Sustainable Production and Consumption 33 (2022) 425–437

Contents lists available at ScienceDirect

Sustainable Production and Consumption

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

Environmental Protection Tax Law on the synergy of pollution reduction and carbon reduction in China: Evidence from a panel data of 107 cities

Xinwei Gao, Na Liu *, Yujie Hua

School of Economics and Management, China University of Petroleum (East China), Qingdao 266580, China

ARTICLE INFO

Article history:
Received 15 April 2022
Received in revised form 4 July 2022
Accepted 5 July 2022
Available online 16 July 2022

Editor: Prof. Yue-Jun Zhang

Keywords:
Environmental protection tax
Pollution reduction
Carbon reduction
Synergy
Difference-in-differences method

ABSTRACT

Many of air pollutants and carbon dioxide (CO_2) have common emission sources, determining that they should be controlled collaboratively rather than treated separately. To protect the environment, China implemented the Environmental Protection Tax (EPT) Law on January 1st, 2018. Yet CO_2 is not included in the tax category, whether the EPT Law can achieve coordinated control of air pollutants and CO_2 emissions remains unclear. This paper examines the role of the EPT Law in the synergy of pollution reduction (PR) and carbon reduction (CR) by employing the Difference-In-Differences (DID) model on China's 107 cities from 2015 to 2019. We find that the policy, although not including CO_2 as one taxable item, has significantly increased the synergistic reduction degree of "sulfur dioxide (SO_2)-CO_2" by 41%, and the synergistic reduction degree of "particulate matter (PM)-CO_2" by 39%. Moreover, strengthening environmental protection supervision, optimizing energy structure and improving green technology innovation are main transmission mechanisms through which EPT Law affects the synergy degree of PR and CR. Further, the heterogeneity of policy effects caused by different magnitudes of tax rate increase is unveiled, showing that the policy effects on the synergy of PR and CR are most significant in regions that raised the SO_2 tax rate beyond 2.4 Yuan and raised the PM tax rate between 2.4 Yuan and 6 Yuan. This paper suggests that the EPT Law serves a critical function in enhancing the synergy of PR and CR, and thus the synergistic effect of air pollutants reduction on carbon reduction should be considered when formulating possible carbon tax rate in the future.

1. Introduction

To achieve the goals of "Beautiful China" and "Carbon Neutrality", China is under high pressure in both pollution control and climate governance. The 2020 Environmental Performance Index (EPI) showed that China's pollutant emission performance ranked 91 out of 180 countries in the world, associated with NO_X emissions growing by an average of 3.6% in the past decade.[1] Related research has also reported that China alone contributed over 27% of total global greenhouse gas emissions in the year of 2019, exceeding those of all developed countries combined.[2] Under this circumstance, coordinated control of pollution reduction (PR) and carbon reduction (CR) has become an inevitable choice since air pollutants and carbon dioxide (CO_2) tend to share the same emission sources (Swart et al., 2004). Since the year of 2015, China has been reforming and revising relevant environmental management policies to improve the synergy of PR and CR, such as Air Pollution Prevention and Control Law revised in 2015 and Three-Year Action Plan for Winning the Blue-Sky Defense issued in 2018, both of which emphasized the coordinated control of carbon emissions when reducing air pollutants.

Among those policies awaiting further reform is Environmental Protection Tax (EPT) Law more urgent. China's EPT Law was enacted on January 1st, 2018, aiming to regulate the pollution behaviors of pollutant discharge units by levying taxes on specific pollutants, associated with 89.27% of the total tax revenues levied being from air pollutants (China's State Administration of Taxation (CSAT), 2020). However, CO_2 is not included in the tax items. How much CO_2 emissions can be reduced by taxing air pollutants? Has the EPT Law realized the synergy of PR and CR without carbon tax? Clarifying these issues can provide theoretical reference for the tax rate reform of pollutants and CO_2, and thus achieving the interconnection of coping with environmental pollution and climate change.

Existing literatures on analyzing EPT policy effect are gradually increasing. Based on CGE-related models, some literatures assessed that levying the sulfur/nitrogen tax could help reduce carbon intensity (Jiang et al., 2022) and carbon emissions (Xiao et al., 2015; Wang et al., 2017). From a micro perspective, EPT policy was proved to

* Corresponding author.
E-mail address: liuna@s.upc.edu.cn (N. Liu).

1 https://sedac.ciesin.columbia.edu/data/collection/epi
2 https://rhg.com/research/chinas-emissions-surpass-developed-countries/

https://doi.org/10.1016/j.spc.2022.07.006
2352-5509/

significantly affect corporate green innovation level (Huang et al., 2022) and illegal emissions (Lu, 2022) based on Difference-In-Differences (DID) model. However, it should be pointed out that literatures using CGE-related models fail to evaluate the implementation effect of current EPT policy due to CGE-related models mainly rely on specific parameters for policy simulation rather than policy evaluation, which can be realized by DID method. Nevertheless, few EPT policy studies using DID method established the synergistic linkage between PR and CR. The synergy index of emissions reduction cross-elasticity introduced by Mao et al. (2012b) can address this problem, but this approach has not yet been applied in field of EPT policy effect evaluation.

In this study, we employ the DID method on China's 107 cities from 2015 to 2019 to quantitatively evaluate the impacts of current EPT Law on the synergy of PR and CR. In addition to constructing the synergy index of PR and CR based on Mao et al. (2012) for benchmark regression, this paper also analyzes the mechanism and heterogeneity of EPT policy effects.

Marginal contributions are perhaps as follows. First, the synergistic nexus between PR and CR in China's 107 cities are innovatively formed in this study, namely the synergistic reduction degree of "SO_2-CO_2" and "PM-CO_2", and applied to the field of EPT policy's effect evaluation. This not only broadens the application scope of the synergy index of PR and CR, but also ascertains the status quo of current EPT policy implementation on the coordinated control of environmental pollution and climate change. Then, we further identify mechanisms through which EPT Law affects the synergy of PR and CR, including environmental protection supervision, energy structure and green technology innovation. The empirical results will help policymakers understand proper ways to strengthen the effectiveness of EPT policy implementation on the coordinated control of PR and CR. Finally, we reveal the heterogeneity of policy effects caused by different magnitudes of tax rate increase, offering enlightenment for the current pollutants and possible future CO_2 tax rate reform.

The remainder of this paper is structured as follows. Section 2 shows the literature review and research hypotheses. Method, model, variables and data are illustrated in Section 3. Empirical results and relevant discussion are presented in Section 4. The final section concludes and proposes some policy recommendations.

2. Literature review

This section includes four parts: (1) an overview of studies on effects of environmental tax; (2) a review of the coordinated control of PR and CR; (3) the knowledge gap in the existing literatures; and (4) research hypotheses developed in our paper.

2.1. Effects of environmental tax

The concept of environmental tax is stemmed from Pigouvian tax theory, stating that polluters need to be taxed for the damage they do in the process of manufacturing (Pigou Arthur Cecil, 1920). Hence environmental tax includes pollution tax, carbon tax, resource tax, energy tax, and transport tax, etc. Most of the research work focus on the economic and environmental impacts of environmental tax.

A growing stream of research reveal the double dividends brought by imposing environmental tax (Bovenberg and Goulder, 2002; Fernández et al., 2011; Wesseh and Lin, 2016), suggesting environmental tax policy has both economic (blue dividend) and environmental (green dividend) benefits. However, several studies find that only green dividend can be realized (Li and Lin, 2013; Zhang et al., 2016; Radulescu et al., 2017; Khastar et al., 2020), while it does not mean the higher the tax, the better the effect (Aydin and Esen, 2018; Bonnet et al., 2018).

Research on green dividend of environmental tax policy revolve about energy tax, vehicle tax, and pollution tax, etc. Mao et al. (2012a), for example, suggested that energy tax played an essential role in reducing pollution and carbon emissions by analyzing the data from transportation sector. Related to this, Jiang et al. (2013) found that enhancing the vehicle tax rate could achieve the co-benefits on PR and CR. In the sphere of pollution tax, Gren et al. (2003) demonstrated that the introduction of taxes on SO_2, NOx and CO_2 could decrease ecological tax reforms' costs and even produce welfare benefits. Besides, Rodríguez et al. (2019) in the case of Portugal, found that a simplification taxation policy could generate double dividends.

Some scholars also dig into the consequences and influencing factors of environmental tax reform. Klenert et al. (2018), for instance, illustrated that the environmental tax reform could reduce inequality under certain conditions. Takeda and Arimura (2021) showed that the carbon tax introduction combined with income taxes reduction could become the most desirable policy for Japan. Considering that China has not yet levied carbon tax, Jiang et al. (2020) found that carbon tax should be introduced to mitigate the possible negative environmental and social-economic impacts caused by resource tax reform in China.

In the realm of China's EPT policy, existing studies have carried out a wealth of research from different perspectives. Jiang et al. (2022) used the China Energy and Environmental Policy Analysis Model (CEEPA) and revealed that levying the sulfur tax/nitrogen tax could reduce carbon intensity. Wang et al. (2017) and Xiao et al. (2015) have also adopted the general equilibrium model to investigate the auxiliary effect of carbon reduction generated by environmental pollution taxes. Different from these policy simulation studies, several scholars have used the DID method to evaluate the implementation effect of the EPT policy, focusing on the various impacts on heavily polluting enterprises. Huang et al. (2022), for instance, confirmed that EPT policy significantly improved corporate green innovation level. Similar conclusion is also proved by Liu et al. (2021b), which holds that market-based incentive environmental regulation like EPT is flexible enough for enterprises to accelerate technological progress. Besides, Lu (2022) estimated the impact of EPT policy on illegal emissions of heavy polluting enterprises and analyzed possible mechanisms.

2.2. The coordinated control of PR and CR

Recently, the focus of environmental policy reform has shifted towards the direction of coordinated control of PR and CR due to greenhouse gas emissions, especially in developing countries. Pollutants and CO_2 tend to be interconnected in terms of emissions reduction technology because of their shared emissions sources (e.g. the burning of fossil fuels), which lays the foundation for coordinated control of PR and CR. For example, Bollen et al. (2009) testified that particular technologies (such as particulate emissions reduction technologies) could help reduce CO_2 emissions. Similarly, Dong et al. (2015) revealed that carbon emission mitigation policies (such as setting carbon cap, introducing relevant technologies etc.) could contribute to air pollutants reduction.

A separate branch of literatures on environment-related policies can also prove that PR and CR have the possibility of coordinated control. For instance, Xue et al. (2015) manifested that wind power system could help reduce both pollution emissions and carbon emissions to a large measure in China. Moreover, China's carbon emissions trading system also has benefits on both carbon reduction (Guo et al., 2021) and haze pollution alleviation (Yang et al., 2022). Also, Kou et al. (2021) studied whether carbon emission trading would beget the co-benefits on SO_2 reduction and showed the results had regional differences.

But most studies on environmental tax policy concentrate on its single emissions reduction effect, either pollution reduction effect or carbon reduction effect. Niu et al. (2018), for example, estimated that China's EPT shocks could lead to carbon emissions reduction by developing an equilibrium model. Further, Han and Li (2020) evaluated how EPT policy affected air quality in China. There are also a few literatures exploring the impacts of environmental tax on both PR and CR, but they only calculate by what percentage of the emissions has been reduced or increased without mentioning the synergy between PR and CR. For instance, evidence from Chile verified that the environmental tax could reduce the emissions of CO_2, PM, and SO_2 by 11%, 48% and 49% respectively, while the NO_X got an actually increase by 5% (Mardones and Cabello, 2019). Perhaps it will be difficult for policymakers to figure out why the same policy will exert different impacts on each pollutant or which pollutant emission is most related to CO_2 if the interaction between pollutants and carbon dioxide is unclear.

Noticeably, Mao et al. (2012b) introduced the synergy index of emissions reduction cross-elasticity to estimate the joint-control effects of SO_2, NOx, and CO_2 in the iron and steel sector. Since then, this index has been applied to specific sectors. For example, Jia et al. (2016) used this assessment method to calculate the emissions reduction cross-elasticity between pollutants and CO_2 brought by various emission reduction measures in the chemical industry; Liu et al. (2017) in the case of Pearl River Delta region, designated five emission reduction scenarios and evaluated the co-control effect of emission based on cross-elasticity method in the transport industry. But this synergy index is quietly rare in the field of environmental tax policy evaluation. Thus, specific propositions for the reform of EPT policy have not yet been submitted from the perspective of coordinated control of PR and CR.

2.3. Knowledge gap

Although there are many studies centering on the EPT policy effect evaluation and coordinated control of PR and CR, some knowledge gaps still exist. (1) Few studies apply the synergy index of PR and CR to policy effects evaluation. Most existing studies that estimate the EPT policy's effect tend to treat PR or CR separately, failing to establish a linkage between PR and CR. Meanwhile, those literatures on the synergy of PR and CR only use the synergy index in emission reduction feature analysis in specific sectors. (2) Few studies use the synergy index in econometric model regression. Methodologically, many literatures on the synergy of PR and CR are either case studies or scenario analysis, few of which do economic model regression. (3) The existing studies lack of mechanism analysis. How EPT policy affects the synergy of PR and CR remains unclear. (4) The research on heterogeneity of policy effects caused by different magnitudes of tax rate increase is also insufficient.

Therefore, we intend to fill these gaps by evaluating the impact of current EPT Law on the synergy of PR and CR. After evaluation of the EPT policy effects, we then make further mechanism and heterogeneity analysis.

2.4. Research hypothesis

The concept of synergy refers to the benefits obtained simultaneously when implementing related policies for various reasons (Intergovernmental Panel on Climate Change (IPCC), 2001), and thus we define "synergy" as the simultaneous reduction of CO_2 and pollutants emissions in this paper.

China's EPT Law was implemented officially on January 1st, 2018, replacing a nearly 40-year-old pollutant discharge fee regulation. This policy change marks a new era in environmental taxation on the air pollutants, water pollutants, solid wastes and the like, aiming to achieve the goal of "less emissions, less taxes" by regulating the behaviors of pollution discharging units. Although the EPT Law does not include the item CO_2, we believe it could still produce benefits on the synergy of PR and CR. Major reasons are possibly as follows.

First, EPT Law could contribute to PR and CR respectively. For one thing, compared with previous pollutant discharge fee, EPT Law is more rigid and standardized, changing the revenue structure of emission units by increasing the tax rate. Thus, polluters would rather increase their investments in environmental protection and regulate emission behaviors in the process of production than pay the charges. For another, the spillover effect of environmental tax's green dividend reveals that the emissions of non-taxable pollutants can be affected by the reduction of taxable pollutants emissions (Lu et al., 2018). To visualize the homogeneity of air pollutants and CO_2, Table 1 highlights the comparison between air pollutants and CO_2 emission factors of China's six heavily-polluted industries based on typical processes. It can be noticed that processes using fossil energy as raw materials always bring about an increase in both pollutants and carbon emissions. Thus, CO_2 could be regarded as one of the non-taxable pollutants which is influenced by the reduction of SO_2 and PM emissions.

Second, the implementation of EPT Law could also improve the synergy degree of PR and CR. Relationship between air pollutants and carbon emissions is supposed to be determined by energy consumption processes, but the application of environment-related policies and consequent emission reduction measures such as flue gas desulfurization and changes in energy fuel mix etc. could intervene this relation (Zheng et al., 2011), bringing uncertainty to whether air pollutants and carbon dioxide can be reduced at the same time. However, China's carbon-intensive energy structure and high energy-consuming industrial structure make it accessible to control PR and CR simultaneously. It is worth noting that the increasing attention from government and the efforts from pollution units are crucial reasons for effectiveness of policy on the synergy of PR and CR.

(1) Environmental protection supervision. Local governments that actively implement the EPT policy tend to pay more attention to whether the pollutant discharge units evade environmental taxes through illegal pollution discharge. Previous study showed that the illegal emission behaviors of enterprises could be significantly restrained under stricter government's environmental supervision (Lu, 2022). In this case, driven by higher violation cost, those illegally discharged units will consciously take pollutant emission reduction measures and thus the synergy of PR and CR are realized owing to this source control method.
(2) Energy structure. Optimization of energy structure is another source management measure to improve the synergistic degree of PR and CR. It is noteworthy that the impartiality of the EPT Law could restrain enterprises, especially those in heavily-polluted industries, from over investment to expand production capacity (Yu et al., 2021). Therefore, the energy consumption of cities will be reduced, especially coal, leading to the reduction of pollutant emissions and carbon emissions simultaneously.
(3) Green technology innovation. EPT Law not only reflects the principle of "whoever pollutes pays", but also reflects the characteristic of "whoever emits less benefits", which means emitters will receive a reduction in tax rate if the concentration of air pollutants is reduced to a certain level. With the combination of penalties and incentives of the environmental pollution tax, emitters tend to invest more in green technology innovation from product design to end-of-pollutant treatment, which can break through the technological isolation of PR and CR (Bashir et al., 2020) and thus make for the co-benefits on the synergy of PR and CR.

Therefore, we develop our main hypotheses as follows.

H1. The implementation of EPT Law will significantly improve the synergy of PR and CR.

H2. Environmental protection supervision, energy structure and green technology innovation play a mediating role in the impact of EPT Law on the synergy of PR and CR.

3. Methods

3.1. Sample selection

This paper adopts DID method to empirically examine the policy effect of EPT Law on the synergy of PR and CR, and takes whether the tax rate has been significantly increased compared with previous pollutant

Table 1
Comparison of air pollutants and CO_2 coefficients of heavily-polluted industries based on typical processes.

Industry	Raw material	Product	Process	SO_2 coefficient	PM coefficient	CO_2 coefficient
Thermal power	Fuel oil	Electric energy, thermal energy	Boiler/gas turbine	4.21 kg/ton raw materials	0.25 kg/ton raw materials	3.1705 tons/ton raw materials
Petroleum	FCC gasoline	Refined gasoline	Adsorption	0.0004 kg/ton fuel	0.0003 kg/ton fuel	2.9251 tons/ton raw materials
Paper making	Natural gas	Chemical wood pulp	Lime kiln	36 g/t product	0.000179 g/t product	2.1622 t/t raw materials
Cement gypsum	Coal	gypsum	Rotary kiln	0.356 kg/ton product	6.153 kg/ton product	1.9003 tons/ton raw materials
Iron making	Coke	Vanadium iron	Blast furnace method	0.12 kg/ton product	0.01 kg/ton product	2.8604 tons/ton raw materials
Machinery	Diesel	Diesel coating products	Diesel industry furnace	19S kg/ton raw materials	3.28 kg/ton raw materials	3.0959 tons/ton raw materials

Note: Data are from Handbook of Emission Accounting Methods and Coefficients of Emission Source Statistics Survey in China 2021.

discharge fee after the implementation of the EPT Law as the standard to divide the experimental group and the control group. It is noticeable that only 11 provinces (municipalities) in China have significantly raised all air pollutants' tax rates, and one province (Shandong) has only raised the tax rate of SO_2 among air pollutants after the implementation of the EPT Law. Remaining provinces have maintained the original rates for pollutants discharge fees. In order to ensure the uniformity of sample grouping and also referred to Jin et al. (2020), this paper regards Shandong province as a member of the experimental group, and thus cities in these 12 provinces (municipalities) are treated as experimental group and remaining cities control group.

Meanwhile, we excluded the third batch of low-carbon pilot cities approved in 2017 from the total sample so as to eliminate the impacts of other policies enacted in the same period as EPT Law. Limited by data acquisition, 107 cities from 2015 to 2019 are selected as final research samples, including 50 cities in the experimental group and 57 cities in the control group. Specific sample selection is shown in Table 2.

3.2. Description of the employed variables and data

3.2.1. Explained variables

First of all, it is necessary to examine the policy effect of EPT Law on air pollutants and CO_2 emissions reduction respectively before testing the impact of EPT Law on the synergy of PR and CR. Hence, air pollutants, carbon dioxide and the synergy of PR and CR are three components of explained variables.

(1) Urban industrial sulfur dioxide emissions (*LNSO2*) and urban industrial particulate matter emissions (*LNPM*). These are two main indicators for air pollutants, measured by the amounts of emissions each city published that year and logarithmic values are taken to ensure the smoothness of the data respectively.

(2) Urban industrial carbon dioxide (*LNCO2*). By referring to IPCC (2006) and Ren et al. (2019), *LNCO2* is determined according to the consumption data of three energy sources, namely urban industrial electricity, urban industrial natural gas and urban

Table 2
Sample selection.

	Provinces	SO_2 tax rate (Yuan/pollution equivalent)	PM tax rate (Yuan/pollution equivalent)	Cities
Experimental group	Beijing	12	12	Beijing
	Jiangsu	Wuxi and Suzhou are taxed 6, while other cities all taxed 4.8		Wuxi, Suqian, Yangzhou, Suzhou, Xuzhou, Nantong, Taizhou, Lianyungang
	Hebei	Divided by region, the first level is 9.6, the second is 6, and the third is 4.8		Xingtai, Cangzhou, Handan, Langfang, Baoding, Hengshui, Tangshan, Chengde, Zhangjiakou, Qinhuangdao
	Henan	4.8	4.8	Xuchang, Hebi, Sanmenxia, Zhoukou, Luohe
	Sichuan	3.9	3.9	Guangyuan, Leshan, Neijiang, Luzhou
	Hunan	2.4	2.4	Shaoyang, Yiyang, Yongzhou, Changde, Zhangjiajie, Hengyang
	Shandong	6	1.2	Rizhao, Binzhou, Weihai, Dezhou, Linyi, Zibo, Qingdao, Zaozhuang
	Shanxi	1.8	1.8	Xinzhou, Jincheng
	Guangxi	1.8	1.8	Guilin, Beihai, Yulin, Nanning, Wuzhou, Laibin
Control group	Hubei	2.4	1.2	Yichang, Xiaogan, Suizhou, Jingmen, Huangshi, Xiangyang, Shiyan
	Guangdong	1.8	1.8	Yangjiang, Shaoguan
	Shanghai	6.65/7.6	1.2	Shanghai
	Yunnan	1.2	1.2	Qujing, Baoshan
	Jilin	1.2	1.2	Songyuan Changchun Siping Jilin Baishan
	Ningxia	1.2	1.2	Guyuan
	Anhui	1.2	1.2	Wuhu
	Xinjiang	1.2	1.2	Urumqi, Karamay
	Jiangxi	1.2	1.2	Jingdezhen, Xinyu, Jiujiang, Yingtan, Ganzhou, Yichun, Pingxiang, Shangrao
	Zhejiang	1.2	1.2	Shaoxing, Hangzhou, Huzhou, Ningbo, Taizhou
	Gansu	1.2	1.2	Jiuquan, Longnan, Qingyang, Baiyin
	Fujian	1.2	1.2	Nanping, Ningde, Zhangzhou, Putian, Fuzhou, Xiamen, Quanzhou
	Liaoning	1.2	1.2	Yingkou, Fuxin, Benxi, Panjin, Fushun
	Shaanxi	1.2	1.2	Weinan, Baoji, Tongchuan, Yan'An, Xianyang
	Heilongjiang	1.2	1.2	Qitaihe, Daqing

industrial liquefied petroleum gas, and their corresponding carbon emission factors.

(3) Synergistic reduction degree of "SO_2-CO_2" (*COFA*) and synergistic reduction degree of "PM-CO_2" (*COFB*). These are two indexes capturing the synergy of PR and CR. The measurements of *COFA* and *COFB* are improved based on the emissions reduction cross-elasticity index introduced by Mao et al. (2012b), which is shown in formula (1) and (2).

$$Esc = \frac{ECO2_{ghg}/CO2_{ghg}}{ESO2_{lap}/SO2_{lap}} \tag{1}$$

$$Epc = \frac{ECO2_{ghg}/CO2_{ghg}}{EPM_{lap}/PM_{lap}} \tag{2}$$

In formula (1), *Esc* represents the coordinated control cross-elasticity between SO_2 and CO_2, and the numerator and denominator suggest the growth rates of CO_2 and SO_2 equivalent emissions respectively. $SO2_{lap}$ means the total equivalent emissions of SO_2 in the previous year, and $CO2_{ghg}$ the total equivalent emissions of CO_2 in the previous year. $ECO2_{ghg}$ indicates the equivalent emissions of CO_2 in the current year minus that of in the previous year. Similarly, $ESO2_{lap}$ signifies the equivalent emissions of SO_2 in the current year minus that of in the previous year.

In formula (2), *Epc* represents the coordinated control cross-elasticity between PM and CO_2. PM_{lap} is the total equivalent emission of particulate matter in the previous year, and EPM_{lap} suggests the equivalent emission of particulate matter in the current year minus that of in the previous year.

Considering that it is not applicable to directly use the values of *Esc* and *Epc* for regression in econometric model due to their ambiguities on corresponding to the degree of synergy. For example, if the value of *Esc* is positive, it is hard to tell whether SO_2 and CO_2 are reduced or increased together. The synergistic degree of PR and CR can be reflected only after the division of the value of cross-elasticity according to the positive and negative of its numerator and denominator (Mao et al., 2021).

Therefore, we divided the degree of synergy into "anti-synergy, weak-synergy and strong-synergy" three levels and assigned values of −1, 0 and 1 respectively based on Mao et al. (2021). The definitions are as follows.

For *COFA*, first, if the numerator and denominator of *Esc* are both positive, it means that CO_2 and SO_2 emissions are increased simultaneously, and the policy plays an "anti-synergistic" role. We take *COFA* as −1 in this "anti-synergy" case. Then, if the numerator and denominator are different in positive and negative (including the case that either side is 0), indicating that there is often "pollution reduction and carbon increase " or "carbon reduction and pollution increase". No matter which pollutant and carbon dioxide are reduced more, the emission reduction of carbon and pollution does not change in the same direction, and this situation can be called "weak-synergy". We take *COFA* as 0 in this "weak-synergy" case. Finally, if both the numerator and denominator are negative, it means that CO_2 and SO_2 emissions are reduced simultaneously and the "strong-synergy" of PR and CR are realized. We take *COFA* as 1 in this "strong-synergy" case. *COFB* is measured in the same way as *COFA*.

3.2.2. Key explanatory variables

The multiplication term of policy and time variables (*Treat*×*After*) is the key explanatory variable. *Treat* is policy dummy variable, denoting whether the city belongs to experimental group (if it belongs to experimental group, *Treat* takes value of 1, and 0 otherwise). And *After* is the time dummy variable, being valued 0 if the year is before 2018, otherwise it is taken as 1. On the whole, *Treat*×*After* values 1 when the sample is from experimental group cities after the year of 2017, and 0 otherwise.

3.2.3. Mechanism variables

According to the inference for effectiveness of policy on the synergy of PR and CR mentioned in Section 2.4, we select environmental protection supervision, energy structure and green technology innovation as three mechanism variables.

(1) Environmental protection supervision (*LNGOV*). Drawing on the studies of Wang and Xu (2015), this paper uses the number of environmental administrative penalty cases received by each city in that year to characterize *LNGOV*, and takes its logarithm to analyze.
(2) Energy structure (*ES*). *ES* is often measured by the percentage of coal consumption to total energy consumption in cities in that year. We use the nighttime light data to decompose the provincial coal consumption and total energy consumption data of the current year into individual prefecture-level cities to derive the *ES* (Zhang et al., 2019b; Shi and Li, 2020).
(3) Green technology innovation (*PERPRAP*, *PERINVP*). Following Zhang et al. (2019a) and Shi and Li (2020), we choose urban green utility patents per capita (*PERPRAP*) and urban green invention patents per capita (*PERINVP*) to reflect the efforts made by enterprises for the progress of green technology.

3.2.4. Control variables

Following prior studies (Zhang et al., 2017; Lu et al., 2018; Ren et al., 2019; Wang et al., 2019), we need to control several variables that may affect PR and CR, including GDP per capita after logarithm (*LNPGDP*), industrial structure (*SEC*) measured by the proportion of added value of secondary industry in total GDP, urbanization rate (*CITYRT*) calculated by the ratio of urban resident population to total population, the urban investment in environmental management after logarithm (*LNENV*), foreign direct investment (*FDI*) computed by the percentage of foreign capital (converted into RMB units) to the city's total GDP in the current year, and number of cars owned after logarithm (*LNCAR*).

3.2.5. Data sources

Considering the availability of data, we collected data from 2015 to 2019 for all variables used. The data of most variables are gathered from the China Urban Statistical Yearbook (2016–2020), and the sources of other variables are as follows.

In mechanism variables, the data of *LNGOV* are collected from China Law Retrieval System.[3] Nighttime lighting data for cities and provinces are collected from the National Oceanic and Atmospheric Administration (NOAA). The data of *PERPRAP* and *PERINVP* are gained from the National Intellectual Property Database and matched with the green list of the international patent classification of the World Intellectual Property Organization (WIPO).

In control variables, the data of *LNENV* are collected from the China Urban Construction Statistical Yearbook (2016–2020), and the data of *LNCAR* are gotten from the websites of the statistical bureaus of each city.

Additionally, in the calculation of urban industrial carbon emissions, the proportion of coal and electricity consumption are obtained from the China Electricity Statistical Yearbook (2016–2020) and the China Electricity Yearbook (2016–2020).

3.3. Baseline model

Many studies use CGE-related equilibrium model to estimate the effect of tax policy (Xiao et al., 2015; Wang et al., 2017; Jiang et al., 2022), but this method often gets rough policy simulation results, rather than the implementation effect evaluation of current policy. DID model, being widely applied in the field of policy evaluation (Corrigan et al., 2018; Wang and Qiu, 2021; Xu et al., 2021), can overcome this shortcoming by subtracting the policy changes of the control group from that of the experimental group and thus estimate the net policy effects.

[3] https://www.pkulaw.com/law?isFromV5=1

This paper adopts DID method to estimate the impact of EPT Law on the synergy of PR and CR accurately. The baseline model is constructed as shown in (3).

$$Y_{it} = \beta_0 + \beta_1 Treat_{it} \times After_{it} + \lambda \sum Controls_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (3)$$

In model (3), Y_{it} represents all explained variables, including *LNSO2, LNPM, LNCO2, COFA*, and *COFB*; $Controls_{it}$ indicates six control variables; μ_i and ν_t signify individual fixed effects and time fixed effects respectively, and ε_{it} is the random disturbance term. If the coefficient β_1 is significantly positive, it means the synergy of PR and CR of experimental group cities has been improved after EPT Law is implemented.

4. Results and discussion

4.1. Descriptive statistics and parallel trend test

4.1.1. Descriptive statistics

Descriptive statistics results of total research samples are reported in Table 3, with the experimental group (EG) containing 250 observations and the control group (CG) 285. Basically, it can be seen that the distribution of the values of all variables in experimental and control group are similar, suggesting two groups are comparable. For *COFA*, the mean value is 0.46 for experimental group and 0.28 for control group. With regard to *COFB*, the mean value in experimental group is 0.35 and the control group 0.14. These indicate that the number of cities in the experimental group achieving the “strong-synergy” of PR and CR is slightly more than that in the control group. In mechanism variables, the average environmental protection supervision level of the experimental group is pretty higher than that of the control group, representing 3.81 and 3.06 respectively. Other mechanism variables show little difference relatively between experimental and control group. In addition, there are no outliers in the sample according to quantiles of each variable.

In order to intuitively reflect the status quo of the synergistic degree of urban PR and CR, scatter diagrams of *COFA* and *COFB* are drawn respectively in Fig. 1 and Fig. 2. The X-axis represents pollutants emission reduction, which is calculated by subtracting the pollutants equivalent emissions of the previous year from that of the current year. Similarly, Y-axis represents carbon emission reduction. Each blue dot represents a city in a particular year. The dots in the third quadrant represent cities realizing the “strong-synergy” of PR and CR. Both the second and fourth quadrants represent “weak-synergy”, and the first quadrant represents “anti-synergy”.

As can be seen from Fig. 1 and Fig. 2, there are more cities realizing the “strong-synergy” of “SO_2-CO_2” than that of “PM-CO_2”. Also, cities not realizing the “strong-synergy” of “SO_2-CO_2” are mainly distributed in the regions of “anti-synergy” and “weak-synergy”, while cities not realizing the “strong-synergy” of “PM-CO_2” are mainly distributed in the region of “weak-synergy”.

4.1.2. Parallel trend test

Parallel trend is the prerequisite for DID model, which means explained variables in the experimental and control groups have approximate development dynamics before occurrence of the policy. This study uses event study method to testify parallel trend by introducing the multiplication term of dummy variables and policy variable *Treat* for each year (the multiplication variables from 2015 to 2019 are *PRE_3*, *PRE_2*, *PRE_1*, *CURRENT*, and *TIME_1* successively) to the model (3). To avoid complete collinearity, the regression is carried out after *PRE_1* is removed and the final results are shown in Table 4.

It is noticed that the regression coefficients of *PRE_3* and *PRE_2* are not significant for all the explained variables, stating that there are few differences before 2018 between experimental and control group in terms of *LNSO2*, *LNPM*, *LNCO2*, *COFA*, and *COFB*. Therefore, the parallel trend assumption holds true.

4.2. Results of baseline model

To test **H1**, Table 5 reports the net policy effects of EPT Law on PR, CR and the synergy of PR and CR.

Columns (1) ~ (2) show the regression results on *LNSO2* and *LNPM*, and the coefficients of *Treat*×*After* are both significantly negative

Table 3
Descriptive statistics.

Variables		Sample	Mean	Standard deviation	Min	25th quantile	Median	75th quantile	Max
LNSO2	EG	250	9.67	1.16	6.25	8.96	9.66	10.60	12.28
	CG	285	9.53	1.07	5.36	8.86	9.57	10.29	12.05
LNPM	EG	250	9.54	1.23	5.69	8.72	9.48	10.36	14.44
	CG	285	9.38	1.15	6.46	8.63	9.37	10.27	12.02
LNCO2	EG	250	15.38	1.14	12.20	14.71	15.35	16.11	18.08
	CG	285	15.10	1.17	11.02	14.43	15.23	15.86	17.98
COFA	EG	250	0.46	0.59	−1.00	0.00	1.00	1.00	1.00
	CG	285	0.28	0.60	−1.00	0.00	0.00	1.00	1.00
COFB	EG	250	0.35	0.66	−1.00	0.00	0.00	1.00	1.00
	CG	285	0.14	0.67	−1.00	0.00	0.00	1.00	1.00
LNPGDP	EG	250	10.85	0.51	9.86	10.46	10.79	11.12	12.10
	CG	285	10.93	0.52	9.41	10.58	10.93	11.32	12.15
SEC	EG	250	44.36	9.52	14.74	39.76	45.12	49.39	65.28
	CG	285	45.94	10.10	13.57	40.79	47.27	52.18	72.90
CITYRT	EG	250	56.24	9.29	37.85	49.55	54.34	61.00	86.60
	CG	285	58.89	14.19	28.16	51.30	57.91	67.03	99.13
LNENV	EG	250	10.38	2.22	0.00	9.63	10.76	11.56	15.40
	CG	285	9.07	3.43	0.00	8.25	9.95	11.13	14.38
FDI	EG	250	0.02	0.02	0.00	0.01	0.01	0.02	0.07
	CG	285	0.02	0.02	0.00	0.00	0.01	0.03	0.18
LNCAR	EG	250	6.58	0.79	4.72	6.01	6.61	7.06	8.68
	CG	285	6.03	0.84	4.34	5.41	5.90	6.53	8.40
LNGOV	EG	250	3.81	1.98	0.00	2.71	4.10	5.19	8.53
	CG	285	3.06	2.03	0.00	1.61	3.14	4.39	8.23
ES	EG	250	0.63	0.27	0.02	0.50	0.64	0.74	1.76
	CG	285	0.64	0.23	0.26	0.47	0.59	0.84	1.28
PERPRAP	EG	250	0.99	1.83	0.03	0.19	0.40	0.81	13.45
	CG	285	1.00	1.39	0.01	0.20	0.42	1.12	7.88
PERINVP	EG	250	1.06	2.45	0.02	0.14	0.25	0.86	18.92
	CG	285	0.85	1.51	0.01	0.13	0.27	0.68	10.06

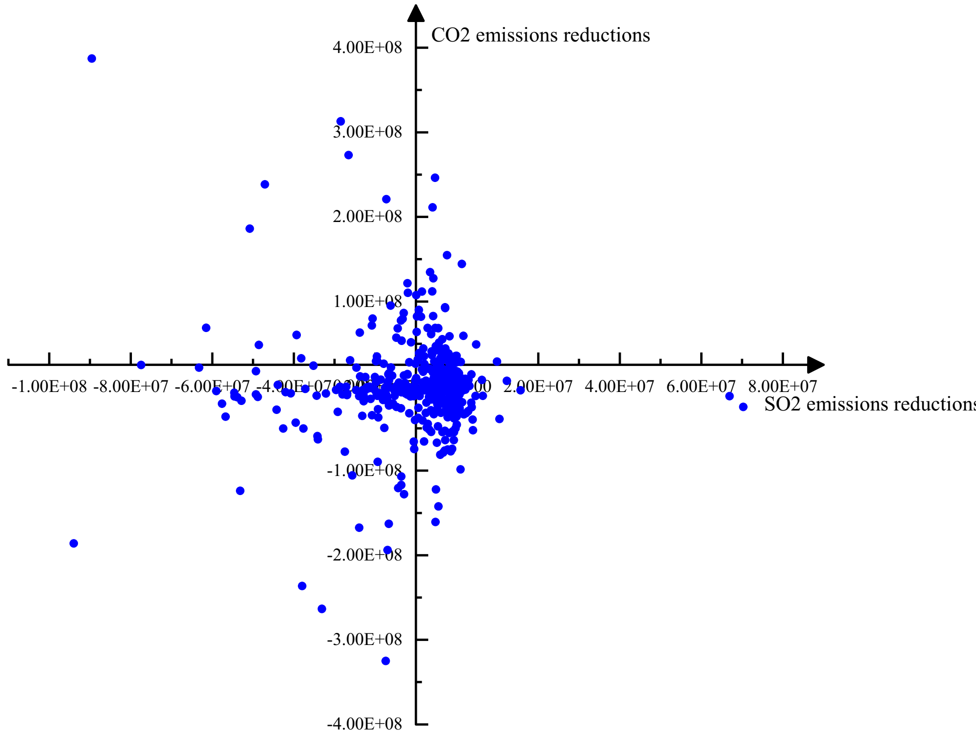

Fig. 1. Distribution of cities on *COFA*.

(−0.14 for SO_2, −0.14 for PM). This implies that EPT Law has significantly reduced urban sulfur dioxide emissions and urban particulate matter emissions. Overall, after controlling for other variables, cities with higher tax rates had a decrease in SO_2 emissions by 14% and a decrease in PM emissions by 14% compared to those cities with the same standards as pollution discharge rates.

Column (3) illustrates that CO_2 emissions of cities in experimental group has been significantly declined by 13% due to EPT Law, associated with the coefficient of *Treat*× *After* being −0.13 ($p < 0.1$).

Column (4) ~ (5) demonstrate the net policy effects of EPT Law on the synergistic degree of PR and CR. It can be seen that the regression coefficients of *Treat*×*After* are both significantly positive at 1% level on *COFA* and *COFB*, respectively 0.41 and 0.39, meaning that the policy can promote the improvement of the synergy of PR and CR, and thus each unit of pollutant reduction can drive more units of CO_2 emissions reduction. H1 is supported.

As the space for reducing air pollutants gradually tightens, carbon dioxide is likely to be included as a sub-tax item in EPT Law in the

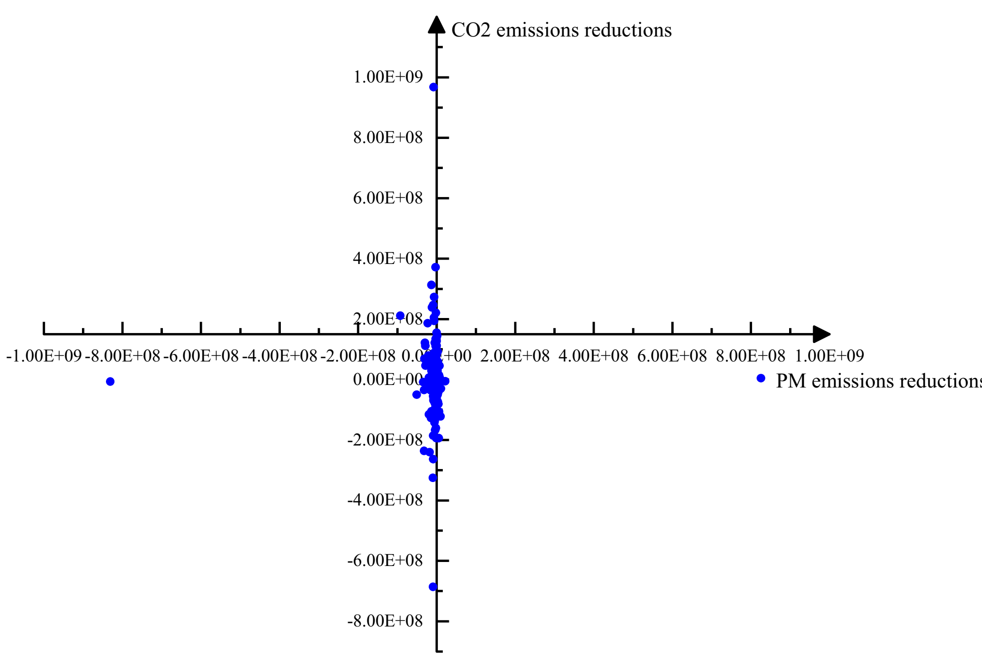

Fig. 2. Distribution of cities on *COFB*.

Table 4
Parallel trend test.

	(1) LNSO2	(2) LNPM	(3) LNCO2	(4) COFA	(5) COFB
PRE_3	0.078	0.027	0.039	0.19	0.21
	(0.64)	(0.22)	(0.36)	(1.63)	(1.60)
PRE_2	0.12	0.10	0.012	0.077	0.094
	(1.14)	(1.14)	(0.10)	(0.72)	(0.75)
CURRENT	−0.033	−0.036	−0.11	0.95***	0.86***
	(−0.34)	(−0.43)	(−1.25)	(8.36)	(6.38)
TIME_1	−0.11	−0.17*	−0.11	0.010	0.091
	(−0.93)	(−1.74)	(−1.19)	(0.08)	(0.59)
LNPGDP	−0.039	0.11	0.55***	0.18	0.17
	(−0.24)	(0.64)	(3.49)	(1.10)	(0.79)
SEC	−0.0068	−0.0077*	−0.016***	0.0053	0.0019
	(−1.40)	(−1.82)	(−3.13)	(1.08)	(0.29)
CITYRT	0.0061	−0.0076	0.079***	0.049**	0.010
	(0.28)	(−0.41)	(3.05)	(2.38)	(0.37)
LNENV	−0.0037	−0.0064	−0.0017	0.0083	0.0073
	(−0.40)	(−0.73)	(−0.17)	(0.85)	(0.67)
FDI	0.35	0.74	2.38	−1.44	−5.53***
	(0.31)	(0.76)	(1.51)	(−0.81)	(−3.17)
LNCAR	0.42	0.037	0.0021	0.22	−0.37
	(1.32)	(0.11)	(0.01)	(0.71)	(−1.02)
constant	8.46***	9.11***	5.51***	−3.88*	0.92
	(4.37)	(3.56)	(2.86)	(−1.71)	(0.35)
Year-fixed	YES	YES	YES	YES	YES
City-fixed	YES	YES	YES	YES	YES
R^2	0.90	0.91	0.92	0.59	0.55
sample	535	535	535	535	535

Note: *p < 0.1, **p < 0.05, ***p < 0.01, t-values in parentheses.

future (Liu et al., 2021a; Ma et al., 2022). If the introduction of carbon tax is the direction of EPT policy reform in the next step, the synergistic emission reduction effects of air pollutants on CO_2 should be taken into account in the formulation of carbon tax rate, and a differentiated carbon tax rate matching current pollution tax rates could be a suitable choice.

4.3. Robustness checks

To confirm the reliability of main findings, three methods including placebo test, propensity score matching combined with DID method (PSM-DID), and replacement with spatial Dubin model, are adopted for robustness checks.

Table 5
DID regression results.

	(1) LNSO2	(2) LNPM	(3) LNCO2	(4) COFA	(5) COFB
Treat×After	−0.14*	−0.14**	−0.13*	0.41***	0.39***
	(−1.87)	(−2.03)	(−1.72)	(4.51)	(3.70)
LNPGDP	−0.014	0.13	0.56***	0.28*	0.25
	(−0.09)	(0.81)	(3.63)	(1.68)	(1.20)
SEC	−0.0066	−0.0074*	−0.016***	0.0066	0.0030
	(−1.34)	(−1.75)	(−3.14)	(1.21)	(0.42)
CITYRT	0.0023	−0.010	0.077***	0.030	−0.0073
	(0.11)	(−0.53)	(3.15)	(1.38)	(−0.27)
LNENV	−0.0035	−0.0060	−0.0019	0.0077	0.0068
	(−0.37)	(−0.67)	(−0.18)	(0.74)	(0.60)
FDI	0.60	0.86	2.45	−1.52	−5.47***
	(0.55)	(0.86)	(1.60)	(−0.94)	(−3.13)
LNCAR	0.41	0.016	0.0062	0.14	−0.44
	(1.29)	(0.05)	(0.03)	(0.40)	(−1.12)
constant	8.37***	9.01***	5.52***	−3.70	1.06
	(4.36)	(3.50)	(2.92)	(−1.61)	(0.40)
Year-fixed	YES	YES	YES	YES	YES
City-fixed	YES	YES	YES	YES	YES
R^2	0.90	0.91	0.92	0.53	0.52
sample	535	535	535	535	535

Note: *p < 0.1, **p < 0.05, ***p < 0.01, t-values in parentheses.

4.3.1. Robustness checks using placebo test

With reference to Cai et al. (2016), a placebo test is conducted by fabricating treatment groups through a random sampling to make a robustness check.

First, 50 cities were selected randomly from the total sample of 107 cities as the experimental group, and the rest as control group. Then, a new multiplication term *Treat2* × *After* was constructed according to the new sample grouping and reconducted regression with DID models. Next, the first two steps were repeated 500 times. Then, the distribution of the 500 regression coefficients and their corresponding p-values were obtained. Finally, we plotted the distribution of those 500 coefficients and p-values in Fig. 3.

As is depicted in Fig. 3, the estimated coefficients are mostly clustered around 0 and the vast majority of p-values are greater than 0.1 (not significant), indicating that previous estimates are unlikely to be influenced by other randomness factors. Therefore, the results of placebo test prove the robustness of our main conclusion.

4.3.2. Robustness checks using the PSM-DID approach

In order to address the possible selection bias in policy evaluation for the reason that the experimental group is not randomly generated, the method of propensity-score-matching (PSM) combined with DID is used for further robustness test. PSM can make the quasi-natural experiment of the EPT Law "approximately" randomized by matching each sample in experimental group to a specific sample in control group according to propensity matching score calculated based on specially designated covariates.

We employed the kernel matching method with put-back to carry out the matching work, accompanied by matching covariates including *LNPGDP*, *SEC*, *CITYRT*, *LNENV*, *FDI*, *LNCAR* and annual dummy variables. After matching work, DID regressions were performed based on the new matched samples (525 observations) and the weights of the covariates. The final results are presented in Table 6.

It is evident from Table 6 that the sign and significance of all coefficients of *Treat×After* are consistent with previous findings, indicating the main conclusion is robust.

4.3.3. Robustness checks using Spatial Dubin Model

Spatial Dubin Model (SDM) is often applied in the studies related to air pollution and carbon emissions because of the spillover effects of environmental pollution and the spatial distribution of CO_2 emissions (Li and Li, 2020; Wang et al., 2021). In this paper, SDM is employed based on DID method to test H1 again. We regard the spatial matrix of inverse distances between cities after standardization as the spatial weight matrix and the obtained regression results are tabulated in Table 7.

Table 7 represents the direct effects regression results of the SDM, indicating that the EPT Law has significantly reduced the emissions of urban industrial sulfur dioxide, urban industrial particulate matter, and urban carbon dioxide emissions, and also significantly increased the synergistic reduction degree of "SO_2-CO_2" and "PM-CO_2". These findings sustain the H1 again, confirming the previous results are reliable.

4.4. Further tests

4.4.1. Mechanism analysis

The theoretical analyses mentioned in Section 2.4 have, to a certain extent, corroborated the effect of environmental protection supervision (*LNGOV*), energy structure (*ES*) and green technology innovation (*PERPRAP* and *PERINVP*) on the synergy of PR and CR. We then employ the empirical tests on whether the policy can exert significant influence on these three mechanism variables to verify their validities, with the regression results shown in Table 8.

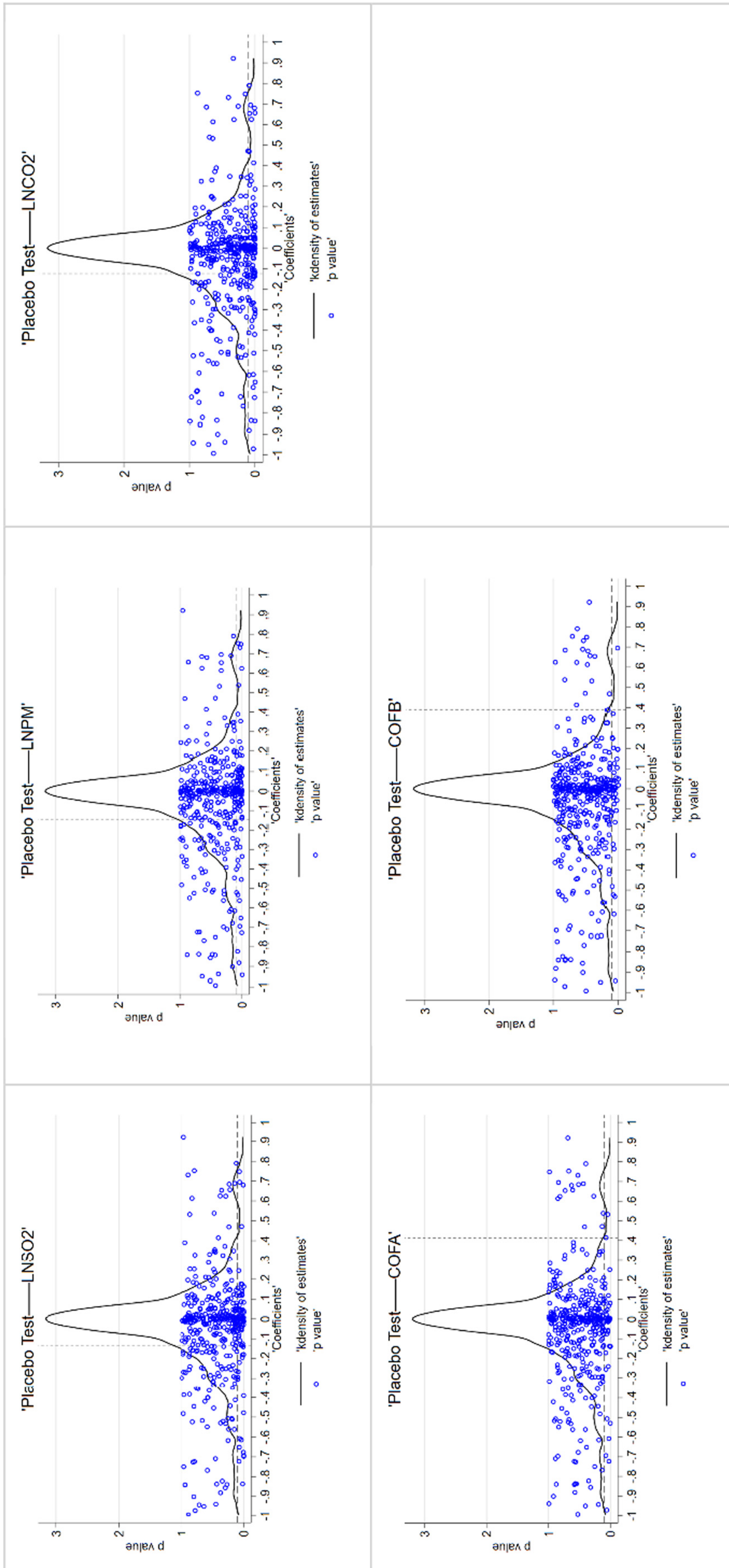

Fig. 3. Placebo test.

Table 6
PSM-DID regression results.

	(1)	(2)	(3)	(4)	(5)
	LNSO2	*LNPM*	*LNCO2*	*COFA*	*COFB*
Treat×After	−0.19**	−0.21***	−0.30***	0.41***	0.43***
	(−2.50)	(−2.74)	(−3.54)	(4.29)	(3.73)
LNPGDP	0.15	0.31	0.50***	0.35	0.43*
	(0.86)	(1.60)	(3.01)	(1.50)	(1.94)
SEC	−0.0095*	−0.013**	−0.020***	0.0078	0.00084
	(−1.73)	(−2.52)	(−3.41)	(1.25)	(0.11)
CITYRT	0.011	−0.0055	0.096***	0.041	0.013
	(0.41)	(−0.25)	(3.74)	(1.64)	(0.47)
LNENV	−0.0027	−0.019*	0.0025	0.0038	0.011
	(−0.24)	(−1.86)	(0.17)	(0.25)	(0.71)
FDI	0.40	1.27	3.58***	−0.96	−5.10***
	(0.35)	(1.21)	(2.79)	(−0.46)	(−2.92)
LNCAR	0.32	−0.20	−0.057	−0.017	−0.10
	(0.92)	(−0.58)	(−0.16)	(−0.05)	(−0.21)
constant	6.95***	8.42***	5.73***	−4.08	−3.16
	(3.44)	(3.20)	(2.77)	(−1.50)	(−1.03)
Year-fixed	YES	YES	YES	YES	YES
City-fixed	YES	YES	YES	YES	YES
R^2	0.91	0.91	0.93	0.56	0.56
sample	525	525	525	525	525

Note: *p < 0.1, **p < 0.05, ***p < 0.01, t-values in parentheses.

Table 8
Mechanism analysis results.

	(1)	(2)	(3)	(4)
	LNGOV	*ES*	*PERPRAP*	*PERINVP*
Treat×After	1.15***	−0.050***	0.30**	0.014
	(5.60)	(−3.73)	(2.26)	(0.11)
LNPGDP	−1.43***	−0.092*	0.71***	0.78***
	(−2.66)	(−1.69)	(4.12)	(2.97)
SEC	−0.0037	0.00091	0.018***	0.0054
	(−0.27)	(0.86)	(2.89)	(1.32)
CITYRT	0.10*	0.0026	−0.14***	−0.12**
	(1.92)	(0.73)	(−3.44)	(−2.48)
LNENV	−0.025	−0.0034*	0.0013	0.016**
	(−1.06)	(−1.73)	(0.20)	(2.37)
FDI	−6.57	−1.34	−2.47	−3.79*
	(−1.60)	(−1.55)	(−1.62)	(−1.90)
LNCAR	−0.69	0.030	−0.37	−1.51***
	(−0.86)	(0.83)	(−1.39)	(−2.60)
constant	14.49**	1.53***	−1.23	3.28
	(2.44)	(3.45)	(−0.74)	(1.28)
Year-fixed	YES	YES	YES	YES
City-fixed	YES	YES	YES	YES
R^2	0.76	0.90	0.92	0.94
sample	535	535	535	535

Note: *p < 0.1, **p < 0.05, ***p < 0.01, t-values in parentheses.

As is depicted in Table 8, results in Column (1) capture the impact of EPT Law on *LNGOV*, indicating that environmental protection supervision is significantly increased in that the coefficient of *Treat×After* is significantly positive (1.15, $p < 0.01$). Meanwhile, *ES* gets significantly optimized by reason of the implementation of the EPT policy, with the coefficient being significantly negative (−0.050, $p < 0.01$). Columns (3) ~ (4) show that *PERPRAP* is significantly increased (the coefficient of *Treat×After* is 0.30, $p < 0.05$), while the policy effect on *PERINVP* is not significant. Considering that green invention patents often have larger scopes and longer review periods than green utility patents, the data limitation coupled with the time lag of *PERINVP* are the possible reasons for its insignificance. Basically, it can be concluded that these three types of variables are significantly affected by the EPT Law and H2 is supported.

According to the combination of theoretical and empirical analysis, it is confirmed that strengthening environmental protection supervision, optimizing energy structure and improving green technology innovation are main transmission mechanisms through which the EPT Law can improve the synergy of PR and CR significantly.

Table 7
Spatial Dubin Model regression results.

	(1)	(2)	(3)	(4)	(5)
Main	*LNSO2*	*LNPM*	*LNCO2*	*COFA*	*COFB*
Treat×After	−0.17***	−0.15**	−0.12**	0.43***	0.40***
	(−2.72)	(−2.34)	(−1.99)	(5.71)	(4.59)
LNPGDP	−0.04	0.19	0.55***	0.26	0.21
	(−0.27)	(1.27)	(3.84)	(1.47)	(1.06)
SEC	−0.0050	−0.0059	−0.015***	0.0064	0.0033
	(−1.18)	(−1.38)	(−3.75)	(1.29)	(0.57)
CITYRT	0.012	−0.0082	0.072***	0.029	−0.0058
	(0.68)	(−0.46)	(4.21)	(1.43)	(−0.24)
LNENV	−0.0036	−0.0069	−0.0028	0.0073	0.0065
	(−0.46)	(−0.87)	(−0.37)	(0.79)	(0.62)
FDI	0.78	0.76	3.22**	−1.95	−5.54***
	(0.55)	(0.52)	(2.30)	(−1.15)	(−2.84)
LNCAR	0.40*	−0.039	0.067	0.18	−0.40
	(1.69)	(−0.16)	(0.29)	(0.64)	(−1.23)
R^2	0.21	0.12	0.0046	0.25	0.25
sample	535	535	535	535	535

Note: *p < 0.1, **p < 0.05, ***p < 0.01, t-values in parentheses.

4.4.2. Heterogeneity analysis

According to our main conclusion, the improvement of synergistic degree of PR and CR benefits from the increase of air pollutants tax rate. Further, is the greater the increase of tax rate, the greater the increase of synergistic degree? Exploring the differences of policy effects caused by different magnitudes of tax rate increase is inevitable to meet the requirements of EPT's tax rate reform.

This paper selects 2.4 Yuan, 4.8 Yuan and 6 Yuan as three tiers and divides the experimental group into six experimental sub-groups based on them. Then, the six new sub-samples are regressed respectively, with the results depicted in Table 9 and Table 10.

Table 9 presents the comparison among policy effects under different SO_2 tax rates. It can be seen that the coefficient of *Treat×After* in column (1) is not significant, meaning that the synergy of PR and CR cannot be improved when the tax rate of SO_2 is increased but less than 2.4 Yuan. Notably, the effects of EPT on *COFA* are significantly strengthened when

Table 9
Policy effects of different tax rates for SO_2.

	(1)	(2)	(3)	(4)	(5)	(6)
	<2.4	≥2.4	<4.8	≥4.8	<6	≥6
	COFA	*COFA*	*COFA*	*COFA*	*COFA*	*COFA*
Treat×After	0.24	0.44***	0.33**	0.44***	0.34***	0.58***
	(1.11)	(4.62)	(2.32)	(4.29)	(3.28)	(4.13)
LNPGDP	0.27	0.23	0.27	0.27	0.26	0.31*
	(1.46)	(1.35)	(1.46)	(1.62)	(1.52)	(1.71)
SEC	0.0054	0.0050	0.0074	0.0017	0.0052	0.0037
	(0.89)	(0.81)	(1.23)	(0.27)	(0.94)	(0.54)
CITYRT	0.072***	0.028	0.059**	0.033	0.041	0.060**
	(2.65)	(1.30)	(2.14)	(1.53)	(1.50)	(2.55)
LNENV	0.0094	0.011	0.012	0.0087	0.0079	0.014
	(0.78)	(1.09)	(1.08)	(0.82)	(0.75)	(1.27)
FDI	−1.77	−1.21	−1.73	−1.23	−1.74	−1.22
	(−1.05)	(−0.72)	(−1.06)	(−0.72)	(−1.09)	(−0.70)
LNCAR	0.19	0.36	0.20	0.38	0.11	0.64
	(0.41)	(1.05)	(0.46)	(1.07)	(0.31)	(1.48)
constant	−5.55**	−4.27*	−5.20*	−4.84**	−3.78	−7.73***
	(−1.98)	(−1.80)	(−1.89)	(−2.02)	(−1.60)	(−2.80)
Year-fixed	YES	YES	YES	YES	YES	YES
City-fixed	YES	YES	YES	YES	YES	YES
R^2	0.53	0.54	0.53	0.54	0.53	0.56
sample	325	495	375	445	470	350

Note: *p < 0.1, **p < 0.05, ***p < 0.01, t-values in parentheses.

Table 10
Policy effects of different tax rates for PM.

	(1)	(2)	(3)	(4)	(5)	(6)
	<2.4	≥2.4	<4.8	≥4.8	<6	≥6
	COFB	*COFB*	*COFB*	*COFB*	*COFB*	*COFB*
Treat×After	0.37	0.40***	0.38**	0.41***	0.40***	0.48*
	(1.58)	(3.61)	(2.36)	(3.54)	(3.67)	(1.87)
LNPGDP	0.39	0.18	0.42*	0.20	0.29	0.24
	(1.58)	(0.86)	(1.73)	(0.95)	(1.38)	(0.97)
SEC	0.0016	0.0011	0.0021	−0.00067	0.0035	−0.0022
	(0.19)	(0.14)	(0.27)	(−0.07)	(0.49)	(−0.22)
CITYRT	−0.0086	−0.0066	−0.026	0.0035	−0.019	0.016
	(−0.23)	(−0.25)	(−0.67)	(0.13)	(−0.65)	(0.49)
LNENV	0.0014	0.0095	0.0088	0.0027	0.0066	0.0054
	(0.11)	(0.83)	(0.69)	(0.23)	(0.59)	(0.41)
FDI	−6.46***	−5.42***	−6.35***	−5.57***	−5.86***	−6.03***
	(−3.53)	(−3.14)	(−3.49)	(−3.21)	(−3.36)	(−3.38)
LNCAR	−0.66	−0.23	−0.65	−0.19	−0.49	−0.21
	(−1.37)	(−0.53)	(−1.43)	(−0.42)	(−1.20)	(−0.43)
constant	0.86	0.69	1.11	0.064	1.32	−0.66
	(0.30)	(0.25)	(0.39)	(0.02)	(0.49)	(−0.22)
Year-fixed	YES	YES	YES	YES	YES	YES
City-fixed	YES	YES	YES	YES	YES	YES
R^2	0.52	0.52	0.52	0.52	0.52	0.53
Sample	325	495	375	445	510	310

Note: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$, t-values in parentheses.

the SO_2 tax rate is greater than 2.4 Yuan according to column (3) and (5). Moreover, results in column (2), (4) and (5) present that the coefficients of *Treat×After* are significantly positive at 1% level if the lower tax rate limits are set to 2.4, 4.8 and 6 respectively. On the whole, the policy effect is more significant in areas where the minimum SO_2 tax rate is set at 2.4 Yuan or above.

Table 10 illustrates the estimated policy effects under different tax rates on PM. Unlike the results in Table 9, column (6) exhibits that the effect of EPT Law on *COFB* is weakened when the lower limit of tax rate on PM is set to 6. Results of column (1) ~ (5) are similar to those in Table 9. Overall, EPT Law has a greater effect on improving the synergy of PM reduction and CO_2 reduction in regions where the minimum PM tax rate is set between 2.4 Yuan and 6 Yuan.

To sum up, the improvement of "anti-synergy" and "weak-synergy" of PR and CR are significant in the regions where the tax rates of air pollutants are raised to a higher level. The results of heterogeneity analysis provide insights for local governments to adjust pollutant tax rates so as to strengthen the role of air pollutants in collaborative carbon reduction.

4.5. Discussion

Most of prior work has documented the effects of environmental tax on PR or CR. Wang et al. (2017), for instance, simulated the impact of environment tax on emission reduction based on the dynamic general equilibrium model. Han and Li (2020) identified the role of China's EPT Law in improving air quality. However, these studies either did not build the connection between PR and CR, or only used policy simulation method to simulate rather than evaluate the EPT policy effect. Although the synergy index of PR and CR has been introduced and used in some industries and regions (Mao et al., 2012b; Jia et al., 2016; Liu et al., 2017), relevant studies have not applied this indicator to the field of policy effect evaluation theoretically and the field of economic model regression methodologically.

Our paper complements the lack of research in the existing literature by evaluating the impact of China's EPT Law on the synergy of PR and CR based on DID model. We found that the synergistic reduction degree of "SO_2-CO_2" has been increased by 41% and the synergistic reduction degree of "PM-CO_2" by 39%, confirming that the EPT Law, although not including CO_2 as a taxable item, has the co-benefits on achieving the interconnection of coping with climate change and environmental pollution. These findings extend those of Niu et al. (2018), which assessed whether China's environmental tax shocks could reduce carbon emissions but only used an equilibrium model to simulate roughly.

Our research findings also shed a little light on China's possible carbon tax imposing in the future. Considering the homogeneity of air pollutants and CO_2 and the space for reducing air pollutants is gradually shrinking because some areas have already set the pollutants tax rates high enough, the levy of carbon tax is the general trend of EPT Law reform. We quantified the amount of carbon reduction driven by air pollutants emission reduction through research, which could provide guidance for the formulation of carbon tax rate.

In addition, our results also provide compelling evidence for helping cities recognize the importance of EPT Law on joint-control of greenhouse gases and pollution emissions. This paper suggests that EPT Law will lead to an increase in the number of cities that realize "strong-synergy" in reducing pollution and carbon emissions, driving the local government to better deploy its efforts to achieve the goals of "Beautiful China" and "Carbon Neutrality". Therefore, those provinces that have not yet implemented EPT Law will be motivated to actively enforce this policy after being inspired by the results of our study.

However, some limitations are worth concerning. Although our research has refined the research samples to the urban level, this estimation is not extremely perfect because the EPT Law targets micro enterprises. Future research is expected to overcome the limitations of data acquisition and further carry out detailed research around the synergy index of PR and CR from the enterprise level.

5. Conclusions and policy implications

For China, coordinated control of air pollutants and carbon dioxide emissions has become the target of further reform of environmental and economic policies including EPT Law. This study empirically evaluates the effects of the EPT Law on the synergy of PR and CR based on the samples of 107 cities in China from 2015–2019. The major findings show that EPT Law has significantly enhanced the synergistic degree of PR and CR. Specifically, the policy has significantly reduced industrial sulfur dioxide emissions, industrial particulate matter emissions and industrial carbon dioxide emissions in the experimental group cities by 14%, 14% and 13% respectively. And the synergistic reduction degree of "SO_2-CO_2" and "PM-CO_2" have been significantly increased by 41% and 39% respectively. Moreover, the improvement of environmental protection supervision, energy structure adjustment and green technology innovation are main transmission mechanisms where EPT Law plays a pivotal role in promoting the synergy of PR and CR. Further, we also find the policy effects on the synergy of PR and CR are most significant in regions that raised the SO_2 tax rate beyond 2.4 yuan and raised the PM tax rate between 2.4 Yuan and 6 Yuan.

Based on the above conclusions, this paper proposes three policy implications conducive to deepening the reform of EPT Law. First, it is imperative to encourage local governments to strictly enforce EPT Law, especially for those governments in areas where the tax rate still maintains the same level as pollutants discharge fee after the implementation of the EPT Law. Second, considering that carbon tax might be the next possible direction of EPT reform, the synergistic carbon reduction effects of air pollutant items should be taken into account when formulating the tax rate for carbon in the next step. Constructing a differentiated carbon tax rate system matching current pollution tax rate could be a recommended EPT policy reform direction. Finally, local governments should pay closer attention to improving the environmental protection supervision level and achieve the joint-control by the taxation department, the Ministry of Ecology and Environment and the Ministry of Industry and Information Technology. Besides, the government should also focus on adjusting the energy structure of cities and increasing support for green technology innovation, which could ensure the effect of EPT Law on the synergy of PR and CR so as to help establish a synergistic management system for reducing both pollution and carbon emissions.

CRediT authorship contribution statement

Xinwei Gao played a guiding role in the manuscript's validation, supervision and revision; Na Liu took charge of detailed analysis for the work and contributed to the writing and revising of the manuscript; Yujie Hua helped modify and edit the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to acknowledge financial support from the National Social Science Foundation Project of China (Grant No. 2020BTJ060) and the Natural Science Fund of Shandong Province (Grant No. ZR2020MG065). Any persistent errors or omissions are entirely the authors' responsibility.

Appendix A. Some calculation results of *COFA* and *COFB*

In order to clearly present the calculation process of *COFA* and *COFB*, we selected the data of two sample cities (Binzhou and Tongchuan) as examples to show the calculation process and results, as shown in Table 1.

Columns (1) to (3) represent the original emission data of CO_2, SO_2 and PM of each city in the specific year, and the unit of data is **ton**.

According to the concept of cross-elasticity, the original emission data of CO_2, SO_2, and PM should be converted into pollution equivalent first, and then the emission growth rate of each will be calculated. The pollution equivalent of CO_2 and the growth of CO_2, SO_2, and PM are shown in columns (4) to (9). For ease of calculation, the data in columns (4) to (9) are in **kilograms**.

The pollution equivalent numbers of SO_2 and PM are obtained by dividing the original emission data by their respective pollution equivalent factors (0.95 kg for SO_2 and 2.18 kg for PM). After figuring these out, we then subtract the pollution equivalent of the current year from that of the previous year to obtain the growth of SO_2 and PM respectively, as shown in columns (8) and (9).

The CO_2 pollution equivalent is calculated by multiplying the raw data (as in column (1)) by the ratio of the current carbon price to the tax rate on specific pollutants (See the notes in Table 1 for the carbon price in each year). The value of CO_2 pollution equivalent converted based on the SO_2 tax rate is named CO2SO2, as shown in column (4). CO2PM in column (5) is the equivalent value of CO_2 pollution equivalent converted on the basis of PM tax rate. Based on columns (4) and (5), the respective growth of CO2SO2 and CO2PM are calculated as shown in columns (8) and (9).

For *COFA*, the values of column (6) and column (8) are the key to determine the positivity of the numerator and denominator in the cross-elasticity formula, so we only need to observe the positivity of column (6) and column (8) to define *COFA*.

If the values of column (6) and column (8) are both positive, it indicates that the CO_2 and SO_2 emissions of this city in the current year have increased compared with previous year, which is the case of "anti-synergy", and *COFA* will be valued −1. If the values of column (6) and column (8) are different in positivity, it indicates that the city has the situation of "pollution reduction and carbon increase " or "carbon reduction and pollution increase", which is the case of "weak-synergy", and *COFA* is defined as 0. If the values of column (6) and column (8) are both negative, it indicates that both CO_2 and SO_2 emissions have reduced compared with previous year, which is the case of "strong-synergy", and *COFA* will be valued 1.

COFB is defined in the same way as *COFA* and will not be repeated here.

In Table 1, we list the *COFA* and *COFB* calculation results of Binzhou and Tongchuan for readers' reference.

Table 1
COFA and *COFB* calculation results of some cities.

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
CITY	YEAR	CO2	SO2	PM	CO2SO2	CO2PM	ΔCO2SO2	ΔCO2PM	ΔSO2	ΔPM	COFA	COFB
Binzhou	2015	9,499,155	93,909	30,123	99,202,842	2.48E+08	48,600,344	1.22E+08	−48,544,211	−29,440,826	0	0
Binzhou	2016	9,653,220.7	157,495	53,570	87,200,760	2.18E+08	−12,002,082	−30,005,206	66,932,632	10,755,505	0	0
Binzhou	2017	56,942,083	72,459	36,355	4.74E+08	1.19E+09	3.87E+08	9.68E+08	−89,511,579	−7,896,789	0	0
Binzhou	2018	69,032,239	56,638	30,481	3.12E+08	1.56E+09	−1.63E+08	3.71E+08	−16,653,684	−2,694,495.4	1	0
Binzhou	2019	61,805,640	34,939	24,877	2.94E+08	1.47E+09	−17,873,659	−89,368,296	−22,841,053	−2,570,642.2	1	1
Tongchuan	2015	1,469,425.8	16,891	54,209	38,364,259	38,364,259	−30,089,266	−30,089,266	−390,526.32	1,211,009.2	1	0
Tongchuan	2016	1,984,730.3	7258	11,844	44,821,825	44,821,825	6,457,566.6	6,457,566.6	−10,140,000	−19,433,486	0	0
Tongchuan	2017	2,574,683.7	8482	12,692	53,617,789	53,617,789	8,795,963.6	8,795,963.6	1,288,421.1	388,990.83	−1	−1
Tongchuan	2018	2,098,718.4	6601	13,147	47,343,589	47,343,589	−6,274,199.8	−6,274,199.8	−1,980,000	208,715.6	1	0
Tongchuan	2019	1,806,341.1	4731	9477	42,900,601	42,900,601	−4,442,987.7	−4,442,987.7	−1,968,421.1	−1,683,486.2	1	1

Note: The average carbon price from 2014 to 2019 are 0.04396 Yuan/kg, 0.03133Yuan/kg, 0.02710Yuan/kg, 0.02499Yuan/kg, 0.02707Yuan/kg and 0.02850Yuan/kg respectively. The data comes from the average annual transaction price of 8 carbon trading pilot markets in China.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.spc.2022.07.006.

References

Aydin, C., Esen, Ö., 2018. Reducing CO2 emissions in the EU member states: do environmental taxes work? J. Environ. Plan. Manag. 61 (13), 2396–2420. https://doi.org/10.1080/09640568.2017.1395731.

Bashir, M.F., Ma, B., Shahbaz, M., Jiao, Z., 2020. The nexus between environmental tax and carbon emissions with the roles of environmental technology and financial development. Plos One 15, e0242412. https://doi.org/10.1371/JOURNAL.PONE.0242412.

Bollen, J., van der Zwaan, B., Brink, C., Eerens, H., 2009. Local air pollution and global climate change: a combined cost-benefit analysis. Resour. Energy Econ. 31, 161–181. https://doi.org/10.1016/J.RESENEECO.2009.03.001.

Bonnet, C., Bouamra-Mechemache, Z., Corre, T., 2018. An environmental tax towards more sustainable food: empirical evidence of the consumption of animal products in France. Ecol. Econ. 147, 48–61. https://doi.org/10.1016/J.ECOLECON.2017.12.032.

Bovenberg, A.L., Goulder, L.H., 2002. Environmental taxation and regulation. Handbook of Public Economics. 3, pp. 1471–1545. https://doi.org/10.1016/S1573-4420(02)80027-1.

Cai, X., Lu, Y., Wu, M., Yu, L., 2016. Does environmental regulation drive away inbound foreign direct investment? Evidence from a quasi-natural experiment in China. J. Dev. Econ. 123, 73–85. https://doi.org/10.1016/J.JDEVECO.2016.08.003.

China's State Administration of Taxation (CSAT), 2020. China Economic and Social Development Yearbook 2020.

Corrigan, A.E., Becker, M.M., Neas, L.M., Cascio, W.E., Rappold, A.G., 2018. Fine particulate matters: the impact of air quality standards on cardiovascular mortality. Environ. Res. 161, 364–369. https://doi.org/10.1016/J.ENVRES.2017.11.025.

Dong, H., Dai, H., Dong, L., Fujita, T., Geng, Y., Klimont, Z., Inoue, T., Bunya, S., Fujii, M., Masui, T., 2015. Pursuing air pollutant co-benefits of CO2 mitigation in China: a provincial leveled analysis. Appl. Energy 144, 165–174. https://doi.org/10.1016/J.APENERGY.2015.02.020.

Fernández, E., Pérez, R., Ruiz, J., 2011. Optimal green tax reforms yielding double dividend. Energy Policy 39, 4253–4263. https://doi.org/10.1016/J.ENPOL.2011.04.041.

Gren, I.M., Bussolo, A.M., Hill, A.M., Pinelli, A.D., 2003. Ecological tax reforms and environmental benefits in Italy and Sweden. Reg. Environ. Chang. 3 (4), 146–153. https://doi.org/10.1007/S10113-002-0054-Z.

Guo, Q., Su, Z., Chiao, C., 2021. Carbon emissions trading policy, carbon finance, and carbon emissions reduction: evidence from a quasi-natural experiment in China. Econ. Chang. Restruct. 1–36. https://doi.org/10.1007/S10644-021-09353-5/TABLES/15.

Han, F., Li, J., 2020. Assessing impacts and determinants of China's environmental protection tax on improving air quality at provincial level based on bayesian statistics. J. Environ. Manag. 271, 111017. https://doi.org/10.1016/J.JENVMAN.2020.111017.

Huang, S., Lin, H., Zhou, Y., Ji, H., Zhu, N., 2022. The influence of the policy of replacing environmental protection fees with taxes on enterprise green innovation—Evidence from China's heavily polluting industries. Sustainability 14, 6850. https://doi.org/10.3390/su14116850.

Intergovernmental Panel on Climate Change (IPCC), 2001. Climate change 2001: Mitigation. Cambridge University Press, Cambridge.

IPCC, 2006. IPCC guidelines for national greenhouse gas inventories. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/.

Jia, X., Xin, G., Qian, Yi, Qian, Yu., 2016. Sectoral co-control of air pollutants: case of a chlor-alkali/polyvinyl chloride sector in China. J. Clean. Prod. 112, 1667–1675. https://doi.org/10.1016/J.JCLEPRO.2015.01.074.

Jiang, P., Chen, Y., Geng, Y., Dong, W., Xue, B., Xu, B., Li, W., 2013. Analysis of the co-benefits of climate change mitigation and air pollution reduction in China. J. Clean. Prod. 58, 130–137. https://doi.org/10.1016/J.JCLEPRO.2013.07.042.

Jiang, H.D., Hao, W.T., Xu, Q.Y., Liang, Q.M., 2020. Socio-economic and environmental impacts of the iron ore resource tax reform in China: a CGE-based analysis. Resources Policy 68, 101775. https://doi.org/10.1016/J.RESOURPOL.2020.101775.

Jiang, H.D., Liu, L.J., Deng, H.M., 2022. Co-benefit comparison of carbon tax, sulfur tax and nitrogen tax: the case of China. Sustain. Prod. Consum. 29, 239–248. https://doi.org/10.1016/J.SPC.2021.10.017.

Jin, Y., Gu, J., Zeng, H., 2020. Does "environmental protection fees replaced with environmental protection taxes" affect corporate performance? Account. Res. 5, 117–133 (in Chinese).

Khastar, M., Aslani, A., Nejati, M., 2020. How does carbon tax affect social welfare and emission reduction in Finland? Energy Rep. 6, 736–744. https://doi.org/10.1016/J.EGYR.2020.03.001.

Klenert, D., Schwerhoff, G., Edenhofer, O., Mattauch, L., 2018. Environmental taxation, inequality and Engel's law: the double dividend of redistribution. Environ. Resour. Econ. 71, 605–624. https://doi.org/10.1007/S10640-016-0070-Y/FIGURES/5.

Kou, P., Han, Y., Qi, X., Li, Y., 2021. Does China's policy of carbon emission trading deliver sulfur dioxide reduction co-benefits? Environ. Dev. Sustain. 1–22. https://doi.org/10.1007/S10668-021-01699-0/FIGURES/11.

Li, J., Li, S., 2020. Energy investment, economic growth and carbon emissions in China—empirical analysis based on spatial durbin model. Energy Policy 140, 111425. https://doi.org/10.1016/J.ENPOL.2020.111425.

Li, A., Lin, B., 2013. Comparing climate policies to reduce carbon emissions in China. Energy Policy 60, 667–674. https://doi.org/10.1016/J.ENPOL.2013.04.041.

Liu, Y.H., Liao, W.Y., Lin, X.F., Li, L., Zeng, X.Lan, 2017. Assessment of Co-benefits of vehicle emission reduction measures for 2015–2020 in the Pearl River Delta region, China. Environ. Pollut. 223, 62–72. https://doi.org/10.1016/J.ENVPOL.2016.12.031.

Liu, J., Bai, J., Deng, Y., Chen, X., Liu, X., 2021a. Impact of energy structure on carbon emission and economy of China in the scenario of carbon taxation. Sci. Total Environ. 762. https://doi.org/10.1016/j.scitotenv.2020.143093.

Liu, L., Jiang, J., Bian, J., Liu, Y., Lin, G., Yin, Y., 2021b. Are environmental regulations holding back industrial growth? Evidence from China. J. Clean. Prod. 306. https://doi.org/10.1016/j.jclepro.2021.127007.

Lu, J., 2022. Can environmental protection tax aggravate illegal pollution discharge of heavy polluting enterprises? Environ. Sci. Pollut. Res. 29, 33796–33808. https://doi.org/10.1007/s11356-021-18002-3.

Lu, H., Liu, Q., Qi, Y., 2018. Re-study on the pollution reduction effect of environmental tax: based on the change of China's sewage charges collection standards. J. China Univ. Geosci. 18, 67–82 (in Chinese).

Ma, N., Yin, G.W., Li, H., Sun, W.L., Wang, Z., Liu, G., Xie, D., 2022. The optimal industrial carbon tax for China under carbon intensity constraints: a dynamic input–output optimization model. Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-022-19162-6.

Mao, X., Yang, S., Liu, Q., Tu, J., Jaccard, M., 2012a. Achieving CO2 emission reduction and the co-benefits of local air pollution abatement in the transportation sector of China. Environ. Sci. Pol. 21, 1–13. https://doi.org/10.1016/J.ENVSCI.2012.03.010.

Mao, X., Zeng, A., Liu, S., Hu, T., Xing, Y., 2012b. Assessment of SO2, NOx and CO2 co-control effects by technological reduction measures in iron & steel industry. Acta Sci. Circumst. 32, 1253–1260. https://doi.org/10.13671/j.hjkxxb.2012.05.007.

Mao, X., Xing, Y., Gao, Y., He, F., Zeng, A., Kuai, P., Hu, T., 2021. Assessment and planning of synergistic control effects of greenhouse gases and air pollutants. China Environ. Sci. 41, 3390–3398 (in Chinese).

Mardones, C., Cabello, M., 2019. Effectiveness of local air pollution and GHG taxes: the case of chilean industrial sources. Energy Econ. 83, 491–500. https://doi.org/10.1016/J.ENECO.2019.08.007.

Niu, T., Yao, X., Shao, S., Li, D., Wang, W., 2018. Environmental tax shocks and carbon emissions: an estimated DSGE model. Struct. Chang. Econ. Dyn. 47, 9–17. https://doi.org/10.1016/J.STRUECO.2018.06.005.

Pigou Arthur Cecil, 1920. The Economics of Welfare. London.

Radulescu, M., Sinisi, C.I., Popescu, C., Iacob, S.E., Popescu, L., 2017. Environmental tax policy in Romania in the context of the EU: double dividend theory. Sustainability 9 (11), 1986. https://doi.org/10.3390/SU9111986.

Ren, Y., Ren, X., Hu, J., 2019. Driving factors of China's city-level carbon emissions from the perspective of spatial spillover effect. Carbon Manage. 10 (6), 551–566. https://doi.org/10.1080/17583004.2019.1676096.

Rodríguez, M., Robaina, M., Teotónio, C., 2019. Sectoral effects of a green tax reform in Portugal. Renew. Sust. Energ. Rev. 104, 408–418. https://doi.org/10.1016/J.RSER.2019.01.016.

Shi, D., Li, S., 2020. Emissions trading system and energy use efficiency——measurements and empirical evidence for cities at and above the prefecture level. China Ind. Econ. 9, 5–23 (in Chinese).

Swart, R., Amann, M., Raes, F., Tuinstra, W., 2004. A good climate for clean air: linkages between climate change and air pollution. Clim. Chang. 66, 263–269. https://doi.org/10.1023/B:CLIM.0000044677.41293.39.

Takeda, S., Arimura, T.H., 2021. A computable general equilibrium analysis of environmental tax reform in Japan with a forward-looking dynamic model. Sustain. Sci. 16 (2), 503–521. https://doi.org/10.1007/s11625-021-00903-4.

Wang, Z., Qiu, S., 2021. Can "energy saving and emission reduction" demonstration city selection actually contribute to pollution abatement in China? Sustain. Prod. Consum. 27, 1882–1902. https://doi.org/10.1016/J.SPC.2021.04.030.

Wang, S., Xu, Y., 2015. Environmental regulation and haze pollution decoupling effect: based on the perspective of enterprise investment preferences. China Ind. Econ. 4, 18–30 (in Chinese).

Wang, Z., Wu, J., Liu, C., Gu, G., 2017. The analysis for synergistic effect of policy of environmental tax with dynamic CGE in China. Integrated Assessment Models of Climate Change Economics, pp. 73–88 https://doi.org/10.1007/978-981-10-3945-4_5.

Wang, R., Zheng, X., Wang, H., Shan, Y., 2019. Emission drivers of cities at different industrialization phases in China. J. Environ. Manag. 250, 109494. https://doi.org/10.1016/J.JENVMAN.2019.109494.

Wang, F., Wang, R., He, Z., 2021. The impact of environmental pollution and green finance on the high-quality development of energy based on spatial dubin model. Resour. Policy 74, 102451. https://doi.org/10.1016/J.RESOURPOL.2021.102451.

Wesseh, P.K., Lin, B., 2016. Modeling environmental policy with and without abatement substitution: a tradeoff between economics and environment? Appl. Energy 167, 34–43. https://doi.org/10.1016/J.APENERGY.2016.01.031.

Xiao, B., Niu, D., Guo, X., Xu, X., 2015. The impacts of environmental tax in China: a dynamic recursive multi-sector CGE model. Energies 8 (8), 7777–7804. https://doi.org/10.3390/EN8087777.

Xu, H., Qiu, L., Liu, Baozhen, Liu, Bei, Wang, H., Lin, W., 2021. Does regional planning policy of Yangtze River Delta improve green technology innovation? Evidence from a quasi-natural experiment in China. Environ. Sci. Pollut. Res. 28, 62321–62337. https://doi.org/10.1007/S11356-021-14946-8/TABLES/7.

Xue, B., Ma, Z., Geng, Y., Heck, P., Ren, W., Tobias, M., Maas, A., Jiang, P., Puppim De Oliveira, J.A., Fujita, T., 2015. A life cycle co-benefits assessment of wind power in China. Renew. Sust. Energ. Rev. 41, 338–346. https://doi.org/10.1016/J.RSER.2014.08.056.

Yang, H., Gan, T., Liang, W., Liao, X., 2022. Can policies aimed at reducing carbon dioxide emissions help mitigate haze pollution? An empirical analysis of the emissions trading system. Environ. Dev. Sustain. 24, 1959–1980. https://doi.org/10.1007/S10668-021-01515-9/TABLES/7.

Yu, L., Sun, F., Bi, Q., Liu, Q., 2021. Will the tax reform of environmental protection fees help improve the capacity utilization of enterprises- quasi natural experimental evidence from the implementation of the environmental protection tax law. J. Shanghai Univ. Financ. Econ. 23, 32–47 (in Chinese).

Zhang, X., Guo, Z., Zheng, Y., Zhu, J., Yang, J., 2016. A CGE analysis of the impacts of a carbon tax on provincial economy in China. Emerg. Mark. Financ. Trade 52 (6), 1372–1384. https://doi.org/10.1080/1540496X.2016.1152801.

Zhang, N., Yu, K., Chen, Z., 2017. How does urbanization affect carbon dioxide emissions? A cross-country panel data analysis. Energy Policy 107, 678–687. https://doi.org/10.1016/J.ENPOL.2017.03.072.

Zhang, D., Rong, Z., Ji, Q., 2019a. Green innovation and firm performance: evidence from listed companies in China. Resour. Conserv. Recycl. 144, 48–55. https://doi.org/10.1016/J.RESCONREC.2019.01.023.

Zhang, P., Shi, X.P., Sun, Y.P., Cui, J., Shao, S., 2019b. Have China's provinces achieved their targets of energy intensity reduction? Reassessment based on nighttime lighting data. Energy Policy 128, 276–283. https://doi.org/10.1016/J.ENPOL.2019.01.014.

Zheng, X., Zhang, L., Yu, Y., Lin, S., 2011. On the nexus of SO2 and CO2 emissions in China: the ancillary benefits of CO2 emission reductions. Reg. Environ. Chang. 11, 883–891. https://doi.org/10.1007/S10113-011-0227-8/TABLES/3.