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RESEARCH ARTICLE

# Central environmental protection inspection and green technology innovation: empirical analysis based on the mechanism and spatial spillover effects

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**Abstract**
In this study, the central environmental protection inspection (CEPI) policy is considered a quasi-natural experiment. Based on the data of 216 Chinese cities from 2008 to 2018, the influence of CEPI on green technology innovation (GTI) is empirically examined mainly using difference-in-differences (DIDs), propensity score matching DID and spatial DID methods. The results indicate that CEPI can effectively promote GTI. Regarding different types of GTI, CEPI mainly promoted utilitarian GTI. Regarding the mechanism, CEPI significantly promotes local GTI mainly through the increase of environmental protection expenditure and research and development investment. Considering the dynamic marginal effect, CEPI starts to significantly promote GTI in the second year after the policy implementation but exhibited no effects in the third year. The extended study shows that GTI effect of CEPI only occurs in small-medium cities and big cities. Furthermore, there is a certain beggar-thy-neighbor effect between inspected and uninspected cities. Finally, the spatial decomposition of CEPI effects shows that the inhibitory effect of CEPI on GTI mainly occurs in the neighboring uninspected cities, while CEPI has no evident inhibition on GTI in neighboring inspected cities.

**Keywords** Central environmental protection inspection · Green technology innovation · Industrial structure optimization · Environmental protection expenditure · Research and development investment · Spatial difference-in-differences

## Introduction

With the acceleration of ecological progress and vigorous progress in the battle against pollution, the public has become increasingly concerned about environmental pollution. An effective means of solving environmental problems and achieving sustainable economic development is technological innovation (TI) (Chege and Wang 2020), especially green technology-oriented TI (Acemoglu et al. 2012). The fifth plenary session of the 19th Central Committee of the Chinese Communist Party called for the unswerving implementation of the new development philosophy, i.e., innovative, coordinated, green, open, and shared development. Innovation is the primary driving force of economic development, and green development is an important guarantee of ecological and environmental quality, indicating that green technology innovation (GTI) is the key to achieving high-quality economic development. China's emphasis on environmental protection (EP) has also accelerated the growth of GTI. According to the China Green Patent Statistics Report in 2018, the number of green patents in China reached 136,000 by the end of 2017. The number of valid green patents reached 73.5% (Fig. 1). However, as the basis of GTI implementation, the government EP system still exhibits some drawbacks, such as weak guidance and insufficient incentive. This causes challenges to address the dual externalities of GTI knowledge spillover and EP, thus impeding establishing a long-term GTI mechanism (Zhang et al. 2021). Therefore, compared to general innovation, GTI is more prone to be affected by environmental legislation.

Therefore, the government should design reasonable environmental regulation (ER) policies with a "visible hand" to promote environmental governance and GTI development. However, due to the inconsistency between

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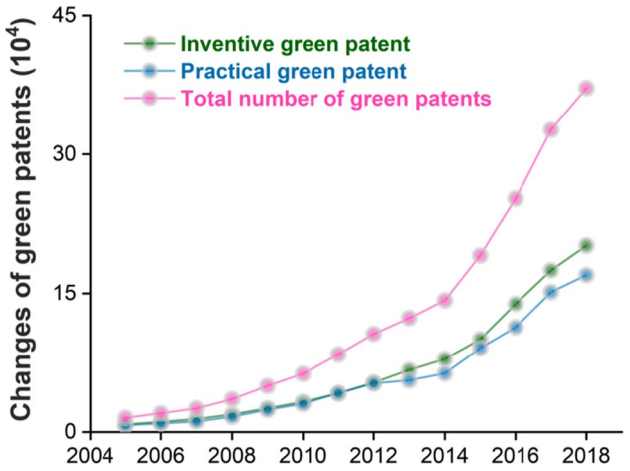


**Fig. 1** Changes of green patents in China during 2005–2018

the development goals of central and local governments, the implementation of ER policies is less efficient, causing difficulties in achieving the expected results. Some local governments have even experienced the phenomenon of "lazy governance" and adopted a one-size-fits-all approach (Wang and Zhou 2021a), increasing the burden of enterprises. Thus, the innovation subjects resist or passively cooperate with the government ER policies and fail to address the core causes of environmental pollution through green technology transformation and innovation. Therefore, China has intensified the EP law enforcement and inspection to reverse the inefficient environmental governance caused by the governments' emphasis on economic growth. The Interim Measures for Interview by the Ministry of Environmental Protection was issued in 2014, which means that the interview system has been officially established. Compared with conventional means of ER, CEPI, as a follow-up monitoring method of regulatory policy effects, is mainly used by the central government to administratively hold local governments accountable for failing to complete pollution prevention and control tasks, to clarify the responsibilities of local governments as the main body of environmental governance, and to urge them to enhance their EP awareness. Can the government's flexible administrative actions for CEPI be followed up by rigid measures such as regional approval limit, listing inspection, and post-inspection media disclosure to achieve both the symptoms and root causes of local environmentally friendly technology progress and environmental governance? The answers to this question will facilitate a more scientific and standardized assessment of the existing EP policies and systems, and thus provide a reference for further development of the effectiveness of the CEPI system and cities to be inspected.

## Background and literature review

### Environmental protection inspection background

In the 1980s, "Law of the People's Republic of China on Prevention and Control of Water Pollution" and "Law of the People's Republic of China on Prevention and Control of Atmospheric Pollution" were established. These laws mention that ecological and EP authorities can inspect officials of local governments in charge of cities where total pollution emissions exceed the limits or environmental quality fails to meet the standards. This is also the first time that the administrative EP inspection has been legalized, but its implementation rules, forms, and legal procedures have not been specified. In addition, the main target of CEPI has been enterprises in the past. Released in May 2014, "Interim measures for the EP department inspection" clearly shows that the Ministry of Environmental Protection may inspect local governments and relevant people who do not perform or fail to perform their EP duties and conduct warning talks according to law, identify relevant problems existing in local EP, put forward rectification requirements, and urge them to complete rectification. This aims to make the inspections more deterrent and warning through public inspections of key local government officials and inviting the media and the public to intervene (Pan and Hong 2022a), which will help cut down the implementation cost of environmental governance policies, effectively solve environmental problems, and promote green development. The distribution of inspected cities is shown in Fig. 2.

### Literature review

For a long time, academic debates have focused on the link between ER and GTI. According to neoclassical economics, ER can result in crowding-out effect or constraint effects, increasing firms' production costs and reducing their innovation potential, which is referred to as the cost compliance effect (Gray 1987). Porter and Van der Linde (1995) proposed Porter's hypothesis, stating that reasonable and effective EP measures can motivate enterprises' TI and induce innovation compensation. In terms of the opposing views of compliance costs and innovation compensation, many scholars have focused on the impact of ER on GTI, but their conclusions are inconsistent. The effect of ER on GTI is classified as boosting (Peng 2020) or inhibition (Chintrakarn 2008; Zhao and Sun 2016), U-shaped relationship (Liu et al. 2020b), or uncertainty (Du et al. 2021).

Firstly, ER is a toolbox full of numerous forms of environmental policies. Different environmental restrictions

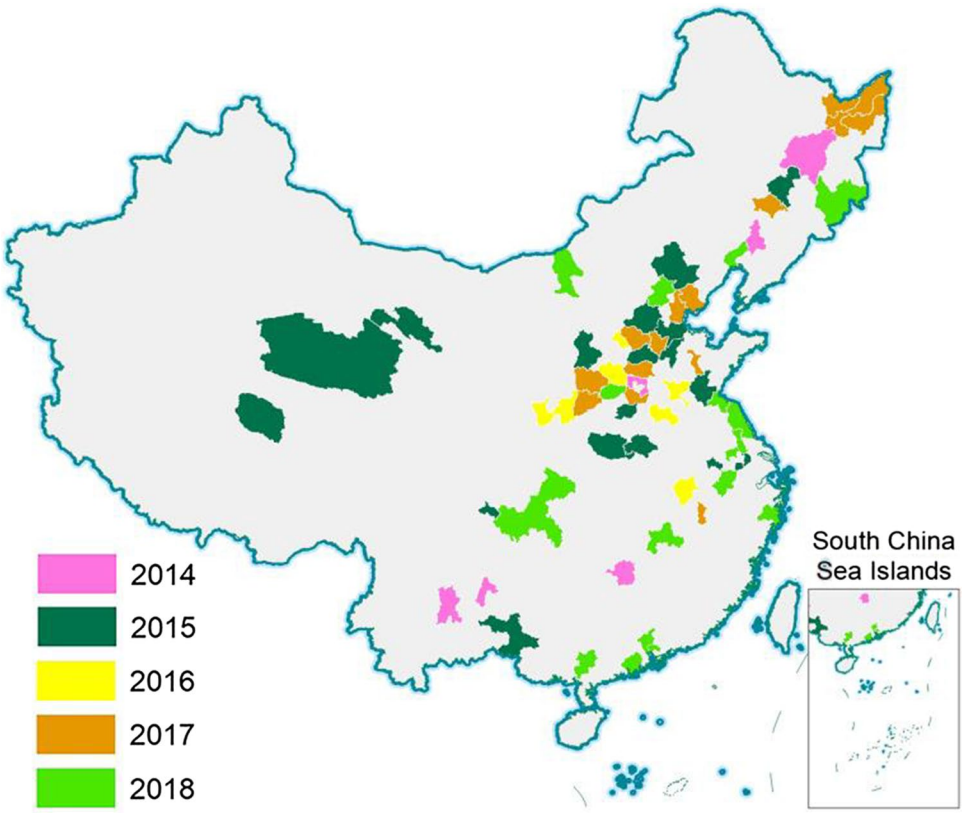


**Fig. 2** Spatial distribution of inspected cities between 2014 and 2018

act in different ways, and the ER measurement methods have varying effects on GTI (Peng 2020; Jiang et al. 2021). The ER measurement includes two types. (1) Quantifiable measurement. Most scholars measure ER by the quantity of ER, sewage charges, taxes, pollutant emissions, and environmental expenditure, etc. (Peng 2020; Du et al. 2021; Feng et al. 2019; Cai et al. 2020). (2) Policy-based ER. There are a few studies on this type of ER, including carbon intensity constraint policies (Yang et al. 2017; Cheng et al. 2019) and new environmental laws (Yu et al. 2021). Apart from the differences due to different ER measures, some scholars have found that the potential endogeneity of ER can lead to biased results (Li and Du 2021a). Therefore, to avoid inconsistent results caused by ER measurement differences and endogeneity issues, scholars have started to use alternative methods to analyze the impact of ER on green development, e.g., the instrumental variable method (Li and Du 2021a), the regression discontinuity design (Ghanem and Zhang 2014), and the difference in difference (DID) method (Yang et al. 2017). This is based on quasi-natural experiments by exogenous ER policies.

Secondly, the design and implementation of ER policies will affect the impact of environmental restrictions on GTI (Porter and Van der Linde 1995). When the enforcement of environmental laws by local governments is weak (Ghanem and Zhang 2014), leveraging the innovation impact of ER will be challenging. There are studies about ER policy, but most of them focus on environmental legislation and law enforcement (Li 2017), which implies a lack of attention to the supervision of the environmental law enforcement process. In recent years, higher levels of governments have continued to emphasize the authority of local EP departments, especially the checks and balances that the higher level of governments have on the lower level of governments (Pan et al. 2022b). Under China's EP administrative system of "vertical classification and horizontal decentralization," enhanced CEPI by the higher-level government will more actively urge local governments to put EP into effect (Zhang et al. 2018). However, some scholars have found that strengthening CEPI in the short term only creates a temporary political blue sky and then causes a more severe pollution rebound (Shen and Ahlers 2019), indicating that the ER implementation effectiveness varies with the inspection intensities.

The above studies indicate that it is imperative to study the impact of ER policies on GTI in CEPI. As an innovative way of environmental law enforcement supervision, CEPI is manifested as a direct inspection of lower-level governments by higher-level EP departments and attempts to promote better inspection of enterprises by local governments through inspection of government (Wang and Luo 2020). The

establishment of this system can effectively reduce the imbalance of government power and the excessive profit-seeking of enterprises and control malicious environmental pollution and illegal production in government-enterprise cooperation (Wu and Wang 2019). In the absence of further improvement in the basic pattern of the current environmental management system, the establishment of the CEPI system can correct the local governance of environmental problems (Pan et al. 2022b) and help promote cleaner production and technological progress of emission reduction in enterprises. At present, most studies on EPI have focused on enterprises' environmental investment (Wang and Luo 2020), environmental governance (Wu and Wang 2019), capital market response (Zeng et al. 2021), and total factor productivity (Wang et al. 2021b), etc. Only a few scholars have discussed the relationship between CEPI and enterprises' environmental performance (Wang and Zhou 2021a). However, there is no in-depth discussion on the impact of local GTI and its pathway research, and the effect on different types of GTI has been rarely studied. In addition, there is no literature on the impact of the CEPI policy spillover effect on GTI. Therefore, it is necessary to conduct further research.

In this paper, the DID, propensity score matching difference-in-differences (PSM-DID), and spatial difference-in-differences (SDID) are used to examine the impact of CEPI on GTI for 216 Chinese cities from 2008 to 2018. The marginal contribution is as follows: firstly, the CEPI system was initially used to evaluate its effect on GTI, which extends the research to the influencing factors of GTI; secondly, based on benchmark analysis, the impact of CEPI on different types of GTI is analyzed to identify the direction of promoting GTI; then, the mechanism of CEPI on GTI is examined and tested from three paths, i.e., structural optimization, R&D investment, and environmental protection expenditure (EPE); in addition, spatial DID is adopted to test the impact of CEPI on GTI and estimate the spatial spillover effect by CEPI, which is helpful to consider how to optimize the existing system from a regional perspective and make full use of the spatial correlation characteristics of CEPI; finally, the dynamic marginal effect of CEPI on GTI is further investigated and the heterogeneity of the impact of CEPI on GTI is studied by distinguishing cities of different sizes and characteristics (Fig. 3).

## Theoretical mechanism and research hypothesis

### Impact direction of CEPI on GTI

As an essential way to urge local governments to actively fulfill their environmental responsibility, CEPI is mainly manifested in that when local EP departments fail to meet their environmental responsibility or do not fulfill their obligations properly, the higher-level government will inspect them according to the law, raise questions and requests for rectification, and supervise administrative measures for EP law enforcement. Firstly, with the intervention of the media and the public, CEPI is more deterrent and can better supervise the local government and indirectly affect the regulation of enterprises, increasing the cost of polluting industries and forcing polluting enterprises to relocate or locally engage in green innovation (Dong et al. 2020). Secondly, CEPI can also solve the problem caused by local governments' obsession with GDP. The CEPI system can also strengthen the authority of higher environmental departments and weaken the illegal intervention by the same level of governments. This direct protection inspection can urge the implementation of environmental policies, enhance ER policies, and effectively stimulate the innovation and development of local GTI. Finally, the Porter hypothesis believes that flexible ER policies can effectively promote innovation

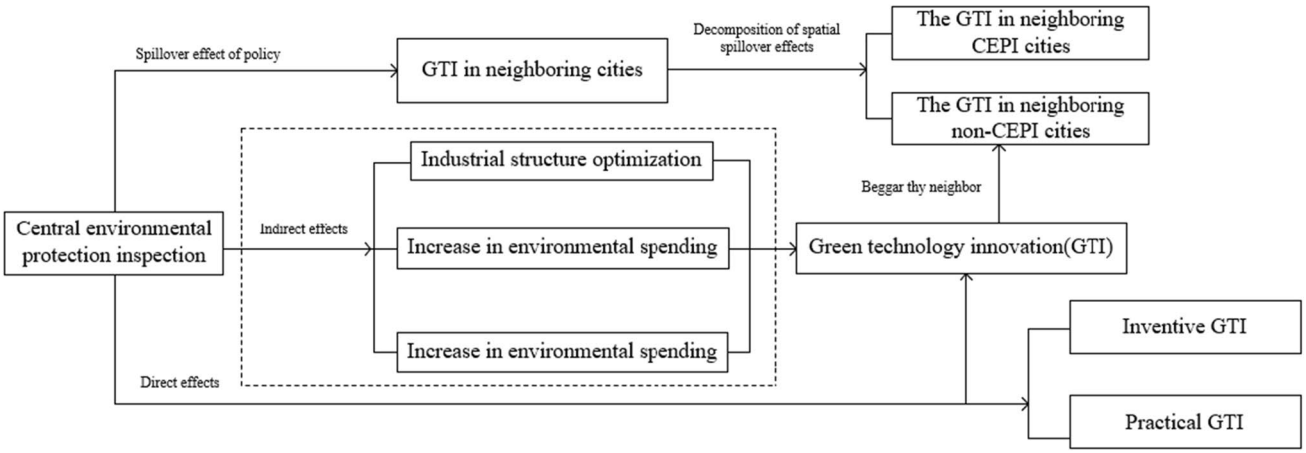


**Fig. 3** Framework of the theoretical mechanism

in a narrow sense. The impact of ER policies on innovation depends more on the characteristics of policy design, such as the effectiveness of ER and supervision, environmental enforcement and policy matching, etc. (Corral 2003). Therefore, CEPI would be conducive to promoting GTI. Based on the theoretical analysis, the following hypothesis is proposed:

*Hypothesis 1*: CEPI can promote local GTI.

## Impact of CEPI on different types of GTI

Generally, in descending order of innovation levels, green patents include inventive green patents, utility green patents, and design green patents (Li and Zheng 2016). Compared with the inventive green patent, utility green patents have a higher output, with lower development difficulties, less investment, and lower quality. Given the lowest innovation level of design patents, the impact of CEPI on inventive GTI and utility GTI was mainly analyzed.

Tong et al. (2014) studied enterprise innovation activities from the perspective of patents. They found that TI is sometimes just a strategic activity for innovation subjects to cope with the government, rather than to improve their competitiveness through high-quality substantive innovation. Thus, with the implementation of the CEPI system, the local government will increase the intensity of environmental supervision to complete the rectification requests by the higher level of governments and put higher demands on the transformation and innovation of polluting enterprises. This will promote such enterprises to cater to government regulation by developing utility GTI with low difficulty and pursuing "quantity" and "speed" of innovation. In addition, local governments are more inclined to focus on efficiency-oriented innovation with short cycles and high output, i.e., utility GTI stands out in the political performance assessment (Wang and Yang 2018). Considering the significant investment in green technology research and development (R&D) and high innovation risk (Gao et al. 2021), it takes a long time to develop substantive innovation that can bring actual green technology progress and upgrade green products (Li and Zheng 2016; Tang et al. 2021). However, CEPI usually requires prompt implementation of rectification, which is quite different from the long-term and high investment required for high-quality and inventive GTI. Therefore, it is not easy to stimulate the development of inventive GTI in a short term. Based on the theoretical analysis, the following hypothesis is proposed:

*Hypothesis 2*: Compared with inventive GTI, the promotion effect of CEPI on practical GTI is more obvious.

## Influencing mechanism of CEPI on GTI

### Structural optimization and GTI

Firstly, the industrial structure dominated by some industries (especially heavy industry) will lead to severe environmental pollution (Li and Bai 2021b), hinder the adjustment and green transformation and upgrading of industrial structures, and inhibit the effective implementation of green industrial policies. The higher proportion of heavy industry in the local industrial structure causes stronger path dependence of its production mode on resources and environment, which will hinder local GTI. Secondly, some scholars have found an environmental elimination mechanism to eliminate high-pollution enterprises with low-level TI capacities (Liu et al. 2020b). The elimination and transfer of polluting industries will reconstruct the regional industrial structure (Zhao et al. 2020; Feng et al. 2020), thus affecting the level of green technology R&D. Finally, Du et al. (2021) stated that improving industrial structure is a vital environmental governance method to promote industrial green transformation. The ER policy can optimize the industrial structure and will enable the transformation of high-polluting industries into clean and low-carbon services (Li et al. 2022), thus promoting local GTI (Dong et al. 2020). With respect to the CEPI implementation, the structural effect of CEPI (as a new EP system) is mainly reflected in accelerating economic restructuring, promoting the transformation and upgrading of obsolete and polluting industries, vigorously developing emerging industries to reduce environmental pollution and promoting the progress of local GTI. However, when strengthening local ER, CEPI may cause polluting industries to relocate instead of promoting local structural optimization and upgrading (Zhao et al. 2020), thus leading to difficulties in effectively stimulating local GTI. Based on the theoretical analysis, the following hypothesis is proposed:

*Hypothesis 3.1*: Implementing the CEPI system may promote local GTI through industrial structure optimization.

### Environmental protection expenditure and GTI

Investment in environmental governance can reduce pollutant emissions to a certain extent and attenuate the environmental problem. Especially in regions with severe environmental pollution, local governments will increase investment in EPE to promote local green development (Fan et al. 2020), since EP investment, as a special kind of investment, can drive economic growth and promote technological progress (Jiang et al. 2021). Green technology progress is a critical factor in pollution prevention and control (Liu et al. 2020a). In addition, government EP expenditure can also stimulate local GTI, drive development through the leading

effect of social capital, and relieve local environmental pollution (Jiang 2018).

With increasingly stronger social demands for environmental issues, the government has put more effort into EP and governance than ever, and environmental inspection standards have been constantly improved; the EP investment has increased (Wu et al. 2021); the supervision and rectification request of CEPI has been improved. The implementation of the CEPI system has strengthened the vertical supervision of the central government over local governments, eliminated barriers to local EP departments during the implementation of CEPI, and prompted local governments to increase support for EP departments in terms of personnel and financial expenditures (Wu and Wang 2019). Thus, the local government's emphasis on EP has increased (Lin et al. 2021). For example, Linyi city increased investment in EP and upgraded EP infrastructure after being inspected in 2017, and the progress in local EP technology was effectively promoted to curb environmental pollution. Based on the theoretical analysis, the following hypothesis is proposed:

*Hypothesis 3.2*: The implementation of the CEPI system can promote local GTI by increasing EP expenditure.

#### Research and development investment and GTI

Schumpeter's innovation theory states that R&D investment is indispensable in the TI. Due to the externality of TI, spillover effects of technology and knowledge, innovation subjects may experience the risk of damage. Advanced TI is also subjected to uncertain income, information asymmetry in the innovation process, and high cost, leading to insufficient R&D input and hindering effective TI development (Aghion et al. 2012). As an emerging technology, GTI has a longer R&D cycle, with higher costs and innovation risks, and high investment is needed to alleviate the dual externalities (Wang and Yang 2018). Therefore, more R&D investment will help promote better progress in GTI (Li et al. 2022).

Studies have shown that implementing ER policies will increase R&D intensities and then promote GTI (Du et al. 2021). Especially at a higher ER level, the ratio of ER compliance cost to enterprise costs continues to increase, which will encourage enterprises to raise R&D investment and urge enterprises to perform GTI (Liu et al. 2020b). Specifically, after implementation of the CEPI system, the concealment of polluting enterprises by the inspected governments will be inhibited, and industrial enterprises with pollution problems have to increase their R&D investment and carry out GTI to reduce the pollution cost caused by ER (Wu and Wang 2019). Based on the theoretical analysis, the following hypothesis is proposed:

*Hypothesis 3.3*: Implementing the CEPI system can promote local GTI by raising R&D investment.

#### Spatial effects of CEPI on the impact of GTI

When local governments formulate or implement ER policies, there are apparent mutual "imitation" behavior and regional interaction effects, and local ER policies have particular spatial correlation effects (Peng 2020; Wu et al. 2021). Considering the regional spatial spillover characteristics of TI (Zhai and An 2021), there are also regional transfer and imitation effects of GTI, which have an apparent spatial spillover effect. Therefore, the impact of CEPI on GTI is analyzed from the perspective of spatial correlation.

ER may cause the relocation of polluting industries to neighboring regions, impair the industrial structure and exacerbate the pollution of neighboring regions (Peng 2020), and hinder the GTI development. Neighboring regions cannot be spared from pollution by environmental governance alone (Feng et al. 2021). Especially when the implementation direction and intensity of ER policies are inconsistent between regions, only strengthening local ER will hinder the GTI in neighboring regions (Zhao et al. 2020). This is mainly reflected in adopting the race to the bottom by neighboring regions to achieve growth, lowering environmental standards to allow the inflow of obsolete polluting industries and enhancing ER policies to encourage GTI. When the emissions reduction standards are included in the assessment system of local officials, local governments will emphasize the ecological environment and adjust the formulation, implementation, and supervision of the ER policy to weaken the imitation of regional ER policies or make these policies independent. This will help improve ecological efficiency (Wu et al. 2021).

Similarly, based on the implementation of the CEPI system, the primary responsibility of local governments for EP can be clarified and improper government intervention can be inhibited in EP. Media and public involvement have made the CEPI a more deterrent "sunshine inspection," which brings pressure to inspected cities and has a warning effect on neighboring cities. Therefore, as a powerful method of environmental supervision, CEPI can coordinate ER policies of inspected regions and drive the collaborative development of GTI through spatial spillover. Based on the theoretical analysis, the following hypothesis is proposed:

*Hypothesis 4*: The warning effect of CEPI may slow down the inhibitory impact of local ER on GTI in neighboring cities. However, this warning effect may only affect inspected neighboring cities and inhibit the GTI in uninspected neighboring cities.

## Econometric models and data

### Econometric models

In 2014, the former Ministry of Environmental Protection officially started to interview key officials of local governments. Given the lack of data in some cities, this paper excluded Hercynian Mongolian Tibetan autonomous prefecture in Qinghai province, Yanbian city, Yichun city, and other cities and took other 48 inspected cities as the research object. DID is a measurement method specially used to evaluate the effect of policy, which regards institutional change and new policy as a natural experiment of external economic system. Specifically, the quasi-natural experiment of the policy is used to randomly divide the research objects into the treatment group and control group. The treatment group is affected by the policy, and vice versa. Referring to the study by Wang et al. (2021b) and Tang et al. (2021), CEPI is considered a natural experiment to investigate the changes of GTI before and after CEPI implementation. Inspected cities are taken as the treatment group, while uninspected cities are the control group. DID is adopted to evaluate the relationship between the CEPI system and GTI. The test includes the following five processes:

Firstly, the impact of CEPI on GTI was examined. Since the timing of CEPI varies for each city, the DID model within consecutive years was adopted for estimation. The model is expressed as:

$$igt_{it} = \alpha_0 + \alpha_1 talk_{it} + \gamma \mathrm{X} + \lambda_i + \lambda_t + \mu_{it} \quad (1)$$

Secondly, given significant differences in the development level between Chinese cities, the treatment group and the control group are not directly comparable. Thus, using the PSM method, the selective bias of samples can be eliminated; using DID, the endogeneity problem can be solved. Therefore, the PSM-DID method is also used to perform robustness test estimation of the above model:

$$igt_{it}^{\mathrm{psm}} = \alpha_0 + \alpha_1 talk_{it} + \gamma \mathrm{X} + \lambda_i + \lambda_t + \mu_{it} \quad (2)$$

where $i$ represents the city; $t$ represents time; $igt$ represents GTI; $talk$ represents dummy variable, indicating inspection status of the city; $\alpha_0$ is the intercept term; $\alpha_1$ is the coefficient measuring the net impact of CEPI on GTI. Significantly positive $\alpha_1$ indicates that CEPI can promote local GTI, while negative $\alpha_1$ indicates that CEPI may inhibit GTI. If the results are not significant, there is no direct relationship between CEPI and GTI. $\gamma$ is the coefficient of the control variable; $\lambda_i$ indicates city fixed effects; $\lambda_t$ indicates time fixed effects; $\mu_{it}$ is the error term.

Thirdly, the impact of CEPI on different types of GTI is analyzed. The GTI is divided into inventive GTI and practical GTI, which are estimated by DID, respectively. The model is expressed as:

$$cgt_{it}\left(pgt_{it}\right) = \alpha_0 + \alpha_1 talk_{it} + \gamma \mathrm{X} + \lambda_i + \lambda_t + \mu_{it} \quad (3)$$

where $cgt$ represents inventive GTI, and $pgt$ represents practical GTI.

Fourthly, if CEPI can promote local GTI, then what is the mechanism? To verify the existence of these mechanisms of action hypotheses, this paper adopts the three-step test proposed by Baron and Kenny (1986). The first step is to verify whether CEPI can promote structural optimization, environmental expenditure, or R&D investment. Secondly, whether CEPI can promote GTI is verified. Then, the three paths are added to the regression in the second-step regression. If $talk$ in the third step becomes insignificant, or significant but smaller, it indicates that the CEPI promotes GTI through these three paths. According to the three-step test, the models are set as:

Step 1: verify the impact of CEPI on three paths:

$$str_{it}\left(inv_{it}, rd_{it}\right) = \chi_0 + \chi_1 talk_{it} + \phi \mathrm{X} + \lambda_i + \lambda_t + \pi_{it} \quad (4)$$

Step 2: verify the impact of CEPI on GTI:

$$igt_{it} = \alpha_0 + \alpha_1 talk_{it} + \gamma \mathrm{X} + \lambda_i + \lambda_t + \mu_{it} \quad (5)$$

Step 3: incorporate three paths into Eq. (5):

$$igt_{it} = \delta_0 + \delta_1 talk_{it} + \theta str_{it}\left(inv_{it}, rd_{it}\right) + \varphi \mathrm{X} + \lambda_i + \lambda_t + o_{it} \quad (6)$$

where $str$ represents structural optimization, $inv$ represents EPE, $rd$ represents R&D; $\chi_0$ and $\delta_0$ are intercept terms, respectively; $\chi_1$ and $\delta_1$ represent the coefficients of the core explanatory variables; $\theta$ is the influence coefficients of the three paths; $\phi$ and $\varphi$ are the coefficients of the control variables; $\pi$ and $o$ are error terms.

Finally, to further identify the spatial impact of CEPI on GTI and the spillover effect of CEPI, the spatial Durbin model (SDM) is established as the initial model. Furthermore, referring to the study by Chagas et al. (2016), the policy implementation effect was further decomposed into the indirect impact of the inspected city on the inspected city ($Wtt$) and the indirect effect of the inspected city on the uninspected city ($Wntt$). Based on Eq. (1), the following model is established:

$$igt_{it} = \beta_0 + \left(\beta_1 + vW\right) talk_{it} + \eta \mathrm{X} + W\eta' \mathrm{X} + \varepsilon_{it} \quad (7)$$

where $\beta_0$ is the intercept term; $W$ denotes spatial weight matrix, $W = I_t \otimes \overline{W}$; $I_t$ is a $T \times T$ dimensional matrix; $\overline{W}$ is a $N \times N$ dimensional spatial weights matrix. If the two regions are adjacent, $W$ is 1; otherwise, $W$ is 0; $Wvtalk$ represents the existence of spatial spillover effects; $v$ represents the size of the spillover effect; $\eta$ is the coefficient of control variables; $\eta'$ is the impact of other local exogenous variables on GTI in neighboring areas; $\varepsilon_{it}$ is the error term. Particularly, spillover effects include the influence of the inspected city on the

neighboring inspected city (*Wtt*) and the influence of the inspected city on the neighboring uninspected city (*Wntt*). The average spillover effects were measured.

## Data

The explained variable *igt* represents the GTI level measured by green patents. Referring to Dong et al. (2020), the classification codes of green patents were obtained from IPC Green Inventory Guideline. According to the green patent classification codes published by the World Intellectual Property Organization (WIPO), China's green patent data at the city level were collected from the State Intellectual Property Office (SIPO) (Du et al. 2021).

Explanatory variable: $talk_{it}$ denotes the implementation of CEPI. If a city is inspected in the $t$ th year, then the $talk_{it}$ of the city in its subsequent years is 1; otherwise, $talk_{it}$ is 0.

According to existing studies, the reasons and basis for the selection of control variables are as follows. In China, as the main body of resource allocation and policy implementation, the government can intervene in the investment direction of regional technological innovation and even affect GTI (Dong et al. 2020). Government intervention is measured by the ratio of government expenditure to GDP. Li and Bai (2021b) mentioned that human capital is an important external support for enterprise R&D and innovation, and its level will affect the introduction of GTI. The average schooling year is used to measure human capital. Chen et al. (2020) found that urbanization strengthens the exchange and exchange of factors, provides an excellent environment for innovation activities, and helps promote technological innovation. Urbanization is measured by the logarithm of the built-up area. The cleanliness of foreign direct investment will directly affect regional energy conservation, emission reduction, and clean production, and even high-quality foreign investment has green technology spillover effect (Peng 2020). The ratio of direct local foreign investment to GDP is used to measure *fdi*. Li and Du (2021a) mentioned that the level of economic development would affect the public's emphasis on environmental protection. Increased public concern about environmental protection will also put pressure on governments and businesses to force GTI. The real GDP per capita is used to measure economic development levels.

In addition, theoretical mechanisms analysis above mentioned that CEPI may affect GTI through industrial structure optimization, EPE and R&D investment. Referring to the study by Wang and Shi (2019), Li and Bai (2021b), industrial structure optimization, EPE and R&D investment are analyzed as intermediary variables. The proportion of the added value of the tertiary industry to the added value of the secondary industry is used to represent industrial structure optimization. EPE is represented by the proportion of government EPE to fiscal expenditure. The ratio of prefectural GDP to provincial GDP multiplied by provincial R&D investment is used to represent R&D investment.

Regarding the uniformity of data, 216 cities are used as research objects for analysis from 2008 to 2018. Real GDP per capita was analyzed based on the constant price in 2000. Specifically, constant prices in 2000 were nominal GDP per capita for that year. The constant price (real GDP per capita) for each year is the current year's nominal GDP per capita divided by the current year's GDP deflator and then multiplied by the GDP deflator in 2000. The data of green patents — a measure of GTI, was obtained from SIPO according to the IPC classification codes published by WIPO. The data of EPE are acquired from the Provincial Statistical Yearbook, the Provincial Fiscal Yearbook, and the City Finance Department, and is represented by the ratio of EPE to fiscal expenditure. Other data are taken from China City Statistical Yearbook. Table 1 shows the indicator definition and descriptive statistics.

# Empirical tests and results analysis

## Analysis of the impact of CEPI on GTI

### Baseline regression analysis

By sorting out relevant theoretical mechanisms, DID is used to investigate the impact of CEPI on GTI. City and time fixed-effect models control individual differences and temporal trends. To investigate the robustness and avoid multicollinearity caused by the increase of control variables, a stepwise regression method is adopted. Control variables are gradually incorporated into the model with only core explanatory variables to investigate the significant difference of regression coefficients.

Table 2 shows the specific baseline regression results. Column (1) is the regression results only including core explanatory variables; the coefficient *talk* is 7.719 and passes the significance test at the 5% level. The CEPI system can promote local GTI, which supports *Hypothesis 1*. The result is in agreement with the research conclusion of Wang et al. (2021c), indicating that the CEPI will promote the green transformation of polluting industrial enterprises by strengthening the supervision of local EP law enforcement and encouraging these enterprises to carry out GTI in order to compensate the regulatory costs. In columns (2) ~ (6), after the control variables, *gov*, *h*, *ey*, *fdi* and *lnurb* are gradually added. The coefficient *talk* is still significantly positive and the significance level has been improved, indicating that the promotion effect of CEPI on GTI is relatively stable.

**Table 1** Descriptive statistics

| Variables | Definition | Observations | Mean | Standard deviation | min | max |
|---|---|---|---|---|---|---|
| igt | Green patent (piece) | 2 376 | 8.63 | 26.12 | 0 | 450 |
| ey | Per capita income (10,000 yuan) | 2 376 | 1.42 | 0.88 | 0.29 | 13.47 |
| fdi | Foreign direct investment (%) | 2 376 | 21.98 | 26.55 | 0 | 152.04 |
| h | Human capital (year) | 2 376 | 1.16 | 0.53 | 0.31 | 4.48 |
| lnurb | Urbanization (LN) | 2 376 | 4.66 | 0.89 | 1.87 | 9.31 |
| gov | Government intervention (%) | 2 376 | 17.33 | 13.88 | 0.94 | 33.49 |
| inv | Environmental protection expenditure (‰) | 2 376 | 2.98 | 2.07 | 0.13 | 31.82 |
| rd | R&D investment (100 million yuan) | 2 376 | 49.41 | 116.28 | 0.33 | 1870.77 |
| str | industrial structure optimization (%) | 2 376 | 0.90 | 0.50 | 0.09 | 4.45 |
| cgt | patent of the green invention (piece) | 2 376 | 5.79 | 19.04 | 0 | 312 |
| pgt | Green utility model innovation (piece) | 2 376 | 2.63 | 7.16 | 0 | 102 |

**Table 2** Analysis of the impact of CEPI on GTI

| Variables | (1) igt | (2) igt | (3) igt | (4) igt | (5) igt | (6) igt |
|---|---|---|---|---|---|---|
| talk | 7.719** | 7.817** | 7.629** | 7.608** | 8.260*** | 8.139*** |
| | (3.118) | (3.115) | (3.119) | (3.089) | (2.884) | (2.859) |
| gov | | 0.089*** | 0.091*** | 0.090*** | 0.088*** | 0.087*** |
| | | (0.033) | (0.034) | (0.034) | (0.030) | (0.030) |
| h | | | 2.921 | 2.954 | 4.855* | 4.921** |
| | | | (2.626) | (2.651) | (2.539) | (2.524) |
| ey | | | | −0.397 | −0.466 | −0.361 |
| | | | | (1.395) | (1.311) | (1.284) |
| fdi | | | | | −0.217*** | −0.216*** |
| | | | | | (0.058) | (0.058) |
| lnurb | | | | | | −1.368* |
| | | | | | | (0.757) |
| Intercept term | 15.437*** | 13.726*** | 11.260*** | 11.799*** | 10.554*** | 17.439*** |
| | (1.081) | (1.135) | (2.273) | (2.756) | (2.436) | (5.325) |
| Time fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| City fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 2 376 | 2 376 | 2 376 | 2 376 | 2 376 | 2 376 |
| $R^2$ | 0.174 | 0.180 | 0.181 | 0.181 | 0.219 | 0.221 |

Notes: t statistics in parentheses. $^{***}P<0.01$, $^{**}P<0.05$, $^{*}P<0.1$

*gov* can significantly promote GTI, which is consistent with the conclusion of Li and Bai (2021b). The government, as the main body of innovation policy formulation and implementation, can lead GTI by intervening in the enterprise's innovation direction. *h* is significantly positive, indicating that as an essential innovation factor, human capital performs an increasingly significant supporting role in the technological R&D process, and the improvement of human capital level can promote GTI. *lnurb* is significantly negative, which is consistent with the conclusion of Wang and Zhou (2021a). The extensive development mode caused by excessive resource consumption and high pollution emissions during urbanization will hinder the innovation and progress of cleaner production technologies. *fdi* is significantly negative, indicating that FDI still introduces "dirty" technologies. FDI takes a long time to introduce foreign technologies, having a weak promotion effect on GTI (Liu et al. 2021). *ey* is significant; this may be attributed to that China is currently in the economic transition stage and the inflection point of decoupling in the environmental Kuznets curve has not yet arrived (Li and Bai 2021b). The incentive role of GTI capability and awareness also needs to be improved.

**Table 3** PSM-DID method suitability test (common support hypothesis)

| Variables | Mean of the treatment group | Mean of the control group | Difference | *T* value | *P*-value |
|---|---|---|---|---|---|
| Government intervention | 19.985 | 20.254 | −0.269 | −0.13 | 0.893 |
| Human capital | 1.035 | 1.043 | −0.008 | −0.12 | 0.903 |
| Economic development level | 1.279 | 1.282 | −0.003 | −0.04 | 0.969 |
| Foreign direct investment | 10.278 | 11.978 | −1.70 | −0.76 | 0.448 |
| Urbanization | 5.088 | 4.963 | 0.125 | 1.08 | 0.280 |

**Table 4** Analysis of the impact of CEPI on GTI by the PSM-DID method

| Variables | (1) igt | (2) igt | (3) igt | (4) igt | (5) igt | (6) igt |
|---|---|---|---|---|---|---|
| talk | 6.703*** | 6.794*** | 6.637*** | 6.729*** | 7.031*** | 6.893*** |
| | (2.565) | (2.558) | (2.540) | (2.499) | (2.275) | (2.235) |
| gov | | 0.081** | 0.083*** | 0.085*** | 0.080*** | 0.080*** |
| | | (0.032) | (0.032) | (0.033) | (0.027) | (0.027) |
| h | | | 2.671 | 2.694 | 4.861** | 5.027** |
| | | | (2.534) | (2.504) | (2.227) | (2.218) |
| ey | | | | 1.925 | 0.512 | 0.822 |
| | | | | (2.257) | (2.238) | (2.147) |
| fdi | | | | | −0.348*** | −0.349*** |
| | | | | | (0.084) | (0.084) |
| lnurb | | | | | | −2.199* |
| | | | | | | (1.246) |
| Intercept term | 15.401*** | 13.803*** | 11.594*** | 8.978** | 9.342** | 19.842** |
| | (1.105) | (1.161) | (2.305) | (4.344) | (3.934) | (8.842) |
| Time fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| City fixed effec | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 2 184 | 2 184 | 2 184 | 2 184 | 2 184 | 2 184 |
| $R^2$ | 0.158 | 0.164 | 0.165 | 0.166 | 0.217 | 0.219 |

## PSM-DID estimation results

To avoid the estimation error caused by DID alone and keep the changing trend of inspected cities and uninspected cities systematically consistent, PSM is used to match the propensity score of inspected and uninspected towns and cities. Then, DID is used to estimate the compared cities, which avoids the different levels of GTI caused by systematic differences as much as possible. Before using PSM, it is necessary to test whether the variables satisfy the common support hypothesis. Results are shown in Table 3 and there is no significant difference in all variables after matching, indicating that the PSM-DID method is feasible (Yang et al. 2021).

The PSM-DID estimation results in Table 4 indicate that *talk* is still significantly positive and had no significant difference with the DID results. This also shows that CEPI can effectively promote local GTI, further supporting the empirical results.

**Table 5** Analysis of the impact of CEPI on different types of GTI

| Variables | (1) cgt | (2) pgt |
|---|---|---|
| talk | 0.815 | 3.342*** |
| | (1.304) | (1.055) |
| Intercept term | 9.217*** | 6.712*** |
| | (3.365) | (1.806) |
| Control variables | YES | YES |
| Time fixed effect | YES | YES |
| City fixed effect | YES | YES |
| Observation | 2 376 | 2 376 |
| $R^2$ | 0.158 | 0.230 |

## Analysis of the impact of CEPI on different types of GTI

In column (1) of Table 5, the influence coefficient of CEPI on inventive GTI is 0.815, but it does not pass the significance test. Column (2) shows that CEPI significantly

promotes utility GTI at the 1% significance level. The results indicate that the implementation of the CEPI system can promote GTI in the inspected cities, but the innovation type is mainly utility GTI, which verifies *Hypothesis 2*. Because local governments are usually required to rectify pollution problems within a specified time after inspections, local governments will also put pressure on enterprises to perform green transformation and innovation. However, as a substantial innovation, inventive GTI contains high green technologies, requires a long R&D cycle and an increasing investment (Li and Zheng 2016; Wang and Yang 2018). This is challenging to meet the time-limited rectification requirements due to the inspection, thus promoting the utility GTI that has relatively lower technology and short R&D cycles. The results show that although the implementation of CEPI improves the efficiency of local environmental governance to a certain extent (Wu and Wang 2019), CEPI only has an "immediate" effect, which gradually decreases and thus does not promote substantial progress in GTI.

### Mechanism test of CEPI effects on GTI

From Table 6, the first-step regression results indicate that CEPI can improve the level of local EPE and R&D investment, while the effect of CEPI on industrial structure optimization is not clear. The second-step results show that CEPI significantly promotes GTI. The third-step results show that when structural optimization, EPE and R&D investment are included in the regression equation, respectively, the significance and coefficients of DID all become smaller, and the coefficient of the structural optimization shows the smallest decrease. Based on the above regression results, it can be seen that CEPI can promote local GTI through increasing EPE and R&D investment, while the effect of structural optimization is insignificant. This conclusion verifies Hypotheses 3.2 and 3.3 but does not support Hypotheses 3.1. Since the CEPI is an administrative mode that can reduce inaction and slow action of local environmental supervision law, the system will urge government departments to formulate relevant policies and measures to settle the environmental pollution issues and increase government fiscal environment protection expenditure (Li and Bai 2021b). Local governments will also increase R&D investment to promote technological progress in pollution control. However, after being inspected, local governments tend to prioritize the internal construction system, strengthen environmental supervision, and then urge industrial enterprises to upgrade their production equipment, while failing to adjust economic and industrial structures to some extent. In addition, due to the long-term issue in the local industrial structure and weak governance foundation, it is difficult to eliminate obsolete production capacity and optimize industrial structure at least for a while.

### Further analysis: spatial spillover effects and effect decomposition

**Spatial correlation and model suitability test** Although the above results have shown that CEPI can improve GTI, the relevant estimation may be biased due to the neglect of spatial correlation between regions, which may violate the stable unit treatment value assumption. Therefore, the analysis of the impact of CEPI on GTI by DID needs to be further extended. The spatial DID is introduced to test the

**Table 6** Mechanism test of the impact of CEPI on GTI

| Variables | Structure optimization | | | environmental protection expenditure | | | R&D | | |
|---|---|---|---|---|---|---|---|---|---|
| | str | igt | igt | inv | igt | igt | rd | igt | igt |
| talk | 0.006 | 8.139*** | 8.063*** | 0.482* | 8.139*** | 7.725*** | 12.735* | 8.139*** | 5.982*** |
| | (0.026) | (2.859) | (2.829) | (0.282) | (2.859) | (2.862) | (7.805) | (2.859) | (2.220) |
| str | | | 11.725 | | | | | | |
| | | | (7.647) | | | | | | |
| inv | | | | | | 0.860** | | | |
| | | | | | | (0.416) | | | |
| rd | | | | | | | | | 0.169*** |
| | | | | | | | | | (0.040) |
| Intercept term | 1.337*** | 17.439*** | 1.758 | 1.878*** | 17.439*** | 15.823 | 118.18 | 17.439*** | −2.576 |
| | (0.089) | (5.325) | (7.726) | (0.507) | (5.325) | (4.810) | (28.67) | (5.325) | (4.558) |
| Control variables | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| City fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observation | 2 376 | 2 376 | 2 376 | 2 376 | 2 376 | 2 376 | 2 376 | 2 376 | 2 376 |
| $R^2$ | 0.537 | 0.221 | 0.241 | 0.049 | 0.221 | 0.233 | 0.209 | 0.221 | 0.565 |

effects of CEPI on GTI of local and neighboring cities. In addition, the spatial decomposition effect of the spatial DID is further subdivided into the influence of CEPI on the GTI in neighboring inspected cities and the uninspected cities.

Variables should be spatially correlated before spatial regression. The results of the Moran index of GTI are shown in Fig. 4. Except for that in 2008, the Moran index in other years is more significantly positive. The *P*-value test results of the Moran index from 2010 to 2018 are all below 0.1. Moran index is positive, and the larger the value is, the stronger the spatial positive correlation is. The results show that GTI has obvious spatial positive correlation, that is, cities with similar level of GTI cluster together, and there is a spatial agglomeration effect. This lays the foundation for discussing the spatial impact of CEPI on GTI. In addition, to verify the applicability of the spatial Durbin model, LR and Wald tests were carried out, and $P < 0.01$, showing that SDM was rejected to degenerate into the spatial lag model and spatial error model. Combined with the Hausman test, the SDM with fixed effects is used to estimate the spillover effect of CEPI on GTI. The specific results are presented in Table 7.

**Spatial spillover effect and decomposition** Columns (1) and (2) in Table 8 show the estimation results of spatial spillover and spatial decomposition effect of CEPI. Rho is positive and passes the significance test, showing a significant spatial effect of GTI. According to the spillover of CEPI in column (1), the impact of *Wtalk* on GTI is negative, indicating that local CEPI inhibits the GTI in neighboring cities. This conclusion is in agreement with the conclusion of Dong et al. (2020) that ER policies hinder the progress of green technology in neighboring cities. CEPI can promote local efforts to strengthen EP, which leads to an increase in neighboring cities in terms of accepting polluting industries, deteriorates the industrial structure of neighboring cities, and inhibits the innovation and development of green technology in neighboring cities.

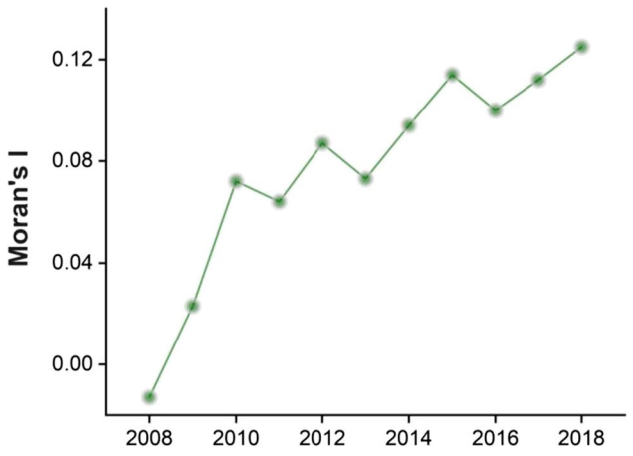


**Fig. 4** Distribution of Moran's I of GTI

To further verify the specific effect of the inspected and uninspected neighboring cities, spatial spillover effects of the CEPI policy are decomposed. The results are shown in

**Table 7** Suitability results of spatial Durbin model

| Models | *T* value | *P* value |
|---|---|---|
| LR-spatial-lag | 21.65 | 0.010 |
| Wald-spatial-lag | 21.69 | 0.009 |
| LR-spatial-error | 37.35 | 0.000 |
| Wald-spatial-error | 36.45 | 0.000 |
| Hausman test | −85.47 | - |

Notes: the result of the *Hausman* test is negative; the basic assumptions of the RE model (Corr(x_it, u_i) = 0) cannot be satisfied. Therefore, FE should be used

**Table 8** Spatial effects of CEPI on local GTI and its decomposition

| Variables | (1) igt | (2) igt |
|---|---|---|
| talk | 10.087*** | 10.009*** |
| | (1.744) | (1.745) |
| Wtalk | −1.072* | |
| | (0.612) | |
| Wtt-talk | | 0.624 |
| | | (1.796) |
| Wntt-talk | | −1.499** |
| | | (0.698) |
| ey | −0.863 | −0.861 |
| | (0.937) | (0.937) |
| gov | 0.108*** | 0.110*** |
| | (0.019) | (0.019) |
| h | 5.867*** | 5.898*** |
| | (1.739) | (1.739) |
| fdi | −0.186*** | −0.186*** |
| | (0.027) | (0.027) |
| lnurb | 0.274 | 0.268 |
| | (0.714) | (0.714) |
| rho | 0.206*** | 0.206*** |
| | (0.024) | (0.025) |
| W-control variable | Yes | Yes |
| Observation | 2 376 | 2 376 |
| $R^2$ | 0.182 | 0.182 |
| Loglik | −9 084.301 | −9 083.809 |

Notes: Wtalk is the average spatial spillover effect of CEPI on GTI; Wtt-talk refers to the impact of CEPI on the GTI of inspected neighboring cities; Wntt-talk refers to the impact of CEPI on the GTI of uninspected neighboring cities

Table 8. *Wtt − talk* is 0.624 but insignificant in column (2). Although there is a positive relationship between inspected cities and inspected neighboring cities regarding GTI, the effect is not significant. When the adjacent cities are inspected, emission reduction standards and green development goals are also included in the evaluation system of officials. Then, inspected cities show more substantial warning effects on neighboring cities. To avoid the second inspection, the neighboring cities began to transform the competition modes from "bottom" to "top" in order to reduce the neighboring transfer of obsolete industries and promote green technology progress. However, the spatial radiation effect is weak due to the "immediate effect" of CEPI (Wu and Wang 2019). Therefore, although CEPI promotes the GTI in inspected neighboring cities, the promotion effect is insignificant. *Wntt − talk* is − 1.449 and is significant at the 5% level, indicating that CEPI inhibits the GTI in uninspected neighboring cities. The conclusion is in agreement with the conclusion of Feng et al. (2020), indicating that when inspected cities and uninspected neighboring cities have different ER intensities, local EP efforts may lead to the relocation of obsolete industries. Especially in the case of lax environmental enforcement in the uninspected neighboring cities, the phenomenon of smoky vehicle riding can occur and hinder GTI development. The results verify *Hypothesis 4*.

**Parallel trend test and dynamic effect** The DID estimation needs to meet an essential premise. If there are no external shocks of CEPI, the GTI development of inspected cities and uninspected cities should be parallel without significant systematic differences. Therefore, based on the method in the reference Hering and Poncet (2014), $talk_{-i}$ representing *i* years before the implementation of the CEPI is incorporated into the model to investigate the difference in GTI before the CEPI. In addition, to investigate the marginal dynamic effect of CEPI on GTI, $talk_i$ representing *i* years after the implementation of the CEPI is also incorporated into the model.

In Table 9, $talk_{-n}$ in Eqs. (1) ~ (6) ($n = 1, 2, 3, 4$, and 5) does not pass the significance test, showing that before CEPI, there were no significant systematic differences in GTI between inspected cities and uninspected cites. The conclusion verifies the parallel hypothesis trend. In addition, regarding the marginal dynamic effect, except for Eqs. (5) and (6) which have been significant since $talk_0$, others have been significant since $talk_1$. However, in all models, the coefficients start to be insignificant in the third year

**Table 9** Parallel trend test and dynamic effectS of CEPI on GTI

| Variables | (1) igt | (2) igt | (3) igt | (4) igt | (5) igt | (6) igt |
|---|---|---|---|---|---|---|
| $talk_{-5}$ | 4.934 | 4.976 | 5.416 | 5.347 | 4.654 | 4.243 |
| | (5.796) | (5.841) | (5.905) | (5.886) | (5.750) | (5.779) |
| $talk_{-4}$ | 2.488 | 2.583 | 3.124 | 3.076 | 3.387 | 3.406 |
| | (5.245) | (5.282) | (5.352) | (5.337) | (5.161) | (5.180) |
| $talk_{-3}$ | 2.148 | 2.233 | 2.520 | 2.481 | 3.115 | 2.947 |
| | (4.360) | (4.383) | (4.340) | (4.393) | (4.318) | (4.331) |
| $talk_{-2}$ | 3.730 | 3.581 | 3.758 | 3.760 | 2.874 | 2.666 |
| | (2.867) | (2.823) | (2.841) | (2.837) | (2.927) | (2.948) |
| $talk_{-1}$ | 6.247 | 6.366 | 6.567 | 6.516 | 6.296 | 5.924 |
| | (4.842) | (4.894) | (4.936) | (4.912) | (4.817) | (4.863) |
| $talk_0$ | 6.494 | 6.585 | 6.480 | 6.444 | 7.762* | 7.613* |
| | (4.281) | (4.309) | (4.311) | (4.300) | (4.002) | (4.002) |
| $talk_1$ | 8.000* | 8.266* | 8.171* | 8.148* | 9.772** | 9.901** |
| | (4.315) | (4.337) | (4.350) | (4.326) | (3.965) | (3.931) |
| $talk_2$ | 14.320** | 13.858* | 13.424* | 13.404* | 13.222** | 12.931** |
| | (7.137) | (7.174) | (7.215) | (7.196) | (6.552) | (6.565) |
| $talk_3$ | 9.662 | 9.914 | 9.441 | 9.432 | 8.964 | 8.370 |
| | (6.382) | (6.425) | (6.276) | (6.268) | (6.356) | (6.435) |
| Intercept term | − 2.943 | − 4.054 | − 8.409 | − 7.840 | − 3.351 | 3.199 |
| | (5.975) | (6.145) | (7.450) | (7.292) | (7.069) | (8.289) |
| Time fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| City fixed effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Observation | 2 376 | 2 376 | 2 376 | 2 376 | 2 376 | 2 376 |
| $R^2$ | 0.171 | 0.177 | 0.178 | 0.178 | 0.216 | 0.217 |

after inspection and also drop sharply. Generally, it can be found that the CEPI has an "immediate" promotion effect on GTI, which is similar to the research result from Tan and Mao (2021), and then the effect begins to gradually decline over time, i.e., the long-term impact of CEPI on GTI is not strong. The nonsustained effect may be related to the type of innovation promoted by CEPI. CEPI incentivizes local governments to increase EP intensities and make some achievements in the short term, which mainly aims to encourage utility GTI rather than incentive innovation to cater for the central supervision. Thus, CEPI may fail to promote the long-term development of local GTI.

**Placebo test** A false CEPI time is constructed to verify its impact on GTI. The false years of CEPI are 2010, 2011, and 2012, respectively, and the core explanatory variables are denoted as $talk^{p4}$, $talk^{p3}$, and $talk^{p2}$. In Table 10, $talk^{p4}$, $talk^{p3}$, and $talk^{p2}$ are all insignificant, and $talk^{p2}$ is even negative, indicating that the impact of CEPI on GTI is not affected by other random factors and that CEPI can indeed promote local GTI.

In addition, the time of the sample is changed to verify the variation of the promotion effect of CEPI on GTI with time. From Table 11, with the change of time, CEPI significantly promote GTI and the effect does not change with the selection of time, further verifying the robustness of results.

### Heterogeneity analysis of the impact of CEPI on GTI

**Endogeneity analysis of city size** The above analyses show that CEPI can promote GTI. Then, does the promoting effect also exist in cities of different sizes? If the effect exists, does it differ among cities? Regarding the city size, large cities have siphoning and agglomeration effects of resources and the allocation efficiency of GTI factors is also higher, which will inhibit the development of GTI. As a spatial aggregation of factor resources, cities are also the source of many environmental problems. Megacities also have a significant scale effect and are plagued by the blind expansion of heavy industry, thus hindering the green development of the economy and society (Wang and Zhou 2021a; Xu et al. 2021). Cities will face the problem of balancing these two effects in their development. However, the implementation of the CEPI system can strengthen the ER supervision, reduce the scale effect due to urban expansion, and then force local GTI. Based on these analyses, the impact of CEPI on GTI at different city scales is discussed. The latest standards issued by the State Council in 2014 are used to delimit cities.

From Table 12, CEPI can promote GTI in both small and medium-sized cities and large cities, while the effect on GTI in large cities was more significant. However, it does not affect the local GTI that supercities are inspected. The result indicates that the GTI effect of CEPI only occurs in small-medium cities and big cities. Since the scale effect

**Table 10** Counterfactual test

| Variables | talk $^{p4}$ | talk $^{p3}$ | talk $^{p2}$ |
|---|---|---|---|
| | igt | igt | igt |
| $talk^{p4}$ | 1.296 | | |
| | (1.192) | | |
| $talk^{p3}$ | | 0.055 | |
| | | (0.994) | |
| $talk^{p2}$ | | | −0.500 |
| | | | (1.228) |
| Intercept term | 18.086 | 18.265 | 18.182 |
| | (11.556) | (11.454) | (11.474) |
| Control variables | Yes | Yes | Yes |
| Time fixed effect | Yes | Yes | Yes |
| City fixed effect | Yes | Yes | Yes |
| Observation | 1 296 | 1 296 | 1 296 |
| $R^2$ | 0.133 | 0.131 | 0.132 |

**Table 11** Time sensitivity test

| Variables | 2013–2015 | 2012–2016 | 2011–2017 |
|---|---|---|---|
| | igt | igt | igt |
| talk | 3.217* | 3.845* | 4.273* |
| | (1.961) | (2.332) | (2.295) |
| Intercept term | 6.462 | 22.913*** | 12.908*** |
| | (8.592) | (5.410) | (4.877) |
| Control variables | Yes | Yes | Yes |
| Time fixed effect | Yes | Yes | Yes |
| City fixed effect | Yes | Yes | Yes |
| Observation | 648 | 1 080 | 1 512 |
| $R^2$ | 0.105 | 0.146 | 0.216 |

**Table 12** Heterogeneity analysis of urban scale

| Variables | Small-medium cities | Big cities | Supercities |
|---|---|---|---|
| | igt | igt | igt |
| talk | 2.820** | 10.609** | −11.410 |
| | (1.413) | (4.774) | (10.119) |
| Intercept term | 1.499 | 6.305 | 633.79 |
| | (2.022) | (4.169) | (410.24) |
| Control variables | Yes | Yes | Yes |
| Time fixed effect | Yes | Yes | Yes |
| City fixed effect | Yes | Yes | Yes |
| Observation | 1 012 | 1 155 | 209 |
| $R^2$ | 0.226 | 0.368 | 0.616 |

in small and medium-sized cities and large cities is smaller than that in megacities, CEPI can urge local governments to ensure rapid rectification and improve environmental governance efficiency in the short term (Wu and Wang 2019), thus promoting the GTI. However, supercities have a large scale effect, which makes it more difficult to rectify the environment after being inspected, and it is difficult to show the effect of GTI in the short term. In addition, the inspection is persuasive rather than warning, and the officials being inspected in supercities are of higher administrative levels. They face less pressure from central inspectors than that in smaller cities. Therefore, supercities fail to effectively promote GTI when they are inspected by the central government.

**Heterogeneity analysis of urban characteristics** The heterogeneity of urban characteristics is further analyzed to determine which urban characteristics contribute to the promotion effect of CEPI on GTI. CEPI mainly achieves green economic development by fostering environmental governance of local governments. Therefore, *gov* and *fdi* are indispensable for EP negotiations to force GTI through pollution prevention and control. Thus, from the perspective of urban characteristics, the heterogeneity analysis on the impact of CEPI on GTI is conducted.

From Table 13, regardless of the level of *fdi* and *gov*, CEPI can promote GTI, while there are differences insignificant levels or impact coefficients. In terms of FDI, the coefficient of CEPI on GTI is positive at higher FDI. In cities with lower FDI, the coefficient is 5.191 and is significant at a 1% level, indicating that the quality of FDI remains relatively low and leads to the spillover of dirty technology (Wang and Luo 2020). Therefore, FDI can reduce the contribution of CEPI to GTI.

Regarding government intervention, the coefficient of CEPI on GTI is not significant at higher *gov*. The coefficient of cities with lower *gov* is 8.753 and is significant at 5% level. The results show that although *gov* has a promotion effect on the implementation of CEPI, the effect weakens with the increase of *gov*. When a city is inspected, the local government will appropriately intervene in enterprises' innovation investment to promote GTI. However, when enterprises dominate GTI, government intervention cannot accurately capture the transformation conditions of green technology R&D incentives. Therefore, the excessive intervention will reduce enterprises' enthusiasm for innovation and will not effectively guide the GTI development (Dong et al. 2020).

## Conclusions and policy implications

GTI is a significant force to promote sustainable economic development. To strengthen the top-level design of GTI drive and fight the battle against pollution, local governments should implement environmental legislation, law enforcement, and supervision, and take various measures to optimize the green R&D environment and enhance innovation vitality. Therefore, based on DID, PSM-DID, and SDID methods, the impact of CEPI on GTI is empirically studied in this paper with 216 Chinese cities from 2008 to 2018. The conclusions are:

(1) CEPI promotes GTI. (2) Regarding the different types of GTI, CEPI mainly promotes practical GTI. (3) Regarding the mechanism of action, CEPI significantly promotes local GTI mainly through the increase of EPE and R&D investment. (4) Regarding the dynamic marginal effect, CEPI selectively promotes GTI, which appears in the following year but disappears in the third year. (5) Regarding the extensional analysis, GTI effect of CEPI only occurs in small-medium cities and big cities. CEPI more significantly promotes GTI of cities with lower FDI and government intervention. (6) Regarding the spatial

**Table 13** Heterogeneity analysis of urban characteristics

| Variables | Higher FDI | Lower FDI | Higher government intervention | Lower government intervention |
|---|---|---|---|---|
| | igt | igt | igt | igt |
| talk | 26.484** | 5.188*** | 7.151 | 8.753** |
| | (11.270) | (1.392) | (5.005) | (3.672) |
| Intercept term | 55.752*** | −0.437 | 23.580 | 17.494*** |
| | (17.103) | (2.343) | (9.039) | (5.224) |
| Control variables | Yes | Yes | Yes | Yes |
| Time fixed effect | Yes | Yes | Yes | Yes |
| City fixed effect | Yes | Yes | Yes | Yes |
| Observation | 825 | 1 551 | 979 | 1 397 |
| $R^2$ | 0.316 | 0.308 | 0.136 | 0.312 |

effect, CEPI has an inhibitory effect on GTI in neighboring cities. SDID further decomposes this effect, and it is found that the inhibitory effect of CEPI on GTI mainly occurs in neighboring uninspected cities but has no apparent inhibitory effect on neighboring inspected cities. In other words, there is a certain beggar-thy-neighbor effect between inspected and uninspected cities. Based on the conclusions, the following policy implications are proposed:

(1) Long-term and short-term rectification requirements after the CEPI should be combined. Local authorities should develop time-bound governance means as soon as possible for the problem that can be solved in a short term. In contrast, for issues that can only be solved in the long term, scientific and reasonable rectification requirements and time frames should be formulated to avoid the crowding-out effect of strategic innovation and high-quality GTI. Furthermore, look-back procedures and environmental monitoring and regulation should be improved to encourage green technology development and progress, thus preventing the return of the pollution problem.

(2) The rectification results of the CEPI should be incorporated into the comprehensive assessment system for officials. The EP meetings should be used as an opportunity to improve the EP management system, encourage local governments to increase EPE and promote the development of energy conservation and EP. Enterprises should increase R&D investment and internalize their pollution costs through green technological progress. In addition, while urging local governments to effectively transmit pressure, CEPI should focus on optimizing the industrial structure, eliminating obsolete production capacity and promoting the development of emerging EP industries.

(3) Relevant policy and institutional design should be optimized to make CEPI robust and rigid. The spatial spillover effect of CEPI on GTI has been demonstrated. Therefore, it is necessary to continuously improve public involvement in the engagement policy, enhance media participation, further strengthen environmental publicity and education and information disclosure, and exert the positive externalities of environmental engagement policies. For inspected cities with issues, the mayors or superior leaders of neighboring municipalities can be invited to participate in interviews to reinforce the spatial radiation effect of EP, thus avoiding the "smoky vehicle" effect between regions and establishing a new pattern of collaborative regional GTI development.

## Appendix

| Abbreviation | Complete spellings | Abbreviation | Complete spellings |
|---|---|---|---|
| CEPI | Central environmental protection inspection | ER | Environmental regulation |
| GTI | Green technology innovation | EP | Environmental protection |
| DID | Difference-in-differences | R&D | Research and development |
| PSM-DID | Propensity score matching difference-in-differences | SDM | Spatial Durbin model |
| SDID | Spatial difference-in-differences | WIPO | World Intellectual Property Organization |
| TI | Technological innovation | SIPO | State Intellectual Property Office |

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**Data availability** The data used to support the findings of this study are available from the corresponding author upon request.

## Declarations

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** All authors have given their consent to publish this research article.

**Conflict of interest** The authors declare no competing interests.

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