm j}$ in Fig. 1, with the horizontal axis indicating the years before and after the distance from the pilot and the vertical axis indicating the magnitude of the estimated value.

From Figure 1,it can be seen that the coefficients of *DID* are not significant when *j*=-4, -3, -2, and -1, which means that there is no significant difference in the trend of SO_2 emission changes of enterprises in the treatment and control groups before the low-carbon pilot reform, so the hypothesis of parallel trends cannot be rejected. In the time after the low-carbon pilot reform, the coefficient of DID_{it}^{+j} on enterprise SO_2 is significant at the 1% level from the year of reform, which means that the low-carbon pilot reform intensifies enterprise SO_2 emissions basically without a time lag and the effect can last for quite a long period of time.

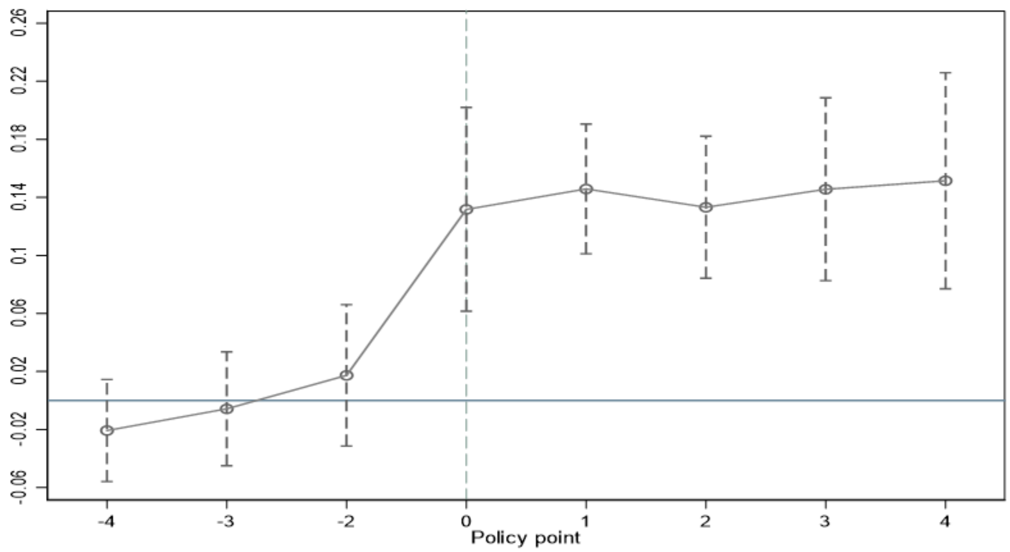

Fig. 1 Parallel trend test. Data source: Drawn by the author

4.2.2. Alternative estimation method

Considering that the sample used in this paper uses matched data at the firm and the prefectural city level, we adopt a standard error clustering analysis to circumvent the heteroskedasticity problem. Specifically, the sample standard errors are clustered at the prefectural city level, and the results show that the significance of the estimated coefficients of the core explanatory variables of the article does not change. The results based on the alternative estimation method are given in row (1) of Table 3, verifying the robustness of the results in Table 2.

Table 3. Robustness tests

	Inspection method		
(1)	Alternative estimation method	Adopting standard error clustering analysis at the prefecture level to circumvent the	0.143*** (0.021)

		heteroskedasticity problem	
(2)	Controls for potential omitted variables	Adding firm- and prefecture-level control variables	0.132*** (0.015)
(3)	Impact of the LCPC on total SO_2 and CO_2 emissions at the municipal level	Using the logarithm of CO_2 emissions from prefecture-level cities	-0.060*** (0.001)
		Using the logarithm of SO_2 emissions from prefecture-level cities	0.028*** (0.003)
(4)	Alternative explanatory variable	Using the logarithm of nitrogen oxide emissions	0.239*** (0.020)

4.2.3. Controls for potential omitted variables

Although we have included firm and year fixed effects and controlled for key indicators at the prefecture level, there is still a possibility of omitted variable bias. Therefore, the firm-level variable corporate indebtedness (*lndebts*) is added to the basic measurement equation. Corporate indebtedness reflects the market's evaluation of a firm's creditworthiness (Meuleman and De Maeseneire 2012), and a moderately indebted operation allows firms to have more abundant funds for activities such as technical equipment improvement and process upgrades. This indicator is measured in this paper by the logarithm of the firm's loan amount to total assets ratio in the current year. We further consider the return on total assets (*ROA*) of the enterprise, expressed as the ratio of enterprise net profit to total assets.

Referring to the method of Xu and Cui(2020), we further add the following prefectural city-level variables: the level of financial development (*Credit*), measured by the ratio of total loans from all financial institutions in the region to regional GDP; the level of infrastructure (*Infrastructure*), measured by the number of telephone subscribers; and the fiscal expenditure of the prefecture-level city (*Fiscal*), measured by the current year's fiscal expenditure. All variables are taken as natural logarithms, except for the level of financial development. The results in row (2) of Table 3 show that the regression coefficients of *DID* change very little in comparison to those in Table 2 after we control for municipality- and firm-level variables, indicating that these potential omitted variables do not impact the basic findings.

4.2.4. Impact of the LCPC on total SO_2 and CO_2 emissions at the municipal level

A potential limitation of using firm-level data is that we can only observe the impact on existing firms. However, environmental regulations may also lead to closures and entry restrictions among industrial firms if the cost of enhanced environmental regulations is so large that firms cannot continue to be profitable (Liu et al. 2021). Therefore, this paper further collects municipal-level data for the analysis, and the estimation results are presented in row (3) of Table 3. The LCPC has a significant effect on SO_2 and CO_2 emissions, the coefficients of the double-difference term of SO_2 emissions in prefecture-level cities are all significantly positive at the 1% level, and the coefficients of the double-difference term of CO_2 in prefecture-level cities are all significantly negative at the 1% level. This indicates that the LCPC decreases CO_2 emissions but increases SO_2 emissions. This result is consistent with the previous analysis. Therefore, the results of the firm-level analysis are reasonable.

4.2.5. Alternative explanatory variable

Other unobservable factors have the potential to confound the conclusions of the main regression model. In this paper, we use other measures of corporate exhaust emissions (e.g., NOx emissions) for robustness testing. This indicator is useful to further rule out confounding factors that affect the explanatory variables. To ensure the robustness of the benchmark results, we replace the explanatory variables in model (1) here with the logarithm of NOx emissions to examine the effect of the LCPC on the SO_2 emissions of enterprises, and the regression results are shown in row (4) of Table 3. The coefficients of the double-difference terms of nitrogen oxide emissions are all significantly positive at the 1% level. This indicates that the LCPC increases the emissions of pollutant gases other than SO_2 gas in the enterprise. This corroborates the robustness of the above baseline analysis.

4.3. Mechanisms

The above analysis shows that the implementation of the LCPC significantly promotes SO_2 emissions from heavy polluters. Therefore, what are the specific transmission mechanisms? In other words, what are the key variables that the LCPC affects to change the level of enterprise SO_2 emissions?

4.3.1. Impact of the LCPC on abatement inputs

Given that we have rich and detailed information on enterprise-level production and pollution in relation to each production process, including the amount of pollution generated in the enterprise's production process and emission reduction facilities, we can measure the enterprise's financial investment in controlling CO_2 and SO_2 (Liu et al. 2021). The total corporate environmental protection input is influenced by corporate output (Lannelongue et al. 2015), on the basis of which we construct a proxy variable for total corporate environmental protection input. In this paper, the provinces and cities included in the scope of the first two rounds of low-carbon pilot projects are used as the treatment group, and the remaining provinces and cities are used as the control group. To analyze the mechanism whereby the LCPC influences enterprise production, we take the increase in the amount of end-of-pipe equipment to control CO_2 and SO_2 emissions is taken as the proxy variable for enterprise capital investment to control CO_2 and

SO_2 emissions, and enterprise output is the proxy variable for total enterprise environmental protection input. The specific model settings are as follows:

$$\ln(M_j)_{it} = \beta_1 + \beta_2 DID_{it} + \beta_3 treat_{it} + \beta_4 post_{it} + \beta_5 Z + \mu_i + \mu_t + \varepsilon_{it} \quad (9)$$

$ln\ (M_j)_{it}$ is the logarithm of the amount of equipment for pollutant *j* of enterprise *i* in year *t*. If *j*=1, $ln\ (M_1)_{it}$ refers to the total environmental protection input of enterprise *i* in year *t*. If *j*=2, $ln\ (M_2)_{it}$ refers to the logarithm of the amount of CO_2 equipment used by enterprise *i* in year *t*; if *j*=3, $ln\ (M_3)_{it}$ refers to the logarithm of the amount of SO_2 equipment used by enterprise *i* in year *t*. The other variables are as in model (1).

From Table 4 (1), we find that the coefficient of total environmental protection investment of heavily polluting enterprises in pilot areas after the implementation of the LCPC is 0.021 and significant at the 1% level, indicating that the low-carbon pilot reform increases the total environmental protection investment of heavily polluting enterprises in the jurisdiction by 2.1%. From Table 4 (2), we find that the reform causes a significant increase of 4.5% in capital investment for CO_2 treatment by heavily polluting enterprises in the jurisdiction; this figure is higher than the growth rate of total environmental protection investment. From Table 4 (3), we find that the reform does not significantly increase capital investment in SO_2 treatment by heavy polluters in the jurisdiction. Under normal circumstances, the growth rates of SO_2- and CO_2-related capital investment and total environmental protection investment are similar; however, implementation of the LCPC makes the growth rate of CO_2-related investment much higher than that of total environmental protection investment, crowding out SO_2-related investment, so that the latter does not increase significantly. This naturally leads SO_2 emissions to increase. Thus, hypothesis 2 is verified.

Table 4. Total investment in environmental protection, capital investment in CO_2 control and capital investment in SO_2 control

	(1)	(2)	(3)
	$\ln(M_1)$	$\ln(M_2)$	$\ln(M_3)$
DID	0.021^{***}	0.045^{***}	0.002
	(0.009)	(0.005)	(0.002)
Constant	5.48^{***}	-0.156	-0.157^{***}
	(0.187)	(0.102)	(0.044)
City FE	YES	YES	YES
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Observations	203673	214800	214800
R squared	0.162	0.371	0.064

4.3.2. Impact of the low-carbon finance policy

The low-carbon pilot regions have all deployed low-carbon financial policies, aiming to provide financial support for the low-carbon transition in the pilot regions. Such policies can facilitate financing for enterprises (Xu and Cui 2020) and alleviate their financial pressure in the process of managing CO_2 emissions, which in turn encourages enterprises to increase their financial investment in managing CO_2 but reduce their investment in SO_2 management. Here, overall credit at the municipal level is used as a proxy variable for low-carbon financial policy to test whether implementation of the LCPC leads enterprises to increase their investment in CO_2 treatment through financial policy and produce a crowding-out effect on investment in SO_2 treatment. In this paper, on the basis of model (9), we take the increase in the amount of end-of-pipe equipment for CO_2 and SO_2 treatment as the proxy variable for the increase in enterprise financial investment in CO_2 and SO_2 treatment and add the loan variable *lnloanct* at the municipal level to construct a triple-difference model as follows:

$$ln\,(M_j)_{it} = \alpha + \beta_1 DID_{it} * lnloan_{ct} + \beta_2 Post_{it} * lnloan_{ct} + \beta_{23} Treat_{it} * lnloan_{ct}$$

$$+\gamma Z + \mu_i + \mu_t + \varepsilon_{it} \quad (10)$$

where $lnloan_{ct}$ is the logarithm of the balance of all loans of financial institutions in city *c* at the end of year *t*.

$ln\ (M_j)_{it}$ is the logarithm of the amount of equipment in enterprise *i* in year *t*. If *j*=1, $ln\ (M_1)_{it}$ refers to the logarithm of the amount of CO_2 equipment used by enterprise *i* in year *t*; if *j*=2, $ln\ (M_2)_{it}$ refers to the logarithm of the amount of SO_2 equipment used by enterprise *i* in year *t*. The regression results are shown in Table 5. The coefficient of the triple-difference term is significantly positive in Table 5 (1), which indicates that the LCPC leads enterprises to increase their capital investment in CO_2 treatment through the corresponding financial policies; on the other hand, Table 5 (2) shows that financial policies inhibit enterprises' capital investment in SO_2 treatment. The possible reason is that the low-carbon financial policies proposed by the pilot regions under their respective low-carbon planning programs mainly target green and low-carbon development, i.e., green industries, projects, and production processes. The financial support for increased inputs SO_2 control is insufficient. At this point, hypothesis 3 is verified.

Table 5. Low-carbon financial policy impacts

	(1) $\ln(M_1)$	(2) $\ln(M_2)$
lncityloan_DID	0.023^{***}	-0.006^{***}
	(0.003)	(0.001)
Constant	-0.216^{*}	-0.244^{***}
	(0.116)	(0.050)
City FE	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
Observations	214800	214800
R squared	0.371	0.064

5. Effect heterogeneity

Although the previous analyses have demonstrated that the LCPC promotes corporate SO_2 emissions, do different types of companies respond differently to this policy? Do different regions implement the policy in different ways?

Do different degrees of fiscal decentralization have an impact on the effectiveness of policy implementation? This section discusses heterogeneity in the policy effect in terms of the intrinsic characteristics of firms, regions, and the degree of fiscal decentralization.

5.1. Heterogeneity by ownership type

Compared with that in developed countries in Europe and the United States, legal and institutional development in developing countries is weaker, and regionally based environmental policies often face greater obstacles and difficulties at the implementation level (Greenstone and Hanna 2014; Li et al. 2016). In the case of enterprises with different ownership types, state-owned enterprises (SOEs) are those invested in or controlled by the central or local governments; SOEs have a significant advantage in resource allocation, especially in terms of receiving financial support (Allen et al. 2005), and are not particularly sensitive to either the compliance cost pressure from environmental regulations or the economic innovation incentives provided by government finance to support environmental protection. In contrast, non-SOEs are self-sustaining, and they face greater expectations to improve their environmental performance through environmental technology innovation (Ren et al. 2019). On the other hand, in terms of information on resource reallocation and technological improvements, nonstate enterprises are more flexible in adjusting and reforming their internal institutional mechanisms and the flow of production factors within the enterprise in response to compliance pressures and are more efficient in reallocating resources under environmental regulations than state-owned enterprises. Therefore, here, the overall sample is divided into three subsamples (state-owned enterprises, private enterprises and foreign enterprises) and the benchmark model re-estimated to further investigate whether the LCPC produces heterogeneous SO_2 emission effects for different types of enterprises.

The estimated results are shown in Table 6. The double-difference term coefficient is significantly positive in the subsample of state-owned enterprises corresponding to column (1); the double-difference term coefficient is significantly positive for the private enterprises in column (2), but the rate of increase is much lower than that in state-owned enterprises. In addition, the coefficient of the double-difference term is not significant for the subsample of foreign firms in column (3). This suggests that there is indeed heterogeneity at the level of enterprise ownership type in the effect of the LCPC on enterprises' exhaust emissions: the LCPC more significantly exacerbates the SO_2 emissions of state-owned enterprises and private enterprises, and the increase is larger in the former than in the latter. The possible reason is that SOEs have stronger path-dependent effects and are generally subject to weaker environmental regulation constraints due to their important responsibilities in local economic development. This is consistent with the findings of Ren et al. (2019), Han and Sang (2018), etc. Ren et al. (2019) find that the emissions trading system has a greater effect on the total factor productivity of non-SOEs than SOEs. Han and Sang (2018) find that SOEs are less motivated to move their products in cleaner directions when facing environmental regulatory constraints because their own political power can reduce the pressure from regulation. For foreign firms, the effect of the LCPC on SO_2 emissions is not significant: it is known that foreign firms have better environmental performance than domestic firms. Because foreign firms are relatively more technologically advanced, have stronger operational capabilities, and are more aware of environmental protection needs, environmental regulations have little effect on their environmental investment and thus no significant effect on their SO_2 emissions. Therefore, non-SOEs' SO_2 emissions are more likely to be exacerbated by the LCPC than SOEs' in high-pollution industries.

Table 6. Heterogeneity by ownership

	(1) State-owned enterprises	(2) Private enterprises	(3) Foreign-owned enterprises

DID	0.275***	0.167***	-0.007
	(0.066)	(0.015)	(0.035)
Constant	9.981***	8.779***	8.443***
	(1.032)	(0.309)	(0.767)
City FE	YES	YES	YES
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Observations	14601	127711	22127
R squared	0.684	0.840	0.850

5.2. Heterogeneity by region

Considering that the economic development conditions and industrial bases of each region differ greatly, the LCPC may have heterogeneous effects on enterprise emissions across regions, and thus, we divide the sample into eastern, central and western regions. The results in columns (1)-(3) of Table 7 show that the coefficients of *DID* are significant at 0.105, 0.178 and 0.274, respectively; i.e., the pilot LCPC reform has a significant effect on enterprise emissions in the east, central region and west of the country. The effect gradually increases from east to west, due to the relatively greater development and stronger business operation capacity in the east, stronger governance capacity of the eastern government, and better policies under the low-carbon pilot reform. The effect of the LCPC in the central and western parts is relatively worse.

Table 7. Heterogeneity by region

	(1) EAST	(2) MID	(3) WEST
DID	0.105***	0.178***	0.274***
	(0.015)	(0.039)	(0.048)
Constant	7.822***	11.188***	11.024***
	(0.351)	(0.654)	(1.011)
City FE	YES	YES	YES
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Observations	105129	37672	21687

R squared	0.861	0.818	0.764

6. Further discussion

6.1. Impact of fiscal decentralization

Fiscal decentralization also has implications for environmental regulation. Fiscal decentralization gives local governments fiscal autonomy and a "residual claim" on revenues so that they can implement public policies that suit their interests relatively independently to achieve their policy targets for CO_2 reduction. Fiscal decentralization gives local governments the right to dispose of resources to ensure the effectiveness of incentives in political promotion tournaments (Zhang 2016). Because the LCPC also involves assessment of local governments, LCPC regional governments have incentives to use the fiscal autonomy granted by fiscal decentralization to meet carbon targets, resulting in fiscal support that inhibits control of SO_2. Fiscal policy focused on reducing CO_2 may crowd out enterprises' SO_2-related investment, which in turn inhibits enterprises' management of SO_2. In short, in low-carbon pilot regions, because of the pressure of performance assessment, local governments are more willing to adopt fiscal tools to reduce CO_2 emissions, which suppresses fiscal support for SO_2 treatment. The higher the degree of fiscal decentralization, the greater is the fiscal autonomy of the region and the fiscal support for reducing CO_2 emissions, which in turn discourages enterprises from investing in SO_2 control.

The existing literature disagrees about how to measure fiscal decentralization, using three main kinds of indicators: expenditure indicators, revenue indicators and fiscal autonomy indicators. This paper draws on the approach of Guo et al. (2020) to construct fiscal decentralization (*FD*) indicators for prefecture-level municipalities. The higher is the degree of fiscal decentralization, the greater the fiscal autonomy of the region, the greater the fiscal support for reducing CO_2 emissions, and the greater the crowding-out effect on the enterprises' investment in managing SO_2 emissions. In this paper, based on model (9), we take the increase in the amount of end-of-pipe equipment to control CO_2 and SO_2 as proxy variables for enterprises' inputs to control CO_2 and SO_2 and add the fiscal decentralization variable *FD* at the municipal level to construct a triple-difference model as follows:

$$ln\ (M_j)_{it} = \alpha + \beta_1 DID_{it} * \mathrm{F}D_{ct} + \beta_2 Post_{it} * \mathrm{F}D_{ct} + \beta_3 Treat_{it} * \mathrm{F}D_{ct} + \beta_4 DID$$

$$+\gamma Z + \mu_i + \mu_t + \varepsilon_{it} \tag{11}$$

where $\mathrm{F}D_{ct}$ is the fiscal weight of municipality *c* in year *t*. $ln\ (M_j)_{it}$ is the logarithm of the amount of equipment in enterprise *i* in year *t*. If *j*=1, $ln\ (M_1)_{it}$ refers to the logarithm of the amount of CO_2 equipment in enterprise *i* in year *t*. If *j*=2, $ln\ (M_2)_{it}$ refers to the logarithm of the amount of SO_2 equipment in enterprise *i* in year *t*. The regression results are shown in Table 8. The coefficient of the triple-difference term is significantly positive in column (1), which indicates that by enhancing financial and taxation support at the municipal level, the LCPC leads enterprises to increase their investment in CO_2 control; on the other hand, it can be seen from Table 8 (2) that the financial and taxation policies do not prompt enterprises to significantly increase their investment in SO_2 control. The possible reason is that the fiscal support policies proposed by the pilot regions in their respective low-carbon planning programs target mainly green and low-carbon development, i.e., green industries, projects and production processes. The fiscal and taxation policies to boost SO_2 inputs are not strong enough.

Table 8. Impact of fiscal decentralization

	(1)	(2)
	$\ln(M_1)$	$\ln(M_2)$
FD_DID	0.336^{***}	0.003
	(0.026)	(0.011)
Constant	-0.543^{***}	-0.497^{***}
	(0.159)	(0.067)
City FE	YES	YES

Firm FE	YES	YES
Year FE	YES	YES
Observations	152170	152170
R squared	0.441	0.085

6.2. Impact of market segmentation

Fiscal decentralization can cause local governments to compete with each other, which in turn causes market segmentation (Deng and Yang 2019). Is there a moderating effect of this market segmentation behavior on the LCPC's influence on enterprise inputs into CO_2 and SO_2 management? In this paper, an interaction term between a local market segmentation indicator and the LCPC indicator is introduced into model (9) to test this conjecture, and a triple-difference model is constructed as follows:

$$ln\,(M_j)_{it} = \alpha + \beta_1 DID_{it} * SEG_{ct} + \beta_2 Post_{it} * SEG_{ct} + \beta_3 Treat_{it} * SEG_{ct} + \beta_4 DID$$

$$+\gamma Z + \mu_i + \mu_t + \varepsilon_{it} \qquad (12)$$

SEG_{ct} is the market segmentation index of city *c* in year *t*. The other indicators are the same as in model (11). The regression results are shown in Table 9. The coefficient of the triple-difference term is not significant in column (1) and significantly negative in column (2), which indicates that the LCPC inhibits enterprise inputs into SO_2 control through the mediating effect of market segmentation, exacerbating enterprises' SO_2 emissions. The possible reason is that LCPC has different assessments of local governments' efforts to control CO_2 and SO_2 intensity, and local governments have more incentives to suppress SO_2 control inputs through market segmentation.

Table 9. Impact of market segmentation

	(1) $\ln(M_1)$	(2) $\ln(M_2)$
SEG_DID	-0.014	-0.040***
	(0.034)	(0.014)
Constant	0.191	-0.549***

	(0.148)	(0.063)
City FE	YES	YES
Firm FE	YES	YES
Year FE	YES	YES
Observations	152170	152170
R squared	0.441	0.085

7. Conclusion

This paper focuses on the impact of the LCPC on the SO_2 emissions of heavily polluting enterprises. The findings include the following: First, the LCPC has significantly exacerbated SO_2 emissions among heavily polluting enterprises in the pilot areas, and the environmental treatment effect of the LCPC needs to be improved. Second, the main transmission mechanism is the loan support provided through low-carbon financial policies under the reform for the treatment of CO_2 inputs of heavily polluting enterprises in pilot areas, which inhibits support for SO_2 treatment inputs. The LCPC has a crowding-out effect, with CO_2 inputs displacing SO_2 inputs in high-pollution industries in the pilot areas, which in turn has increased enterprises SO_2 emissions. Third, the LCPC has significantly aggravated the SO_2 emissions of enterprises across the eastern, central and western regions, on the one hand, and private and state-owned enterprises, on the other, with an increasing trend across these two sets of subsamples. Fourth, it is further found that fiscal decentralization and the market segmentation resulting from fiscal decentralization mediate the effect on enterprise CO_2 control and inhibit inputs into SO_2 control.

The findings of this paper have the following four policy implications.

First, the empirical results of this paper prove that the LCPC increases the SO_2 emissions and has a negative effect on the clean production of heavily polluting enterprises; thus, the ecological and environmental management effect of the LCPC needs to be improved. In the past 20 years, the role of low-carbon technology in promoting economic and social change has become increasingly significant, and many cities around the world have constructed low-carbon zones as an important means of enhancing the competitiveness of cities and even countries. Compared with those of developed countries, the legal and institutional development of developing countries is weaker, and area-based environmental policies often face greater obstacles and difficulties at the implementation level. The results of this paper suggest that the effectiveness of low-carbon policies, a type of area-based environmental policy, needs to be improved in the largest developing countries, and the findings of this study are useful for us to re-examine the effectiveness of enterprise environmental governance under the LCPC.

Second, the results of the mechanism analysis suggest that the loan support provided under the policy for CO_2 treatment inputs in the pilot areas for heavy polluters inhibits loan support for SO_2 treatment inputs. The growth rate of investment in CO_2 mitigation among heavy polluters in the pilot areas is much higher than that in total environmental protection inputs, but the investment growth rate of SO_2 inputs does not increase significantly. This suggests that the design and planning of low-carbon policies should include clearer and more comprehensive planning and support for innovation and technological upgrading to achieve synergistic management of the ecological environment and climate change so that these enterprises can achieve the goal of reducing both greenhouse gas and pollution emissions.

Third, the results obtained based on the heterogeneity analysis show that the LCPC's effects vary greatly by geography, ownership type and level of fiscal autonomy. To strengthen the ecological environment, we should use flexible and appropriate environmental regulations to give firms continuous innovation incentives. This paper finds that the effect of the LCPC varies among firms by ownership, geographical area and fiscal autonomy level: this difference also reflects that the government needs to make environmental policies with greater consideration of different firms characteristics. The design of the LCPC system should take into account these aspects, and in addition to creating a level playing field for less developed regions and nonstate enterprises, the monitoring mechanism can be designed to apply greater compliance pressure on less developed regions, regions with greater fiscal autonomy, and state-owned enterprises.

Fourth, based on further research results, fiscal decentralization and the associated mediating effect of market segmentation promote inputs into enterprise CO_2 governance and inhibit inputs into enterprise SO_2 governance. We should increase marketization in the economy, reduce unnecessary government intervention, and in general leverage the role of the market in resource allocation.

The findings of this paper imply that the LCPC has a negative effect on cleaner production among heavily polluting enterprises and that the ecological and environmental management effect of the LCPC needs to be improved. China's sustained high economic growth for more than 40 years has brought about severe resource and environmental pressure; alleviating this pressure requires continuous efforts and reforms, and the LCPC is one of the flagship efforts among many environmental reforms. A scientific and systematic assessment of the effectiveness of the regional-based LCPC provides experience and inspiration to formulate relevant environmental pollution prevention and control policies in developing countries in the short term; in the long term, it is of great practical significance to help developing countries to build ecological civilization as a millennium plan for sustainable development.

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Author information

Affiliations

School of Economics and Trade, Hunan University, Changsha 410205, Hunan,China

Ping Guo, Jin Li, Renrui Xiao & Donghao Duan

School of Economics and Trade, Hunan University of Technology and Business, Changsha 410205,Hunan,China

Jinsong Kuang & Yifei Zhu

School of Public Administration, Hunan University, Changsha 410205, Hunan,China

Baocong Huang

Contributions

Ping Guo: conceptualization, supervision; Jin Li: methodology, software;,formal analysis;,data curation,writing—original draft, writing—review and edit,visualization;Jinsong Kuang: methodology; writing—review and edit; validation; funding acquisition;Renrui Xiao: validation, writing—review and edit; Donghao Duan: methodology, validation; Baocong Huang: methodology, validation; Yifei Zhu: methodology, validation.

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