International Review of Economics and Finance 94 (2024) 103400

Contents lists available at ScienceDirect

International Review of Economics and Finance

journal homepage: www.elsevier.com/locate/iref

Cleaner production promotion law and pollution: Firm level evidence from China☆

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ARTICLE INFO

JEL classification:
Q52
Q58

Keywords:
Pollution emission
Cleaner production
Sulfur dioxide
Firm heterogeneity
Porter effect

ABSTRACT

Using the formulation and implementation of China's Cleaner Production Promotion Law (CPPL) in 2003 as a quasi-natural experiment and a unique combined dataset of Annual Survey of Industrial Production Database and China Industrial Enterprise Pollution Emissions Database over 1998–2013, we investigate the impact of ex-ante prevention policies on firm pollution emissions. Our DID and DDD results show that: 1) The CPPL has significantly reduced firm's per unit of output emissions of SO2 and COD; 2) China's CPPL reduced firm pollution emissions intensity by reducing resource consumption, increasing firms' TFP and the number of green patents (Porter effect), and increasing the total amount of pollutants removal per unit of output; 3) The impact of CPPL on pollution shows modest firm heterogeneity, with larger effects on SOEs and on large-scale enterprises. The conclusions of this paper reveal that China's CPPL, as a formal rule of law regulation and ex-ante prevention policy, not only reduces the pollution intensity of enterprises from the input side, but also stimulate the Porter effect, and reduces the pollution removal level.

1. Introduction

Balancing economic development and environmental protection is an important issue for sustainable economic growth, especially for developing countries like China. (Byrne, 1997; Selden & Song, 1994). Under the pressure of maintaining rapid economic growth, developing countries are more likely to deviate from sustainable development, making environmental issues particularly prominent (Serageldin et al., 1994). In China, the rapid economic development in recent years has been accompanied by per capita resources shortage and severe environmental degradation. According to the 2018 Environmental Performance Index (EPI) released by Yale University and Columbia University, China scored only 50.74 (out of 100) of the 180 participating countries, ranking 120th. The accelerated industrialization and urbanization have further brought great challenges to China's environmental protection. In such context, it is urgent to shift the growth mode from factor driven to innovation driven.

The importance of environmental problems has inspired a lot of attentions (e.g., Eisenbarth, 2017; Wu et al., 2017; Chen et al.,

☆ This paper is supported by the National Natural Science Foundation of China (72273125), the Philosophy and Social Science Planning Project of Zhejiang Province (22NDQN203YB, 22ZJQN13YB), the Start-up Foundation of Hangzhou Normal University (Project Name: Research on the Emission Reduction Effect and Mechanism of Green Credit) and the Fundamental Research Funds for the Central Universities.

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https://doi.org/10.1016/j.iref.2024.103400
Received 15 December 2023; Received in revised form 6 April 2024; Accepted 16 June 2024
Available online 17 June 2024
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2018; Li et al., 2020). However, existing literatures have mainly focused on end-of-pipe regulations, with few studies focusing on ex-ante prevention policies. Moreover, empirically analyzing the impact of ex-ante prevention policies on firm-level pollution emissions has been difficult due to the lack of micro level data. This study is designed to fill in this literature gap by evaluating the influence of ex-ante prevention policy on firm pollution emissions. Specifically, combing a unique dataset from the Annual Survey of Industrial Production (ASIP) Database and China Industrial Enterprise Pollution Emissions (IEPE) Database, we systematically explore the impact of China's Cleaner Production Promotion Law (CPPL), the most representative ex-ante prevention policy in China, and attempts to make a useful supplement to existing studies. China's CPPL was enacted on January 1, 2003. This law is the most representative ex-ante prevention policy in China with the aim to promote cleaner production and protect environment by increasing the efficiency of resource utilization, decreasing and avoiding the generation of pollutants. Specifically, the law requires improving design, using clean energy and raw materials, adopting advanced technology and equipment, improving management and comprehensive utilization, etc. The law controls pollution from the source, improves resource utilization efficiency, reduces or avoids the generation and discharge of pollutants in the process of production, service and product use, to reduce or eliminate the impact on human health and environment.

For a long time, end-of-pipe treatment is mostly used as environmental governance in China. The end-of-pipe treatment means the pattern of treatment after pollution to meet the pollutant emission standards. The treatment pushes up the pollution control cost, making it difficult to eliminate pollution fundamentally and leaving potential problems for future environmental protection and economic development. In contrast, the ex-ante pollution control reduces or eliminates pollution emission from the sources by discharging the production technologies with high technology resource consumption and heavy environmental pollution.

Chinese government implemented the CPPL in 2003 in order to promote cleaner production, improve resource utilization efficiency, reduce and avoid pollution generation, protect and improve the environment, ensure human health, and promote the sustainable development of economy and society. Cleaner production is the most typical ex-ante control policy in China and an overall environmental strategy for prevention. The enforcement of the CPPL provides us a unique natural experiment to study the impact of ex-ante prevention policy on pollution emission.

Based on a unique combined dataset of ASIP Database and IEPE Database from 1998 to 2013, this paper utilizes both the difference-in-differences (DID) model and the difference-in-difference-in-differences (DDD) model to study the impact of China's CPPL on firm pollution emission. We focus on SO2 and COD, and find that the CPPL has significant effects on these two pollution. Existing research has pointed out that a logarithmic transformation by adding 1 to all continuous variables may yield estimates without a natural interpretation and is prone to errors in sign on expected values. Thus, we followed Chen and Roth (2023) and used Poisson QMLE estimation to conduct a robustness test, and the results indicates that this transformation does not alter the results of this paper.

Parallel trends of treatment and control groups show there is a clear common trend between two groups before the implementation of the law and there is a divergence after the implementation. Furthermore, the results of dynamic effect estimation show that the impact of CPPL is not significant before 2003 and shows a significant negative impact in the following years. Both the parallel trends and the dynamic effect indicate the validity of the results.

One potential explanation for the results is that some omitted events coinciding with the enactment of CPPL could be the underlying cause of changes in pollution emission such as China's accession to the WTO, the establishment of permanent normal trade relations between China and the United States, the regulations of foreign investment policies in China and Chinese local industrial policies. Thus, we step by step control the impact of these events to rule out possible explanations. We further conduct a series of placebo tests. Our results are qualitatively robust to these tests.

Since the introduction of China's CPPL at the national level, each province has formulated supporting policies in different times. We use the DDD approach, where we compare changes in relative emissions of firms across industries and then contrast this effect for different provinces experiencing local regulations at different points.

Our results show that (1) The SO2 and COD emissions per unit of output at the enterprise level has decreased more in the provinces where the local cleaner production law has been implemented, which is consistent with our baseline results. (2) China's CPPL reduces firm SO2 and COD emissions by reducing the inputs of total coal consumption intensity (per unit of output) and fuel oil consumption intensity, and by increasing the total factor productivity (TFP) and the number of green patents of affected firms has increased significantly, which means that the Porter effect has been stimulated. In the meanwhile, CPPL increases SO2 removal per unit of output, the number of waste gas treatment facilities, the number of desulfurization facilities and lifting the desulfurization capacity of desulfurization facility. (3) There are modest firm heterogeneities in the effect of the law. Specifically, the effect of the law on SOEs and large firms are greater.

Our results suggest that the deceased consumption of resource inputs, TFP and green innovation upgrading and the increased ability of pollution treatment are three possible mechanisms that help explain the overall negative relation between CPPL and firm pollution. Further, understanding the heterogeneous impact of cleaner production laws will help improve China's CPPL and better guide enterprises to reduce pollution and promote environmental protection.

This paper contributes to the literature on environmental regulation on three grounds. To our knowledge, we are the first to comprehensively investigate the effects of China's CPPL on firm pollution. Empirical evidence on pollution emission has primarily focused on the end-of-pipe regulations at industry or region level (e.g. Li et al., 2020; Zhang et al., 2018). However, few studies explore the effect of ex-ante pollution control policy. Cleaner production policy aims to reduce pollution emissions from the source, which helps to reduce pollution fundamentally and is a better way to control pollution. As the first country in the world to formulate a cleaner production promotion law, China is by far the only country with a cleaner production promotion law. By focusing on the world's largest developing country, we study the impact of China's CPPL, a formal ex-ante prevention legal regulation, on firm pollution, which has practical significance and implications for the prevention and control of pollution for other developing countries.

Second, this paper studies the impact of environmental regulation on pollution emissions at the firm level by using a unique combined dataset of ASIP Database and IEPE Database from 1998 to 2013. Existing papers mainly focuses on the impact of environmental regulation on the pollution discharge at the industry level or province level, such as Cai et al. (2016), Chen et al. (2018). The study of the relationship between environmental regulation and pollution at the firm level is extremely lacking because of the difficulty in obtaining the pollution discharge data at firm level. With ASIP Database and IEPE Database, we are able to explore the effect of environmental regulation on firms' pollution behavior. The advantage of using firm-level data to assess the effectiveness of environmental regulations in China in reducing emission activity are two folds: First, since firms are the main body of pollution discharge, the research on the impact of environmental regulation on firms' pollution behavior can accurately clarify the microcosmic effect of environmental regulation. Second, firm level data allows us to examine rich heterogeneity effects of the CPPL on firms' pollution emission, such as firms with different productivity or scale.

Third, we use a DID and triple difference approach which provides us a better identification strategy. With the implementation of China's CPPL as a quasi-natural experiment, the DID and triple difference allows us to control for unobserved provincial and industry characteristics. Parallel trends test, dynamic effect and placebo tests further confirmed the validity of our results.

The reminder of the paper is organized as follows: Section 2 reviews relevant literature. Section 3 introduces the background of China's CPPL. Section 4 presents empirical strategy including empirical specification, variable and data. Section 5 reports main empirical results. Section 6 conducts mechanisms analysis. Section 7 concludes.

2. Literature review

Our study is closely related to two strands of literature. First, this paper is related to the study on the effect of environmental regulation. Existing environmental regulations can be divided into three types according to the regulatory attributes: administrative regulation, market regulation and legalized regulations. Typical administrative regulations include environmental administrative penalties and vehicle restrictions (Viard & Fu, 2015), environmental monitoring (Zhang et al., 2018), and clean technology R&D subsidies (Acemoglu et al., 2016). Typical market-based regulations include emissions trading systems (Fowlie et al., 2012). Typical legalized regulations include "Environmental Protection Law of the People's Republic of China", "Water Pollution Prevention Law", "Air Pollution Prevention Law", environmental protection courts, etc.

The impact of environmental regulation is extensive, such as pollution heaven (Dong et al., 2012; Marconi, 2012; Millimet & Roy, 2016), productivity and pollution cost (Murty et al., 2006; Shapiro & Walker, 2018). Empirical evidence about the China's 11th Five-Year Plan's water pollution reduction mandates show that the regulation has not taken effect in an improvement in overall water quality since spatially differentiated regulation stringency shift water-polluting activities toward areas where the environmental regulations are looser (Chen et al., 2018; Wu et al., 2017). Li et al. (2020) shows the enforcement of China's high-quality gasoline standards significantly reduce air pollution. As for mechanisms, the results show that, on the one hand, environmental regulations have increased production costs of enterprises and reduced their competitiveness (Murty et al., 2006); on the other hand, environmental regulations have forced firms to invest in innovation, increase productivity and competitiveness, and compensate for the rising costs of environmental regulations, namely Porter effect holds (Porter, 1991).

Second, emerging papers focus on a series of factors affecting pollution emissions besides environmental regulations, such as economic growth, trade liberalization and FDI. The typical environmental Kuznets hypothesis holds that economic growth has an inverted U-shaped effect on environmental pollution (Grossman & Krueger, 1991; Shen, 2006). Trade liberalization affects pollution through scale effects, structure effects and technological effects (Dean & Lovely, 2010; Grossman & Krueger, 1995; Mazhar & Majeed, 2023). FDI affects firm pollution in developing countries through pollution heaven effect (Bao et al., 2011; Kwablah, 2023).

As research advances, more and more studies are focusing on the impact of preventive policies on the environment, especially the impact of technological innovation and front-end preventive policies. For example, Chen et al. (2022) find that innovation significantly reduces firms' pollution discharges through decreasing energy consumption and misallocation of resources. Zhou and Liu (2024) reveal that firms' digital technology transformation significantly reduces CO2 emissions. However, research on how preventive environmental policies affect corporate pollution is extremely rare. With an analytic hierarchy process (AHP), Shi et al. (2008) studies the barriers to the implementation of cleaner production in Chinese small- and medium-sized firms.

This paper contributes to the existing research in three aspects: First, unlike existing research that focuses on end-of-pipe governance policies, we focused on the impact of ex-ante prevention policies on pollution emissions among the first batch. Second, this paper applies firm level data and analyzes the impact of the CPPL on firm pollution emissions. Due to the lack of firm-level pollution data, existing studies are unable to deeply analyze the impact of cleaner production policies on firm pollution emissions. The firm-level pollution data allows us to analyze in detail the rich firm heterogeneity effects of the impact of CPPL. Firm heterogeneity is a key feature of new trade theory. The study of firm heterogeneity allows us to subdivide different firms in the same industry and explore which firms are vulnerable to the cleaner production policy. Third, we use the quasi-natural experiment of China's CPPL in 2003, and applies DID model and the DDD model to identify the causality.

3. Background of China's CPPL

On June 29, 2002, the 28th meeting of the Standing Committee of the Ninth National People's Congress of the People's Republic of China passed the Cleaner Production Promotion Law, which came into force on January 1, 2003. On February 29, 2012, the twenty-fifth meeting of the Standing Committee of the Eleventh National People's Congress reviewed and adopted the Decision of the Standing Committee of the National People's Congress on Amending the Cleaner Production Promotion Law, and the revised China's CPPL came into effect on July 1, 2012. Due to the availability of data, this paper focuses on and reviews the China's CPPL formulated in 2002.

The CPPL points out that cleaner production refers to continuous measures to improve design, use clean energy and raw materials, adopt advanced process technology and equipment, improve management and comprehensive utilization to reduce pollution from the source and improve resource utilization efficiency to reduce or avoid the generation and discharge of pollutants in the production, service and product use and for the purpose to reduce or eliminate the harm to human health and the environment. China's CPPL contains six chapters, which are the general rules, the promoting measures of cleaner production, the implementation of cleaner production, incentive measures, legal responsibilities, and supplementary articles. In total, it includes 40 specific provisions, as shown in Table A1-A4 in Appendix.

The CPPL promotes cleaner production mainly through 11 measures, which are fiscal and taxation policies, preparation of implementation plans, increased capital investment, establishment of service systems, publication of guidance catalogs, elimination of backward production, establishment of environmental protection marks, support of technology and product research and development, establishment of cleaner production courses, priority purchase of environmental protection products, and announcement of companies that failed to meet the standards. See Table A1 in the Appendix for details.

The CPPL mainly implements cleaner production in 10 aspects, namely new construction projects, technological transformation, products and packaging, large-scale electromechanical products, agriculture, service enterprises, constructional engineering, mineral resources, waste recycling, cleaner production testing and audit. See Table A2 in the Appendix for details.

The CPPL mainly encourages cleaner production from five aspects: establishing a recognition system, giving financial support, arranging fund support, tax incentives, and regarding costs related to cleaner production as operating costs. For detailed incentive measures, see Table A3 in the Appendix.

In addition, the CPPL also lists five cases of legal liability for failure to perform cleaner production as shown in Table A4 in the Appendix. Those who fail to perform cleaner production duties, who fail to publicize energy consumption or the generation and discharge of key pollutants, who do not mark the ingredients of the product materials or do not mark them truthfully, who produce and sell construction and decoration materials with toxic and hazardous substances exceeding national standards, and who do not implement compulsory cleaner production audits or commit frauds in cleaner production audits, or companies that implement compulsory cleaner production audits do not report or fail to report the audit results truthfully, all will be punished by law.

It can be seen from above analysis that China's CPPL has a complete set of supporting implementation measures, including both incentives and punishments measures, and are supposed to be effective in implementing cleaner production.

4. Empirical strategy

4.1. Empirical specification

4.1.1. Baseline specification

To investigate the impact of China's CPPL on firm pollution emissions, we constructed a difference-in-difference estimation framework, as shown in model (1).

$$\ln Pollution_{ft} = \alpha + \theta Post_t \times Treat_i + \varphi \ln X_{ft} + \nu_f + \nu_t + \varepsilon_{ft} \quad (1)$$

Where f represents firm, t represents year. $Pollution_{ft}$ represents firm pollution intensity, calculated by emissions per unit (1000 RMB) of output. $Post_t$ is a time dummy variable indicating the implementation of the CPPL in year t. That is, $Post_t$ equals 0 for the years before the law was introduced (1998–2002), and 1 for the first year and all the subsequent years of the law (2003–2013). $Treat_i$ is a dummy variable of the treatment group, and the high-polluting industry before the impact of the event (i.e. 2001) is used as a proxy. For details, see the "Variable definition" sub-section of this section. X_{ft} is a set of control variables at the firm level, including firm size (number of employed workers), firm age, firm capital intensity (fixed assets per capita), asset-liability ratio, export value, etc. To control time-invariant firm characteristics and annual economic shocks, model (1) includes firm fixed effects ν_f, and year fixed effects ν_t. ε_{ft} is a random disturbance. The estimated coefficient, θ of the intersection of the dummy variable $Post_t$, and the treatment group variable $Treat_i$, $Post_t \times Treat_i$, is the focus of this paper. It measures the impact of the CPPL on the level of emissions for firms in high-polluting industry relative to firms in the low-polluting industry (first difference) after the promulgation of China's Cleaner Production Promotion Law compared to before it was promulgated (second difference).

4.1.2. Flexible estimation model

This paper transforms model (1) to obtain a more flexible estimation equation, which can reflect the annual change of firm pollution emissions from high pollution industries. The specific specification is as follows:

$$\ln Pollution_{ft} = \alpha + \sum\nolimits_{t=1998, t\neq 2003}^{2013} \theta_t \times \text{year}_t \times Treat_i + \varphi \ln X_{ft} + \nu_f + \nu_t + \varepsilon_{ft} \quad (2)$$

Where $year_t$ is a dummy for year t. θ_t measures the change in pollution of firms in high-polluting industries relative to low-polluting industries in year t relative to the initial year of the sample (1998). The reference year is 2003, when the CPPL came effect for the first time. In particular, if China's CPPL comes into effect, θ_t should be expected to become significant in 2003 and later, but was not significant before 2003, otherwise the CPPL has no effect.

4.1.3. DDD specification

Some provinces have introduced local cleaner production regulations, while others do not. So, will the introduction of relevant local regulations enhance the effect of CPPL? To answer this question, we exploit the fact that after the introduction of China's CPPL at the national level, various provinces have successively issued local cleaner production policies, and conduct a DDD (triple difference) estimation as one of our main specifications. Based on model (1) and whether each province implemented local cleaner production policies, the DDD estimation specification is as follows,

$$\begin{aligned} \ln Pollution_{ft} = \alpha + \chi Post_t \times Treat_i \times TreatP_p + \theta Post_t \times Treat_i \\ + \varphi Treat_i \times TreatP_p + \eta Post_t \times TreatP_p + \varphi \ln X_{ft} \\ + \nu_f + \nu_t + \varepsilon_{ft} \end{aligned} \tag{3}$$

Where $TreatP_p$ is a provincial dummy variable representing whether provincial cleaner production policy was implemented in province p, with p = 1 for Yes and p = 0 for No. $Post_t \times Treat_i \times TreatP_p$ is the triple difference term, of which the estimated coefficient χ measures the change of firm pollution in high-polluting industry relative to low-polluting industry (first difference), in the years after the implementation of China's CPPL, compared with in previous years (second difference), in the provinces that implemented local cleaner production promotion policy relative to those that did not implement (third difference). χ is a key coefficient of our interest in the paper, and a negative sign indicates China's CPPL facilitates reduction in firm pollution. Model (3) incorporates the intersections of any two of the three single terms of the triple intersection term $Post_t \times Treat_i \times TreatP_p$, namely $Post_t \times Treat_i$, $Treat_i \times TreatP_p$, $Post_t \times TreatP_p$. Since the model controls province by year fixed effects, the coefficient of $Post_t \times TreatP_p$ was omitted. The meaning of the coefficient θ of $Post_t \times Treat_i$ is completely consistent with model (1), and is expected be negative if the law has significant effects. In addition, model (3) controls the same control variables and fixed effects as model (1).

4.2. Variable definition

4.2.1. Outcome variable

The outcome variable in this paper is firm level pollution emission intensity, that is, the amount of pollution emission per unit (1000 RMB) output (total emissions divided by the gross industrial output of the firm). Pollution indicators include sulfur dioxide (SO2), and chemical oxygen demand (COD).

4.2.2. Key independent variable

The core explanatory variables of this paper are the intersection of the time dummy variable (*Post*) of the introduction of the CPPL and the industry dummy variable of the treatment group (*Treat*), and the triple intersection of the two and the provincial dummy variable (those implemented local cleaner production policy VS those did not).

Industry dummy variable of treatment group (*Treat*). In the baseline regression, we consider the top 50% of industries in 2001 in terms of pollution intensity (sulfur dioxide emissions per unit output, i.e., industry sulfur dioxide emissions divided by gross industrial output) as high-polluting industries. As robustness checks, the top 50% of industries in terms of pollution intensity in 1999, 2000 and 1998–2002 as a whole are regarded as treated groups respectively.

Time dummy variable of the event (*Post*). The CPPL of China was revised and adopted at the 28th meeting of the Standing Committee of the Ninth National People's Congress on June 29, 2002, and came into force on January 1, 2003. Therefore, *Post* is equal to 1 in 2003 and the years afterwards, and is equal to 0 in previous years.

Provincial dummy variable of whether a province introduced local cleaner production promotion policy ($TreatP_p$). During the sample period, a total of 15 provinces implemented supporting cleaner production policies, namely Zhejiang, Jiangxi, Chongqing, Hebei, Guizhou, Guangxi, Shandong, Inner Mongolia, Henan, Sichuan, Yunnan, Gansu, Qinghai, Ningxia, Xinjiang. For these provinces, $TreatP_p$ is equal to 1 and $TreatP_p$ is equal to 0 otherwise.

4.2.3. Control variables

In the baseline regression, we include a series of control variables that change over time at the firm and industry levels as follows.

(1) The number of employees to control the size of the firm (*labor*).
(2) Firm age which is equal to year minus the year of establishment of the firm, to control the experience of the firm (*age*).
(3) Fixed assets per capita, which is measured by firm fixed assets divided by the total number of employees to control capital intensity of the firm (*klr*).
(4) Asset-liability ratio, measured by total debt divided by total assets to firm's ability of using debt to promote business operations (*lev*).
(5) Export value to control the ability of the firm to export to international market (*export*).
(6) Input tariff (*itariff*). Following the methods of Amiti and Konings (2007), Goldberg et al. (2010), Topalova and Khandelwal (2011), Liu and Qiu (2016), we use the 2002 input-output table to construct industry-level input import tariffs as shown below.

$$InputT_{it} = \sum_j Share_{ij} \cdot OutputT_{jt} \tag{4}$$

Where $InputT_{it}$ represents input tariff of industry i in year t. $OutputT_{jt}$ is the output tariff of industry j in year t, which is calculated based on simple weighted average of six-digit HS codes. $Share_{ij}$ is the direct input coefficient of industry j to industry i calculated using the input-output table.

(7) Output tariff (*ytariff*). According to Amiti and Konings (2007), import tariffs on output products are derived from the simple weighted average of the tariff of HS6 products.
(8) Trade policy uncertainty (*ntrgap*). As pointed out by Pierce and Schott (2016), the United States granted a permanent normal trade relationship (PNTR) to China when China joined the WTO, which greatly reduced the uncertainty of Sino-US trade policy. To eliminate such possibility, this paper incorporates the trade policy uncertainty (NTRgap) into the model, which is the difference between the second-column tariff and the first-column tariff.
(9) FDI policy (*FDI*). During the sample period, China's FDI policy has undergone major changes. The Catalogue for the Guidance of Industries for Foreign Investment was first formulated in 1995 and have experienced at least seven revisions since then. The first revised version took effect on January 1, 1998, the second revised version on April 1, 2002, the third on January 1, 2005, the fourth revised version on December 1, 2007, the fifth revised version on January 30, 2012, the sixth revised version on April 10, 2015, and the seventh revised version took effect on July 28, 2017. Among them, a relatively large revision was made in 2002. To rule out the effect of FDI on firm pollution, we include FDI policy in the model.

In order to reduce the effect of heteroscedasticity, the natural logarithm is taken after adding 1 to all continuous variables. The main variables are defined in Table 1.

4.3. Data

This paper mainly uses the following series of datasets.

(1) The Annual Survey of Industrial Production (ASIP) Database over the period of 1998–2013. The database covers the production and financial data of all state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) with annual sales of more than 5 million RMB before 2011 and more than 20 million RMB since 2011. The data are collected through annual surveys conducted by the National Bureau of Statistics of China (see Brandt et al., 2017 for a detailed discussion). The firms in ASIP accounted for 91% of gross output, 71% of employment, 97% of exports, and 91% of total fixed assets in 2004 (Brandt et al., 2017). The Chinese Industry Classification (CIC) codes changed during the sample period, with the change announced in 2002. For 1944–2003, the older version of the CIC code (GB/T4754-1994) was applied, with the new CIC code GB/T4754-2002 becoming effective from 2003. We convert the old CIC version to the new CIC version using Brandt et al. (2017) concordance. We utilize information on firms' registered types (variable *dengji zhuce leixing*) to construct ownership categories. Following Brandt et al. (2017), if a firm has mixed ownership, we assign the ownership status based on the largest ownership share in terms of registered capital. Firms are divided into three categories: SOEs, FIEs, and POEs. The foreign-invested firms include subsidiaries from Hong Kong, Macao, and Taiwan, along with wholly FIEs and joint ventures with local governments.
(2) China Industrial Enterprise Pollution Emissions (IEPE) Database over 1998–2013. The data is collected by the National Bureau of Statistics of China. The data comes from the original data reported by Chinese industrial enterprises, which also constitutes the specific data source of the China Environmental Statistics Yearbook. The survey method is to issue the forms one by one to the key surveyed industrial enterprises, who will fill in and submit them to the National Bureau of Statistics. The key survey unit is the industrial enterprises whose selected pollutants account for more than 85% of the total pollutant discharge of the region. Industrial enterprises that discharge heavy metal harmful substances in industrial wastewater and industrial enterprises that produce hazardous waste are all regarded as key survey enterprises. The database covers the amount of major pollutants discharged by China in total control. This database is currently the most comprehensive firm-level pollution emission data.

We use firm codes and Chinese name to merge the ASIP and the IEPE Database. Finally, we have more than 300 thousand observations with a few missing observations for several variables.

(3) China's import tariff data which is from the World Bank WITS. WITS provides multi-series (BEC, HS, ISIC, SITC) bilateral import tariff data for countries around the world.

Table 1
Variable definition.

Variable	Definition	Measurement
ln*so2*	Log of sulfur dioxide emissions per unit output (ton/1000 RMB)	ln (sulfur dioxide emissions/gross industrial output +1)
ln*cod*	Logo of chemical oxygen demand emissions per unit output (kg/1000 RMB)	ln (chemical oxygen demand emissions/gross industrial output +1)
ln*labor*	Log of number of employees	ln (Number of employees +1)
ln*age*	Log of firm age	ln (year – year of firm registration +1)
ln*klr*	Log of fixed assets per capita	ln (fixed asset/number of employees +1)
ln*lev*	Log of debt-to-assets ratio	ln (total debt/total asset +1)
ln*export*	Log of export	ln (Export delivery value + 1)

(4) China's input-output table in 2002 which is from the National Bureau of Statistics of China. The data covers 122 sectors across the country.
(5) The Catalogue for the Guidance of Industries for Foreign Investment in 2002, 2004, and 2007 which is from Sheng and Yang (2016) and Liang et al. (2024).

4.4. Descriptive statistics

Table 2 reports the descriptive statistical results of main variables, and Table 3 reports the correlation coefficient matrix of main control variables. Table 3 shows that the correlation coefficients between any other two independent variables are low, with the highest correlation coefficient between firm age and the number of employees, 0.280. Table 3 shows that there is no serious multi-collinearity problem between the main explanatory variables.

5. Empirical analysis

5.1. Baseline regression

The baseline regression results are reported in Table 4. The results show that when controlling for a series of time-variant firm characteristics, and a set of fixed effects, the promulgation of the CPPL significantly reduced sulfur dioxide emissions at the level of 1%. Specifically, the CPPL leads to the reduction of sulfur dioxide emissions per unit output of firms by 9.8%. Column (2) shows that, the CPPL also has a significant negative effect on COD emissions at 1% level, with the magnitude being −8.2%.

We speculate that the adjustment of the CPPL in 2012 is a further deepening of the CPPL introduced in 2002. To verify this view, we tried to narrow the sample range to 1998–2011. However, surprisingly, the results in columns (3) and (4) show that the absolute values of the coefficient increase instead. This finding shows that compared with the adjustment of the CPPL in 2012, the impact of the policy introduced in 2003 was much larger. To maintain more observations in the sample, this paper keeps retaining the sample period from 1998 to 2013 to ensure the comprehensiveness and accuracy of the research.

Existing research has pointed out that logarithmic transformation by adding 1 may yield estimates without a natural interpretation and is prone to errors in sign on expected values (Chen & Roth, 2023). Given that logarithmic transformation by adding 1 is still the mainstream approach at present, we still adopt this approach in main analysis. At the same time, we followed Chen and Roth (2023) and used Poisson QMLE estimation to conduct a robustness test. Chen and Roth (2023) show that treatment effects for the dependent variable log (1+Y) in DID specification should not be interpreted as approximating a percentage effect. One conveniently method to target the average proportional treatment effect on the treated can be obtained using Poisson QMLE to estimate. Thus, we conducted a Poisson QMLE regression to test the robustness of the main results. The Poisson results in column (5) and (6) show that the average treatment effect of SO2 and COD are −0.226 and −0.314, respectively, indicating that this transformation does not change the significance of the results of this paper.

The above results show that the CPPL has significantly reduced firms' SO2 and COD emission intensity, and has played a significant role in promoting cleaner production.

5.2. Dynamic effects

The results of dynamic effect regression are reported in Figs. 1 and 2. The results in Fig. 1 show that before 2003, the CPPL had positive or negative effects on the amount of sulfur dioxide emissions per unit output of firms, but they were not significant. Although it was not significant in 2004, the CPPL had a significant reduction effect on firm SO2 emission intensity since 2005. In 2005 and forward years, the estimated coefficients are all negative and significant at the 1% level. This shows that since the CPPL was implemented in 2003, after a lag period of one or two years, it has had a significant negative impact on SO2 emission intensity, which strongly proves the validity of the DID results.

Fig. 2 shows the parallel trends of COD. Fig. 2 shows that there was no significant difference between the treatment group and the control group before 2002. Beginning in 2002, CPPLs significantly increased COD intensity.

The above results show that after controlling for firm characteristics and firm FE and year FE, there is no significant difference in SO2 or COD emission intensity of firms in high-polluting industries between 2003 and 1998. However, since 2003, the SO2, or COD intensity of firms in high-pollution industries have shown a significant decline, corroborating the basic conclusion of this paper that the

Table 2
Descriptive statistics.

Variable	N	Mean	SD	Min	Max
ln*so2*	405775	0.569	0.816	0.000	12.148
ln*cod*	426325	0.268	0.621	0.000	12.345
ln*labor*	516147	5.553	1.134	2.398	12.316
ln*age*	520320	2.335	0.860	0.000	7.601
ln*klr*	515067	4.271	1.372	0.000	14.503
ln*lev*	488001	0.504	0.308	0.000	7.880
ln*export*	512761	0.445	0.985	0.000	14.833

Table 3
Correlation coefficient matrix.

	ln*labor*	ln*age*	ln*klr*	ln*lev*	ln*export*
ln*labor*	1				
ln*age*	0.280	1			
ln*klr*	0.039	−0.050	1		
ln*lev*	0.060	0.070	−0.108	1	
ln*export*	0.127	−0.045	−0.059	−0.096	1

Table 4
Baseline regression.

	(1)	(2)	(3)	(4)	(5)	(6)
	ln*so2*	ln*cod*	ln*so2*	ln*cod*	ln*so2*	ln*cod*
	1998–2013		1998–2011		QMLE-Poisson	
postxtreat	−0.098***	−0.082***	−0.108***	−0.092***	−0.226***	−0.314***
	(0.015)	(0.028)	(0.015)	(0.032)	(0.006)	(0.011)
Prop. Effect	−0.093				−0.202	−0.269
ln*labor*	−0.106***	−0.071***	−0.112***	−0.073***	−0.256***	−0.313***
	(0.009)	(0.013)	(0.010)	(0.013)	(0.006)	(0.009)
ln*age*	−0.002	−0.005**	−0.002	−0.005*	−0.102***	−0.148***
	(0.005)	(0.003)	(0.004)	(0.003)	(0.004)	(0.008)
ln*klr*	−0.009***	−0.008*	−0.006*	−0.005	−0.053***	−0.062***
	(0.003)	(0.004)	(0.003)	(0.004)	(0.003)	(0.005)
ln*lev*	−0.038***	−0.010	−0.039***	−0.010	−0.035***	−0.038***
	(0.009)	(0.007)	(0.009)	(0.008)	(0.005)	(0.009)
ln*export*	−0.017***	−0.011***	−0.017***	−0.012***	−0.046***	−0.051***
	(0.003)	(0.002)	(0.003)	(0.003)	(0.005)	(0.006)
FirmFE	Y	Y	Y	Y	Y	Y
YearFE	Y	Y	Y	Y	Y	Y
N	345457	361652	325358	337081	323434	336367
r2_a	0.744	0.685	0.741	0.688		

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

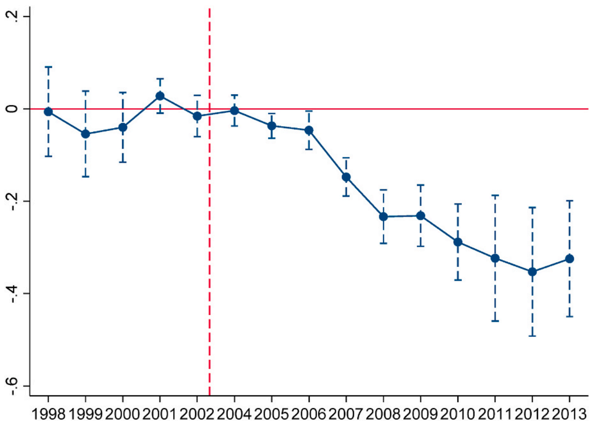

Fig. 1. Event study for SO2.

promulgation of the CPPL has reduced the intensity of these three pollutants.

5.3. Controlling simultaneous events

Around 2003, there were some major related events that may have an impact on Chinese firms' pollution emissions, such as accession to the WTO, granting of the permanent normal trade relationship (PNTR) to China by the United States, and the opening and revising of foreign investment policies, and the introduction of the "Regulations on the Collection and Utilization of Pollution Levy" policy. If these events are related to disturbance items and are not excluded, the estimation results in this paper may be biased. Therefore, we need to consider the impact of these related events. This paper mainly considers four types of related events. The first is

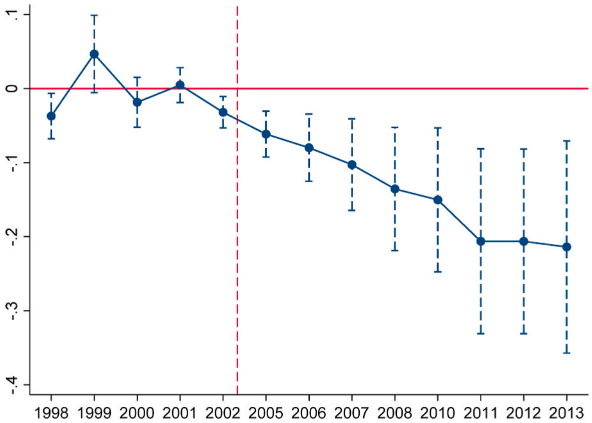

Fig. 2. Event study for COD.
Note: In the COD sample, due to missing data for 2004 and 2009, and 2003 being used as the base year, the estimated values for 2003, 2004, and 2009 are missing.

China's accession to the WTO, the second is the granting of the PNTR, the third is the revision the foreign investment policy, and the last is the introduction of the "Regulations on the Collection and Utilization of Pollution Levy" policy.

5.3.1. *China's WTO accession*

The biggest impact of China's WTO accession is the sharp drop in import tariffs. In 2002, China's overall most-favored nation (MFN) ad valorem import tariff fell from 17.5% to 12.4%. Not only has the output tariff dropped significantly, but the input tariff has also dropped significantly. Therefore, this paper includes both input tariffs and output tariff to exclude the impact of China's WTO accession on firm pollution during the sample period. Following Liu and Qiu (2016), to alleviate the endogeneity of import tariffs, the tariff level before the WTO accession (e.g. 2001) is used to form the cross-terms with time dummy variable, Post02 (Post02 is equal to 1 in 2002 and subsequent years, and 0 otherwise).

5.3.2. *PNTR*

In order to develop trade relations with China, the United States granted China a temporary normal trade relationship (NTR) in 1980, which means that the United States agreed to reduce its import tariffs from China from column two to column one. Prior to China's accession to the WTO, there was a large degree of uncertainty each year as to whether China would obtain NTR status for exports to the United States, especially when a political event occurred in the late 1980s, which led the United States to refuse to grant China NTR concessions for following three consecutive years. Before 2002, this temporary NTR arrangement required the US Congress to vote on whether to continue to grant China NTR status in the following year. The U.S. House of Representatives conducts a vote

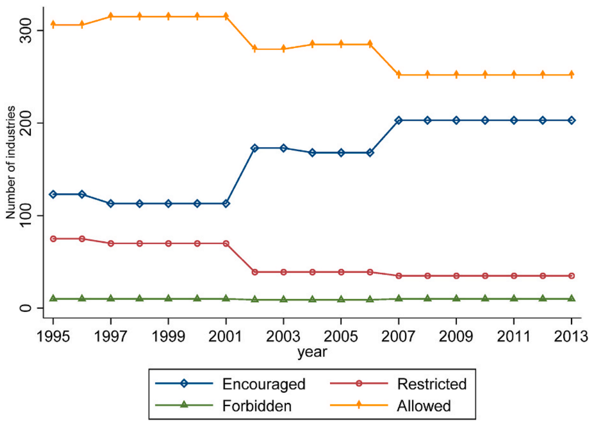

Fig. 3. FDI policy over 1995–2013.
Note: Some industries may appear repeatedly in the same policy category in the same year (year-policy-industry), and some industries may appear conflictly in different policy categories (for example, an industry appeared in both encouragement and restriction in 1995). This figure do not consider industries of policy conflicts by removing the duplicate records of year-policy-industry. The result is similar to the figure if industries of policy conflict are deleted. If no policy revisions occurred in a given year, the FDI policy for that year will keep the same with the most recently revised policy arrangement.

every year to decide whether to grant China NTR status. At the end of 2001, China and the United States established a permanent normal trade relationship (PNTR), which eliminated the uncertainty of Sino-US trade policy. Following Pierce and Schott (2016), this paper uses the cross term of NTR gap (the difference of column 2 tariff and column 1 tariff) and Post02 to control the impact of the PNTR.

5.3.3. FDI policy

In order to guide the direction of foreign investment, China first formulated the "Guidance Catalog for Foreign Investment Industries" in June 1995. Since then, the Catalogue was revised in 1997, 2002, 2004, 2007, 2011 and other years, with the latest revision being in 2017. In fact, in order to fulfill the commitment of the WTO accession, the Catalogue was substantially revised in 2002. To visually examine the changes in foreign investment policies, we plot the number of industries in the encouraged, restricted, prohibited, and allowed industries from 1995 to 2013 in Fig. 3. Fig. 3 shows that the number of industries in different categories has changed in the year of revision. It is obvious that there was a very large mutation in 2002 and 2007, and the most obvious change was in 2002. In contrast, the FDI policies in 1997 and 2004 remain almost unchanged. This paper uses number of industries in encouraged category in the measurement of the "Guidance Catalogue for Foreign Investment Industries" by Sheng and Yang (2016) to control the impact of FDI policies.

5.3.4. The pollution levy policy

The "Regulations on the Collection and Utilization of Pollution Levy" policy were simultaneously implemented in 2003, a policy closely related to the research question in this paper. Thus, we consider excluding the effects of this policy. Specifically, we use the variable levyr, which is the proportion of the sewage charges collected by each province in 2002 to GDP (the sewage charge revenue (RMB) corresponding to GDP (100 million RMB)) to identify the treatment group. If the revenue from sewage fees in a province before the introduction of the pollution levy policy was higher, then the province would be more affected by the policy. *Post2003* is a dummy variable indicating the time when the pollution levy policy was introduced. It takes the value 1 in 2003 and subsequent years and takes the value 0 otherwise. Therefore, this paper uses *levyr*post2003* to control the impact of the pollution levy policy.

The regression results after controlling related events are reported in Table 5. The results show that input tariffs have no significant impact on SO2, but the decrease in input tariffs significantly increases a firm's COD intensity. The output tariff has no significant impact on the emission intensity of the three pollutants.

Similar to input import liberalization, PNTR has no significant impact on SO2, but significantly increases the emission intensity of COD. In the meanwhile, FDI policy does not affect firms' pollution intensity. The collection of sewage charges is indeed conducive to significantly reducing SO2 emission intensity, but the impact on CO2 is not significant. After controlling for the impact of sewage charges, the impact of CPPL is still significantly negative, indicating that the conclusion of this paper is robust.

Table 5
Results controlling related events.

	(1)	(2)
	lnso2	lncod
postxtreat	−0.069***	−0.100***
	(0.011)	(0.031)
ln*itariffxpost02*	0.015	−0.098***
	(0.023)	(0.026)
ln*ytariffxpost02*	0.011	0.005
	(0.012)	(0.014)
ln*ntrgapxpost02*	0.014	0.055**
	(0.014)	(0.025)
FDIxpost	0.001	−0.003
	(0.002)	(0.003)
levyrxpost2003	−0.019***	−0.001
	(0.004)	(0.003)
ln*labor*	−0.099***	−0.073***
	(0.008)	(0.013)
ln*age*	−0.006*	−0.004
	(0.004)	(0.003)
lnklr	−0.004*	−0.009*
	(0.002)	(0.005)
ln*lev*	−0.037***	−0.011
	(0.009)	(0.008)
ln*export*	−0.016***	−0.012***
	(0.003)	(0.003)
FirmFE	Y	Y
YearFE	Y	Y
N	289225	315313
r2_a	0.693	0.696

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

What is most noteworthy is that after controlling the related events, the impact of the CPPL on the SO2, or COD intensity of a firm is still significantly negative at the level of 1%, indicating that the effect of the CPPL on firm pollution is highly robust.

5.4. Triple difference results

Based on whether each province implements local cleaner production policy as the third dimension, we constructed a triple difference model. The results reported in Table 6 show that the CPPL has a significant negative impact on firm's pollution intensity at 1% level (with the DID coefficient −0.049 and −0.082). Furthermore, the DDD coefficient is −0.087 and −0.091 and significant at 5% level, suggesting the effect of the CPPL is larger in provinces where local cleaner production policy was implemented, verifying our baseline results.

5.5. Alternative treated group

In the baseline regression, we used the 2001 high-pollution industry as the treatment group and the low-pollution industry as the control group. In this subsection, we use high-pollution industries in 1998, 2000, and 1998–2002, respectively as the treatment group, and low-pollution industries as the control group, to test the robustness of the baseline results. The results are reported in Table 7. The results show that the CPPL still has a negative impact on firm pollution emissions and is very significant, revealing that the baseline results are highly robust.

5.6. Controlling time-varying industry and provincial characteristics

Industrial policies and regional policies may affect firm pollution emission behavior, thereby weakening the randomness and effects of cleaner production policies. To exclude such possibilities, this paper incorporates time-varying two-digit industry fixed effects and time-varying provincial fixed effects into the model, and estimates are shown in Table 8. The results show that after controlling for time-varying industry and province fixed effects, the CPPL still has a significant inhibitory effect on firms' SO2 and COD emission intensity, indicating that the previous conclusions are robust.

Table 6
DDD results.

	(1)	(2)
	lnso2	lncod
DDD	−0.087***	−0.091**
	(0.017)	(0.039)
postxtreat	−0.049***	−0.082***
	(0.009)	(0.022)
postxERI	−0.012	−0.001
	(0.011)	(0.011)
treatxERI	0.113***	0.137***
	(0.017)	(0.046)
ln*itariffxpost02*	0.015	−0.098***
	(0.023)	(0.025)
ln*ytariffxpost02*	0.012	0.005
	(0.012)	(0.013)
ln*ntrgapxpost02*	0.012	0.053**
	(0.012)	(0.023)
FDIxpost	0.001	−0.003
	(0.002)	(0.003)
ln*labor*	−0.098***	−0.072***
	(0.008)	(0.013)
ln*age*	−0.007*	−0.005*
	(0.004)	(0.003)
ln*klr*	−0.003	−0.008*
	(0.002)	(0.004)
ln*lev*	−0.035***	−0.009
	(0.009)	(0.008)
ln*export*	−0.015***	−0.012***
	(0.003)	(0.003)
FirmFE	Y	Y
YearFE	Y	Y
N	289600	315807
r2_a	0.694	0.696

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

Table 7
Results using alternative treated group.

	(1)	(2)	(3)	(4)	(5)	(6)
	lnso2	lncod	lnso2	lncod	lnso2	lncod
	Treated group by 1998		Treated group by 2000		Treated group by 1998–2002	
postxtreat	−0.088***	−0.090***	−0.081***	−0.091***	−0.085***	−0.093***
	(0.010)	(0.031)	(0.010)	(0.028)	(0.010)	(0.030)
ln*itariffxpost02*	0.012	−0.097***	0.021	−0.087***	0.006	−0.106***
	(0.022)	(0.028)	(0.023)	(0.028)	(0.023)	(0.027)
ln*ytariffxpost02*	0.010	0.001	0.007	−0.002	0.015	0.008
	(0.012)	(0.017)	(0.012)	(0.017)	(0.012)	(0.014)
ln*ntrgapxpost02*	0.007	0.047*	0.009	0.050**	0.010	0.051**
	(0.013)	(0.024)	(0.013)	(0.024)	(0.013)	(0.024)
FDIxpost	0.001	−0.003	0.001	−0.003	0.001	−0.003
	(0.002)	(0.004)	(0.002)	(0.004)	(0.002)	(0.003)
ln*labor*	−0.099***	−0.074***	−0.099***	−0.074***	−0.099***	−0.073***
	(0.008)	(0.013)	(0.008)	(0.013)	(0.008)	(0.013)
ln*age*	−0.006*	−0.005*	−0.006*	−0.005*	−0.006*	−0.005
	(0.004)	(0.003)	(0.004)	(0.003)	(0.004)	(0.003)
lnklr	−0.004*	−0.009*	−0.004**	−0.009*	−0.004*	−0.009*
	(0.002)	(0.005)	(0.002)	(0.005)	(0.002)	(0.005)
ln*lev*	−0.036***	−0.010	−0.036***	−0.010	−0.036***	−0.010
	(0.009)	(0.008)	(0.009)	(0.008)	(0.009)	(0.008)
ln*export*	−0.016***	−0.012***	−0.015***	−0.012***	−0.015***	−0.012***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
FirmFE	Y	Y	Y	Y	Y	Y
YearFE	Y	Y	Y	Y	Y	Y
N	289600	315807	289600	315807	289600	315807
r2_a	0.693	0.696	0.693	0.696	0.693	0.696

Note: The treated groups in columns (1)–(3), columns (4)–(6) and columns (7)–(9) are determined by the high pollution industry in 1998, 2000, and 1998–2002. ***, **, and * indicate significant levels at 1%, 5%, and 10%, respectively.

Table 8
Results controlling time-varying industry and provincial characteristics.

	(1)	(2)
	lnso2	lncod
postxtreat	−0.032***	−0.043***
	(0.009)	(0.016)
ln*itariffxpost02*	0.006	−0.071
	(0.038)	(0.054)
ln*ytariffxpost02*	0.018	0.002
	(0.011)	(0.012)
ln*ntrgapxpost02*	0.020*	0.015
	(0.012)	(0.015)
FDIxpost	0.002	−0.005**
	(0.002)	(0.002)
ln*labor*	−0.076***	−0.053***
	(0.007)	(0.008)
ln*age*	−0.008**	−0.002
	(0.003)	(0.003)
lnklr	−0.029***	−0.024***
	(0.003)	(0.004)
ln*lev*	−0.051***	−0.031***
	(0.012)	(0.009)
ln*export*	−0.022***	−0.017***
	(0.003)	(0.003)
FirmFE	Y	Y
YearFE	Y	Y
Time-varying industry FE	Y	Y
Time-varying provincial FE	Y	Y
N	289596	315806
r2_a	0.709	0.714

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

5.7. Policy randomness

To test the randomness and endogeneity of the CPPL, this paper uses the industry level characteristics (industry size, capital intensity, ratio of new products value to total output, ratio of output value of state-owned enterprises) of the sample in the initial year (1998) as determinants of the dummy variables of the treated group, i.e. to regress treated group on these industry characteristics, and the results are reported in Table 9. The results show that the 1998 industry output value, the ratio of new product value, and the ratio of SOE output value have a significant impact on the dummy variable of the treated group. In the subsequent regressions, this paper controls the pre-determined variables by crossing them with *Post* and incorporate the interactions into the model and get the regression results in Table 10. The results show that after controlling the pre-determined variables, the coefficients of the DID interactions still remain significantly negative at the 1% level. This shows that the conclusions of this paper are sound, and the CPPL has significantly reduced firm emissions.

5.8. Placebo test

Following Abadie et al. (2010), we produce random treated groups and control groups according to the permutation test, and uses them as placebo tests for baseline regressions. To ensure comparability, ratio of the randomly assigned treated group and the control group is set to be consistent with the baseline regression. For each placebo test, this paper conducted 100 random replacement tests. The graph of the distribution of the estimated coefficients of the DID interactions of randomly assigned treated group for SO2 and COD, are shown in Figs. 4 and 5, respectively. As can be seen from these three figures, the estimation coefficients in each placebo test are generally normally distributed around zero, which is significantly different from the baseline regression results and corroborates the conclusion of this paper.

5.9. Heterogenous analysis

We next turn to examine the heterogenous effect of the CPPL on firm emissions. This paper mainly examines the heterogeneity in five dimensions: ownership differences and scale differences. In this section, we focus on the impact of cleaner production law on firm emission intensity of SO2.

5.9.1. By ownership

For two reasons, FIEs and domestic enterprises may be affected by the CPPL differently. On the one hand, according to the "Pollution Haven" hypothesis, FIEs tend to move from developed countries to developing countries, which results in higher pollution levels by FIEs than domestic enterprises (Wang & Wheeler, 2005). Therefore, CPPL may have a greater impact on FIEs. On the other hand, FIEs have higher technical level and energy efficiency, so their pollution intensity is lower (Jiang et al., 2014), resulting in them being less affected by CPPL. The column (1) of Table 11 reports the regression results of firms of different ownerships.

The results show that CPPL significantly inhibits the SO2 intensity of SOEs. In contrast, the impact of CPPL on FIEs is significantly smaller than that of SOEs, and the impact on private enterprises is not significantly different from that of SOEs. This result partly

Table 9
The pre-determinants of treated group.

	(1)	(2)
	treat	treat
	LPM	Logit
ln*outp98*	0.027**	0.142**
	(0.013)	(0.065)
klr98	0.000	−0.001
	(0.000)	(0.002)
soeshare98	0.132	0.670*
	(0.085)	(0.396)
newr98	−1.268***	−6.614***
	(0.147)	(1.085)
expint98	−0.326***	−1.505***
	(0.114)	(0.536)
Constant	0.246	−1.290
	(0.186)	(0.868)
IndustryFE	Y	Y
N	419	419
r2_a	0.109	

Note: The data are industry-year panel data. The standard errors are clustered at the four-digit industry level. Column (1) is estimated using a linear probability model, and column (2) is estimated using a Logit model. ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

Table 10
Results of controlling pre-determinants.

	(1)	(2)
	lnso2	lncod
postxtreat	−0.068***	−0.080***
	(0.010)	(0.020)
ln*itariffxpost02*	0.007	−0.098***
	(0.023)	(0.028)
ln*ytariffxpost02*	0.010	0.005
	(0.012)	(0.016)
ln*ntrgapxpost02*	0.002	0.035
	(0.012)	(0.025)
FDIxpost	0.001	−0.004
	(0.002)	(0.004)
ln*labor*	−0.100***	−0.073***
	(0.008)	(0.013)
ln*age*	−0.007**	−0.005*
	(0.004)	(0.003)
lnklr	−0.004*	−0.008*
	(0.002)	(0.004)
ln*lev*	−0.036***	−0.010
	(0.009)	(0.008)
ln*export*	−0.015***	−0.012***
	(0.003)	(0.003)
ln*outp98xpost*	−0.000	−0.016
	(0.004)	(0.012)
klr98xpost	0.000	0.000
	(0.000)	(0.000)
soeshare98xpost	−0.039*	−0.002
	(0.020)	(0.045)
newr98xpost	0.031	0.124*
	(0.044)	(0.070)
expint98xpost	0.082**	0.061
	(0.032)	(0.092)
FirmFE	Y	Y
YearFE	Y	Y
N	289269	315323
r2_a	0.693	0.696

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

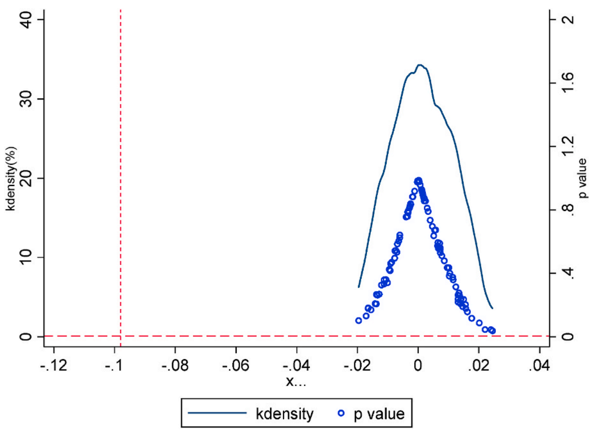

Fig. 4. Placebo test of SO2.

confirms the pollution heaven hypothesis.

5.9.2. By firm size

Qi et al. (2021) using firm-level data find that larger firms are more likely to use clean technology and have less pollution. Thus, CPPL is likely to have a large impact on SMEs. This paper examines the impact of the CPPL on pollution emissions for firms of different sizes. This paper divides the whole sample into large-scale enterprises and small-scale enterprises according to the median value of the

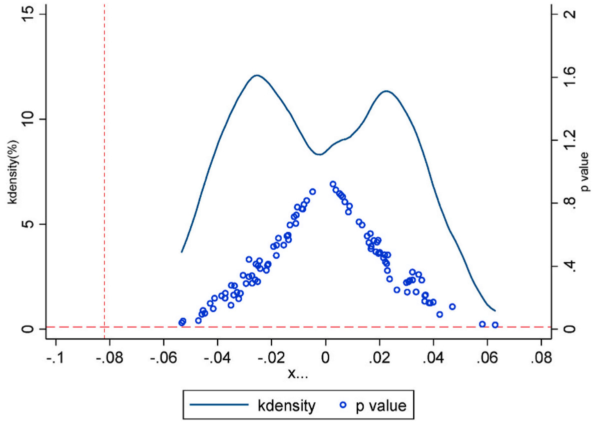

Fig. 5. Placebo test of COD.

Table 11
Results of heterogenous analysis.

	(1)	(2)
	lnso2	lnso2
	By ownership	By firm size
postxtreat	−0.104***	0.028***
	(0.015)	(0.010)
postxtreatxFIE	0.108***	
	(0.017)	
postxtreatxPOE	0.013	
	(0.017)	
postxtreatxlarge		−0.190***
		(0.013)
ln*itariffxpost02*	0.009	0.012
	(0.023)	(0.026)
ln*ytariffxpost02*	0.011	0.008
	(0.012)	(0.014)
ln*ntrgapxpost02*	0.010	0.008
	(0.013)	(0.014)
FDIxpost	0.001	0.000
	(0.002)	(0.002)
ln*labor*	−0.099***	−0.078***
	(0.008)	(0.007)
ln*age*	−0.008**	−0.005
	(0.004)	(0.004)
lnklr	−0.004*	−0.000
	(0.002)	(0.002)
ln*lev*	−0.035***	−0.040***
	(0.009)	(0.009)
ln*export*	−0.015***	−0.014***
	(0.003)	(0.002)
FirmFE	Y	Y
YearFE	Y	Y
CIC4FE	Y	Y
N	289600	289600
r2_a	0.693	0.698

Note: ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

firm's total industrial output value. The regression results by firm size are shown in column (2) of Table 11. The results show that the CPPL has a significant negative impact on large firms, and the impact on large firms is greater than the impact on small firms.

6. Mechanism analysis

The promulgation of the CPPL may affect the firm's pollution emission level from three aspects. First, the CPPL may reduce firm's resource consumption from the input side. The lower the resource consumption, e.g. energy and raw materials, the more beneficial it is to reduce the pollution emission intensity of the firm. We call this effect as resource reduction effect.

Second, it forced firms to carry out transformation and upgrading, improve technical level and total factor productivity, adopt new products and new processes, and essentially reduce pollution emission intensity. We refer to this effect as radical cure effect or Porter effect. Matching the IEPE dataset with the ASIP dataset, we can calculate the total factor productivity of enterprises, green patents by further matching firm level Chinese patent database, and thus provide data basis for testing Porter effect.

Third, although the CPP law is a front-end preventive policy, its legal responsibilities or punitive measures still involve penalties for back-end results. For example, those who fail to publish energy consumption or key pollutant production and emission conditions in accordance with regulations will be fined up to 100,000 RMB. This will lead enterprises to adopt back-end governance measures to pretend to achieve the effect of front-end governance in order to cater to assessments. This effect was called palliative effect in this paper. China Industrial Enterprise Pollution Emissions (IEPE) Database provides data related to firm pollution treatment, and allows us to examine the palliative effect.

6.1. Resource reduction effect

The regression results of resource consumption per unit output are reported in Table 12. The results show that in the first column, the coefficients of the DID terms are significantly negative at the 1% level, the estimated coefficient in the second column is significantly negative at the 10% level, and the coefficient in the third column is positive but not significant. The results imply that the CPPL has significantly reduced total coal consumption per unit output of the firm, the fuel oil consumption per unit output of the firm, whereas there is no significant effect on clean gas consumption per unit output of the firm.

6.2. Porter effect

The more important question is whether the CPPL really forces firms to upgrade their technology, increase productivity, and move to use cleaner production methods, that is, whether it not only cures for the symptoms but the root cause as well, achieving the Porter effect. Due to data availability, this paper uses firm's total factor productivity calculated by the ACF method (Ackerberg et al., 2015) to test the porter effect. Following Albino et al. (2014) and Yu et al. (2021), this paper uses the International Patent Classification (IPC) green list to define green patents. The IPC Green List covers seven green technology categories, and each class is divided into a detailed set of subclasses, each of which was linked to the relevant IPC code. Following Ding et al. (2022), this paper uses these relevant IPC codes to count the number of invention patents and utility models, and sums them up to obtain the total number of green patents granted annually at the firm level. We do not consider design patents due to their lower innovation intensity and lack of associated IPC codes. Following Amore and Bennedsen (2016), we date the green patents granted at the time of patent application. Patent data comes from the website of the State Intellectual Property Office of China.

Related results are shown in Table 13. The results show that the CPPL at the 5% level has significantly increased firm's total factor productivity and green patent applications. This shows that the promulgation of the CPPL did force firms to achieve technological progress and competitiveness, that is, successfully to achieve the Porter effect.

6.3. Pollution treatment

Table 14 reports the relationship between the cleaner production law and the firm's pollution treatment, the number of desulfurization facilities and desulfurization capacity. After the implementation of the CPPL, the SO2 removal per unit of output of the firm increased significantly, and the number of waste gas treatment facilities and the number of desulfurization facilities also increased significantly. Moreover, the firm's desulfurization capacity of desulfurization facility has also been significantly improved. It shows that the CPPL reduces pollution emissions by increasing the number of enterprise pollution facilities, upgrading the treatment capacity of pollution facilities, and increasing the amount of pollution treatment by enterprises.

7. Concluding remarks

Based on a unique combined dataset of the Chinese Industrial Enterprise Pollution Emissions dataset and China's Annual Survey of Industrial Production dataset from 1998 to 2013, this paper investigated the impact of the promulgation of China Cleaner Production Promotion Law on firm pollution emissions using the difference-in-difference and triple difference framework. We focus on the impact of on firm's SO2 and COD. Our results show that the promulgation of the CPPL did significantly reduced the SO2 and COD emissions per unit of output (emission intensity) of firms. The results of the dynamic effect estimation show that the impact of the CPPL was not significant before 2003, and showed a significant negative impact in 2003 and the years forward, indicating that the DID result was valid. To separate the impact of simultaneous events such as accession to the WTO, the US granting China permanent normal trade relations, revision of foreign investment policies, and regional industrial policies, we included into the model the interactions of input tariffs, output tariffs, NTR tariff gap, FDI encouraged policies with the occurrence time of these events, and randomly set the treatment group using the placebo tests, and the results remained highly robust. The results are also robust when the policy of Regulations on the Collection and Utilization of Pollution Levy was considered. This paper finds that China's CPPL reduces firm's pollutant discharge level by decreasing firm's resource consumption, increasing firm's total amount of pollutant treatment intensity. In the meanwhile, it successfully increases firm's total factor productivity and the number of green patents of firms, that is, it stimulates the Porter effect. This paper also explores the rich firm heterogeneity of the impact of China CPPL on firm pollution emissions, finding larger effects on

Table 12
Regression results of resource consumption.

	(1)	(2)	(3)
	ln(total coal consumption/output)	ln(fuel oil consumption/output)	ln(clean gas consumption/output)
postxtreat	−0.008***	−0.002*	0.001
	(0.003)	(0.001)	(0.001)
ln*itariffxpost02*	0.002	0.002	−0.000
	(0.006)	(0.003)	(0.001)
ln*ytariffxpost02*	0.007	−0.001	−0.001
	(0.005)	(0.002)	(0.001)
ln*ntrgapxpost02*	0.011**	−0.001	0.001
	(0.005)	(0.001)	(0.001)
FDIxpost	0.000	−0.000	−0.001*
	(0.001)	(0.000)	(0.000)
ln*labor*	−0.045***	−0.002***	−0.001
	(0.006)	(0.001)	(0.001)
ln*age*	−0.005**	−0.000	0.001
	(0.002)	(0.000)	(0.001)
lnklr	0.005***	0.001***	−0.000
	(0.002)	(0.000)	(0.000)
ln*lev*	−0.014***	−0.003***	−0.001
	(0.004)	(0.001)	(0.001)
ln*export*	−0.003***	−0.000*	0.000
	(0.001)	(0.000)	(0.000)
FirmFE	Y	Y	Y
YearFE	Y	Y	Y
N	153835	147165	90227
r2_a	0.635	0.350	0.172

Note: The outcome variable in column (1) is the total coal consumption per unit output of the firm (ton/thousand RMB), and the fuel oil consumption per unit output of the firm (ton/thousand RMB) in column (2), the clean gas consumption per unit output of the firm (ton/thousand RMB) in column (3). ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

Table 13
Regression result for Porter effect.

	(1)	(2)
	TFP	ln*GreenPatent*
postxtreat	0.003**	0.056***
	(0.001)	(0.014)
ln*itariffxpost02*	−0.145***	0.044**
	(0.041)	(0.022)
ln*ytariffxpost02*	−0.023	−0.005
	(0.022)	(0.012)
ln*ntrgapxpost02*	−0.057***	−0.015
	(0.021)	(0.011)
FDIxpost	0.011*	−0.014**
	(0.006)	(0.006)
ln*labor*	−0.029**	−0.036***
	(0.013)	(0.006)
ln*age*	0.044***	0.033***
	(0.007)	(0.004)
lnklr	0.003	−0.034***
	(0.006)	(0.003)
ln*lev*	−0.059***	0.021***
	(0.012)	(0.006)
ln*export*	0.048***	−0.005***
	(0.006)	(0.002)
FirmFE	Y	Y
YearFE	Y	Y
N	356465	380296
r2_a	−0.256	0.497

Note: The outcome variables in column (1) and (2) are firm's total factor productivity calculated by the ACF method (*trans*-log production function) and the number of green patents. ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

Table 14
Regression results of firm pollution treatment.

	(1)	(2)	(3)	(4)	(5)
	ln(SO2 removal)	ln(Number of waste gas treatment facilities)	ln(Number of desulfurization facilities)	ln(processing capacity of waste gas treatment facility)	ln(desulfurization capacity of desulfurization facility)
postxtreat	0.027***	0.042***	0.028***	0.054	0.056**
	(0.007)	(0.013)	(0.005)	(0.066)	(0.023)
ln*itariffxpost02*	−0.003	−0.096***	−0.014	−0.331**	−0.104*
	(0.011)	(0.026)	(0.010)	(0.137)	(0.053)
ln*ytariffxpost02*	0.009*	0.039**	0.010*	0.113*	0.044
	(0.005)	(0.015)	(0.006)	(0.068)	(0.027)
ln*ntrgapxpost02*	0.009	−0.008	−0.013**	−0.024	−0.052*
	(0.007)	(0.011)	(0.006)	(0.055)	(0.027)
FDIxpost	−0.003	−0.010**	−0.005***	−0.039**	−0.030***
	(0.002)	(0.005)	(0.002)	(0.020)	(0.008)
ln*labor*	−0.048***	0.093***	0.026***	0.275***	0.090***
	(0.007)	(0.007)	(0.005)	(0.045)	(0.017)
ln*age*	0.001	0.020***	0.004	0.098***	0.028**
	(0.004)	(0.004)	(0.004)	(0.037)	(0.012)
lnklr	0.016***	0.035***	0.018***	0.172***	0.074***
	(0.004)	(0.004)	(0.003)	(0.025)	(0.010)
ln*lev*	−0.024**	−0.018**	−0.008	0.036	0.089**
	(0.011)	(0.008)	(0.009)	(0.052)	(0.036)
ln*export*	−0.005***	−0.005**	−0.003*	−0.004	−0.013**
	(0.002)	(0.002)	(0.002)	(0.015)	(0.006)
FirmFE	Y	Y	Y	Y	Y
YearFE	Y	Y	Y	Y	Y
N	158323	222625	128482	171483	127534
r2_a	0.574	0.739	0.708	0.717	0.636

Note: The outcome variables in column (1)–(2) are the amount of sulfur dioxide removal per unit of output of the firm (kg), the number of waste gas treatment facilities, the number of desulfurization facilities, processing capacity of waste gas treatment facility (standard cubic meter per hour), and desulfurization capacity of desulfurization facility (kg per hour). ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

SOEs and large firms.

The conclusions of this paper have typical and important policy implications. The conclusions of this paper reveal that the CPPL, as a formal rule of law regulation and ex-ante prevention policy, not only reduces the pollution level of enterprises from the input side, but also reduces the pollution removal level, and can also stimulate the Porter effect. On the one hand, as China's rare official ex-ante prevention policy, the CPPL has played an important role in suppressing firm pollution emissions, which means that China should introduce more ex-ante prevention policies to reduce firm pollutants from the source and to achieve green development. On the other hand, as China's heavy-weight ex-ante prevention policy, the CPPL have the advantages of driving firms to reduce emissions from the perspective of back-end governance, and promoting polluted firms to adopt new technology and to increase total factor productivity, successfully stimulating the Porter effect. In the following days, more measures to guarantee the implementation of China CPPL can be introduced to better help firms achieve green transformation. It should be noted that when assessing the effectiveness of CPPL, measures should be taken to identify whether a target firm has truly adopted cleaner production technologies, rather than just reducing pollution by reducing back-end pollution treatment. Strict supervision of this issue affects whether CPPL truly fulfills its original policy intention. For other developing countries, learning from China's practices and formulating and implementing cleaner production laws is a good way to control pollution.

Declaration of competing interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work.

Data availability

Data will be made available on request.

Appendix

Table A1
Promoting measures in China's CPPL

No	Measures
1	Formulate fiscal and tax policies conducive to the implementation of cleaner production
2	Preparation and implementation of national cleaner production promotion plan
3	Strengthen capital investment in cleaner production promotion
4	Organize and support the establishment of an information system and technical advisory service system to promote cleaner production
5	Regularly release clean production technology, process, equipment and product-oriented catalog
6	Eliminate outdated production technologies, processes, equipment and products that waste resources and seriously pollute the environment within a time limit
7	Approve the establishment of product marks for environmental and resource protection, and formulate corresponding standards
8	Guide and support the development of cleaner production technology and environmentally friendly products and the demonstration and promotion of cleaner production technology
9	Incorporate cleaner production technology and management courses into relevant higher education, vocational education and technical training systems
10	Priority purchase of energy-saving, water-saving, waste recycling and other products that are conducive to environmental and resource protection
11	Announce the list of enterprises that do not meet the energy consumption control indicators and key pollutant emission control indicators

Note: The information comes from China Cleaner Production Promotion Law and is compiled by the author.

Table A2
Implementing measures in China's CPPL

No	Measures
1	Environmental impact assessment of new construction, reconstruction and expansion projects
2	Enterprises should adopt cleaner production measures for technological transformation
3	The design of products and packaging is preferably non-toxic, harmless, easy to degrade or easy to recycle
4	Enterprises producing large-scale electromechanical equipment and other products should indicate the standard grade of material composition
5	Agriculture should scientifically use chemical fertilizers, improve planting and breeding techniques, and prevent agricultural environmental pollution
6	Service enterprises should adopt environmentally friendly technologies and equipment to reduce or not use consumer products that waste resources and pollute the environment
7	Construction projects should use energy-saving, water-saving and other architectural design schemes, construction and decoration materials, construction components and equipment that are conducive to environmental and resource protection
8	In the exploration and exploitation of mineral resources, exploration, mining methods and technological techniques that are conducive to the rational use of resources, protecting the environment and prevention of pollution shall be adopted
9	The enterprise can recycle or transfer the generated waste and waste heat to other qualified enterprises and individuals
10	Enterprises monitor resource consumption and waste generation, and conduct cleaner production audits of production and services as needed.

Note: The information comes from China Cleaner Production Promotion Law and is compiled by the author.

Table A3
Incentive measures in China's CPPL

No	Measures
1	The state establishes a commendation and reward system for cleaner production, and commends and rewards units and individuals that have made outstanding achievements in cleaner production
2	The government will provide financial support to projects that engage in cleaner production research, demonstration and training, implement key national cleaner production technological transformation, and carry out voluntary transformation to conserve resources and reduce pollution emissions.
3	Set up a small and medium-sized enterprise development fund and arrange an appropriate amount to support the implementation of cleaner production by small and medium-sized enterprises
4	Those who use waste according to law and recover raw materials from waste to produce products in accordance with national regulations will enjoy preferential tax treatment
5	The expenses for clean production audits and training of enterprises can be regarded as the operating costs of enterprises

Note: The information comes from China Cleaner Production Promotion Law and is compiled by the author.

Table A4
Legal liability in China's CPPL

No	Legal liability
1	Dispose of some supervisors and other directly responsible personnel who fail to perform their duties in accordance with the law
2	A fine of up to 100,000 yuan for those failing to publicize energy consumption or the generation and discharge of key pollutants in accordance with regulations
3	Those who do not mark the ingredients of the product materials or do not mark them truthfully shall be ordered to make corrections within a time limit, otherwise a fine of not more than 50,000 yuan shall be imposed
4	Those who produce and sell construction and decoration materials with toxic and hazardous substances exceeding national standards shall be held accountable for administrative, civil and criminal legal responsibilities
5	Those who do not implement compulsory cleaner production audits or commit frauds in cleaner production audits, or companies that implement compulsory cleaner production audits do not report or fail to report the audit results truthfully, shall be ordered to make corrections within a time limit; A fine of less than 100,000 yuan

Note: The information comes from China Cleaner Production Promotion Law and is compiled by the author.

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