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Paths to low-carbon development in China: The role of government environmental target constraints

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Keywords: *government environmental target constraints; carbon emissions; energy consumption; industrial structure optimization; green technology innovation*

Abstract

Research background: To achieve the targets for carbon peak and air quality improvement, local governments should propose environmental targets and develop realization paths that are tailored to their unique local conditions. They then promote low-carbon development through the implementation of multiple measures.

Purpose of the article: As the government performance appraisal system im-proves, the question arises as to whether governments take the initiative to com-bine environmental policies with government target constraints to reduce carbon emissions.

Methods: The announcement of environmental target constraints by local governments in government work reports is considered a quasi-natural experiment. This study examines the effect of government environmental target constraints (GETC) on carbon emissions (CEs) using differences-in-differences (DID), propensity score matching-DID (PSM-DID), and spatial-DID (SDID) with data from 241 Chinese cities from 2003 to 2019.

Findings & value added: The results demonstrate that GETC can effectively reduce local CEs, with the inhibitory effect being most effective in the first two years after setting environmental targets, but diminishing in the third year. GETC can reduce local CEs through three paths: reducing energy consumption, promoting industrial structure optimization, and encouraging green technology innovation. Spatial spillover effects show that GETC reduces local CEs while exacerbating CEs in neighboring cities, indicating a beggar-thy-neighbor effect in conventional environmental regulation policy. This effect is observed mainly in the geographic matrix and the economic-geographic matrix, but not in the economic matrix. According to heterogeneity analysis, GETC in the eastern and central cities can significantly reduce CEs. The inhibitory effect of GETC on local CEs is stronger in cities where secretaries and mayors have longer tenures and higher levels of education. The paper's theoretical value lies in exploring the reduction of CEs through the combination of government self-restraint and environmental policies, providing a new solution for local governments to achieve CEs reduction. Furthermore, it offers practical insights into the improvement of the Chinese government assessment system.

Introduction

With the frequent occurrence of global extreme weather events, climate change has become a common crisis and challenge for the whole world. To cope with global warming, China has set the goal of achieving carbon peak by 2030 and carbon neutrality by 2060, as stated in the government work report. Actively reducing carbon emissions (CEs) is not only an objective requirement for complying with global development trends, but also a significant opportunity for promoting China's sustainable development. However, China's current CEs intensity remains significantly higher than the world average and is decreasing at a slow pace (Zhang *et al.*, 2021). The BP World Energy Statistics Yearbook reports that China's coal and fossil fuel consumption continued to grow in 2020, resulting in a 0.6% increase in CEs, and a share of total global CEs at 31%, indicating the pressing need for China to reduce its current CEs. Since CEs are mostly externalities in the economic production process, market mechanisms may fail in the process of CEs reduction (Wen & Lee, 2020). Therefore, addressing CEs has become an urgent environmental issue for governments to tackle at present.

To promote low-carbon development, the government should use its visible hand to compensate for market failures. This means a series of government environmental regulations (ER) can facilitate achieving carbon reduction targets (Li *et al.*, 2022). However, under a GDP-based assessment, governments often prioritize economic growth at the expense of the environment, resulting in greatly reduced effects of government ER policies (Bai *et al.*, 2019). Local government assessment systems have been continuously improved. In addition to economic incentives, environmental performance is included in the assessment of local officials. Various regulations protect the environmental assessment, and clear quantitative control indicators are in place. Although local governments' ER targets mainly focus on conventional pollutants such as sewage and air pollutants, the burning of fossil fuels such as coal, industrial production, and tourism development not only emits conventional pollutants, but also produces a considerable amount of carbon dioxide and black carbon, indicating a homogeneity between conventional pollutants and greenhouse gases (Li *et al.*, 2022). Therefore, in the context of increasing economic downward pressure due to the epidemic and China being in a critical period of CEs reduction, the purpose of this study is to examine whether government environmental target constraint (GETC) is effective and whether it has the effect of CEs reduction synergies. Can GETC differ from traditional ER in achieving inter-regional low-carbon synergistic development? It is essential to examine if local governments can take the initiative to combine environmental policies with government target constraint behaviors to reduce CEs.

This paper has several contributions compared to previous research. Firstly, it is the first study to analyze the CEs reduction effect of governmental target constraints from the perspective of environmental targets. By combining ER with governmental self-restraint, a valuable addition to the related literature is offered in this field. Secondly, the influence mechanism of the GETC on CEs is examined and tested from three aspects: scale, structural, and technology effects. This approach provides a theoretical path reference for the effective performance of the GETC. Thirdly, the spatial effect of the GETC on CEs reduction is analyzed to determine whether local GETC policies bring about positive or negative competition among neighboring regional governments. These findings provide important practical suggestions for the improvement of the Chinese government assessment system and joint environmental governance. Additionally, from the perspectives of the characteristics of government officials and the distribution of cities, examining the differences in the impact of GETCs on CEs can provide a reference for the development of environmental policies that suit local realities in each city.

The study is structured as follows: section 2 reviews the existing literature; section 3 presents the theory and research hypotheses; section 4 outlines the methodology used in the study; section 5 presents the results of the empirical study; section 6 discusses the results in comparison to other studies; and the final section provides the conclusions.

Literature review

Local officials were encouraged by promotion tournaments to adjust their behavior based on their performance evaluations to win political promotions (Wang & Lei, 2021). Under the early assessment system based on GDP incentives, local governments competed to propose higher economic development targets than others. To achieve these goals, local governments vigorously attracted foreign investment and even lowered local environmental protection standards, leading to China's remarkable economic growth. However, this extensive growth has had a detrimental effect on the environment (Bai *et al.*, 2019). In 2001, the "10th Five Year Plan" raised environmental protection issues to the level of overall national planning to address pollution problems. Although only expected pollution reduction targets were set without effective constraints on local officials, the emission reduction targets were ultimately not achieved. Since then, the central government has tried to incorporate environmental indicators into performance evaluations to regulate government behavior. In 2007, the Ministry of Environmental Protection and various cities signed the *Letter of Responsibility for the Total Amount Reduction Target of Major Pollutants during the "11th Five Year Plan"*, quantifying the reduction tasks to ensure the completion of the reduction targets. At this point, environmental goal constraints were incorporated into the official assessment system. However, local officials tend to prioritize economic growth, and environmental protection is often overlooked. Therefore, the central government further improved the official evaluation system in 2009, adding environmental performance evaluation criteria. In 2011, the State Council issued the *Assessment Method for Total Emission Reduction of Major Pollutants*, which incorporated a one-vote veto system and environmental accountability into the assessment system, once again strengthening the environmental goal constraints of local governments and encouraging them to participate more actively in environmental governance. Therefore, the initiative of local governments to include pollution reduction targets in government work reports will inevitably impact emission reduction, thereby affecting CEs.

ER is an important method for environmental protection, and the relationship between ER and CEs has been studied extensively. On one hand, some scholars have found that ER can effectively reduce CEs through "forced emission reduction." For example, Zhao *et al.* (2020a) found that ER can force enterprises to reduce fossil energy consumption to reduce CEs, while Pei *et al.* (2019) demonstrated that ER can also reduce CEs by improving technological efficiency. Zhao *et al.* (2020b) proposed that strict environmental control can curb CEs, but different levels of ER in different regions can lead to the transfer of CEs within the region, resulting in a Carbon Heaven effect. On the other hand, some studies suggest that ER has difficulty effectively reducing CEs. Sinn (2008) pioneered the idea of the "green paradox," arguing that ER policies may lead to greater energy purchases and increased energy consumption in other regions, making it more difficult to reduce energy consumption and pollutants through energy reduction policies. Van der Werf and Di Maria (2012) showed that the lag in the implementation of the government's carbon tax policy and clean alternative energy subsidies would lead to an increase in current energy consumption and thus increase CEs. Additionally, governments may adopt race-to-the-bottom behavior for ER to promote extensive economic growth, which is not conducive to energy conservation (Bai *et al.*, 2019). Moreover, Zhang *et al.* (2020) found that as the level of ER improves, the inhibitory effect of ER on CEs intensifies, and CEs can also be reduced through the introduction of clean foreign capital. Jiang and Ma (2021) demonstrated that insufficient ER has an innovation inhibition effect[1], hindering CEs reduction, whereas higher levels of ER would have an innovation compensation effect[2] to reduce CEs. Zhang *et al.* (2021) found that the impact of ER on CEs has not yet crossed the inflection point (green paradox stage).

The impact of ER on CEs can be categorized into three perspectives: "reverse forced emission reduction," "green paradox," and an inverted "U" shape. However, these studies have not reached a consistent conclusion, which may be due to the different types of ERs and measurement methods used, leading to differences in CE reduction effects (Qi *et al.*, 2022). Peng *et al.* (2021) analyzed the impact of heterogeneous ER on carbon productivity and found that compared to compulsory and market-based ER, voluntary ER have an insignificant effect on CEs. To avoid endogeneity problems, Shi *et al.* (2019) measured ER using keywords related to environmental governance in government work reports. Some scholars have studied the impact of exogenous ER policies on CEs by using quasi-natural experiments, such as environmental information disclosure (Lin *et al.*, 2021), low-carbon city pilots (Yu & Zhang, 2021), and mandatory emissions trading schemes for energy-intensive industries (Ouyang *et al.*, 2020), to investigate the impact of ER policies on CEs.

However, few studies have considered the impact of environmental performance incorporated into the government assessment system on CEs, leading to a lack of analysis on the CEs reduction effect of government target constraints from the perspective of environmental targets. Thus, this study differs from previous research by discussing the effect of the combination of government self-restraint and environmental policy on CEs reduction. Furthermore, while some studies have only discussed the causal relationship between ER and CEs, this study examines the multiple mechanisms of GETC on CEs reduction. Additionally, this study innovatively examines the spillover effect of GETC policies and analyzes the competition effect of intergovernmental ER policies.

[1] The introduction of ER will inevitably increase business costs and then inhibit innovation.

[2] ER stimulates firms to adapt and invest in environmental technologies, enhancing their capacity to innovate.

Theory and research hypothesis

The direct impact of GETC on CEs

When GETC is incorporated into the official assessment system, local leaders increase environmental protection expenditure to achieve environmental targets, avoid rejection by one vote, and meet political performance assessment, which hinders emission reduction. However, the inclusion of environmental pollutant emission constraint targets in government work reports reflects a determination to environmental governance, promoting local economic structure and avoiding pollution emissions caused by extensive economic development, which helps to promote the decoupling of economic development and CEs (Asici & Acar, 2018). Competitive behavior among local governments in ER may lead to pollution transfer and increased local CEs (Zhang *et al.*, 2021). However, the inclusion of environmental assessment in government performance means that GDP is no longer the only standard for measuring local development levels. With the continuous improvement of quantitative standards for environmental assessment, interregional governments' competition to lower environmental standards for growth will be reduced, and ER will shift from "bottom-to-bottom competition" to "top-to-top competition" (Wang & Lei, 2021), which is conducive to promoting CE reduction.

The green paradox suggests that the strengthening of ERs will cause energy owners on the supply side to accelerate energy exploitation, which will lead to lower energy prices, increased supply, and increased CEs (Sinn, 2008). However, the limited reserves of fossil energy cannot realize unlimited supply, and there is a possibility that energy demand and price may rise simultaneously (Van der Ploeg & Withagen, 2012). Additionally, green paradox will only lead to a short-term increase in CEs, and the implementation of GETC will increase ERs, transforming the relationship between ER and CEs from a "green paradox" to "forced emission reduction" (Wenbo & Yan, 2018). Therefore, we propose the following research hypothesis:

Hypothesis 1: *GETC can reduce CEs.*

The mechanism of the indirect impact of GETC on CEs

GETC has a direct impact on CEs through political performance incentives and enhanced ERs, as well as through energy, industrial, and other channels (Li *et al.*, 2022). This study discusses the effect mechanism of GETC on CEs from three aspects: scale effect (energy consumption), structure effect (industrial structure optimization), and technology effect (green technology innovation).

China's energy demand and consumption are still relatively higher, and the energy structure is dominated by fossil fuels, which directly produce many CEs (Liu *et al.*, 2019). Strict government-formulated ER can change the energy investment structure, reducing the use of nonrenewable energy sources and helping to reduce CEs (Xie *et al.*, 2021). ER can also avoid high energy consumption and emissions caused by extensive economic development (Aşici & Acar, 2018). Furthermore, the GETC means that the government clearly specifies the number of pollutant emission reductions for the year in the government work report at the beginning of the year. To effectively reduce such pollutants, local governments will quickly adopt environmental policies according to the local situation, reducing energy consumption intensity (ECI) and avoiding the rebound of energy consumption intensity caused by policy delay, which helps to reduce CEs. Therefore, we propose the following research hypothesis:

Hypothesis 2: *GETC can reduce CEs by reducing ECI.*

China's current economic development model has not completely shifted from extensive to intensive development, with industrialization based on heavy industry consuming a large amount of fossil fuels (Qi *et al.*, 2022). Strict ER can increase the cost of local polluters and highly carbon-intensive enterprises, leading them to exit the market or conduct industrial adjustment and upgrading locally (Zhao *et al.*, 2020b). ER can also create environmental barriers by raising the access threshold for highly carbon-intensive enterprises, preventing the entry of non-environmental enterprises (Zhao *et al.*, 2020b), thereby helping to reduce CEs.

Additionally, the self-restraint behavior of local governments in disclosing annual environmental targets strengthens ER behavior. The crowding out effect brought by the above ER on local polluting enterprises will drive regional industrial upgrading. Furthermore, for the environmental protection industry, after the government sets environmental target constraints, strict environmental policies are conducive to clean enterprises, improving their profits and attracting social capital and factors to flow to the clean industry (Wang & Shen, 2016). Therefore, we propose the following research hypothesis:

Hypothesis 3: *GETC can reduce CEs through industrial structure optimization.*

Innovation plays a key role in sustainable development (Brodny & Tutak, 2023; Sánchez & Galdeano, 2023). Especially green technology, which can reduce ecological environmental pollution, has become an area of increasing social attention. Green technology innovation (GTI) can help local governments monitor the pollution emission information of enterprises in a timely manner, provide enterprises with targeted schemes to control pollutants (Xu *et al.*, 2021), and reduce CEs in the production process.

Porter's hypothesis proposes a close relationship between ER and technological innovation (Porter & Linde, 1995). On the one hand, reasonable and effective ER policies can compensate for the cost increase caused by ER through enterprise technology innovation, resulting in an "innovation compensation effect" (Porter & Linde, 1995). Furthermore, when ER is continuously strengthened, it can reduce carbon dioxide emissions through technological innovation, especially GTI (Zhang *et al.*, 2021). Strict ER caused by GETC will not only lead to the innovation compensation effect through GTI, but also avoid the loss of competitiveness of enterprises (Peng *et al.*, 2021).

Neoclassical economic theory advocates disincentive theory, which argues that ER leads to higher production costs (Peña *et al.*, 2023) and inhibit firms' technological innovation, resulting in a "compliance cost effect" (Gray *et al.*, 1987). However, others argue that ER does not inhibit GTI, but there may be a time lag for environmental regulations to stimulate GTI development (Jiang & Ma, 2021). When ER is relatively high, it can effectively motivate firms to engage in GTI (Hu & Wang, 2020). Therefore, we propose the following research hypothesis:

Hypothesis 4: *GETC can reduce CEs through GTI.*

Spatial Effects of GETC on CEs

Local governments may exhibit significant imitation behaviors and regional interactions when formulating or implementing environmental regulatory policies, resulting in a spatial correlation effect in ER policies (Feng *et al.*, 2020). Certain spatial correlation effects also exist in CEs between regions, such as CE spillovers or transfer effects (Zhao *et al.*, 2020b), which have significant spatial spillover effects. Therefore, government environmental governance behavior not only affects local CEs, but also responds to CEs in surrounding cities.

The improvement of local ER may hinder neighboring cleaner production when ER policies differ between cities (Dong *et al.*, 2020). When GETC is set, local carbon polluters may move to other cities to avoid the cost increase caused by target setting or undertake GTI in the original region to compensate for the cost and reduce their CEs. However, neighboring governments may lower the threshold of environmental protection standards for the survival of high emission enterprises, making it difficult for ER policies to reduce CEs. The inconsistency of government ER may lead to the relocation of polluting industries to neighboring cities, aggravating the pollution emissions of neighboring cities and hindering their low-carbon development (Zhao *et al.*, 2020b). In other words, neighboring cities cannot be isolated from environmental governance. Due to differences in the environmental goal setting and regulation implementation of local governments, it is possible for enterprises with high CEs to avoid environmental pollution problems. Consequently, cities with weak or unclear environmental constraints may become havens for pollution-intensive enterprises, resulting in the beggar-thy-neighbour phenomenon (Li *et al.*, 2022). Therefore, we propose the following research hypothesis:

Hypothesis 5: *GETC may increase CEs in neighboring cities when reducing local CEs.*

Research methods

Model setting

In 2007, the Ministry of Environmental Protection signed the Eleventh Five-Year Plan (Responsibility Statement) with provinces, municipalities, autonomous regions, and municipalities directly under the central government to reduce the total amount of major pollutants. This marked the formal inclusion of GETC in the officials' assessment system. However, not all local governments would include GETC in their government work reports, resulting in a difference in the GETC due to inconsistent responses to the Responsibility Statement. This paper compiles data on the GETC of governments by collecting their work reports. Following Wang *et al*. (2023), local governments are considered to have exercised self-regulation only if specific pollutant reduction targets are explicitly stated in the government work report. DID is an important method for the estimation of group causal effects and can be understood as a simulation of a random assignment experiment to verify causality in the absence of a random experiment. For a natural experiment (such as the GETC), it divides the full sample data into two groups: one group is affected by the intervention, the treatment group, and the other group is not affected by the same intervention, the control group. Therefore, cities that propose GETC are used as the treatment group, while cities that do not explicitly propose GETC are the control group.

To estimate the impact of GETC on CEs, we use the differences-in-differences (DID) method with consecutive years.

$$CO2_{it} = \alpha_0 + \alpha_1 GETC_{it} + \gamma X + \lambda_i + \lambda_t + \mu_{it} \tag{1}$$

To address potential self-selective bias in the data and avoid errors associated with direct estimation, we use the PSM-DID method, which can often remove selective bias from the data.

$$CO2_{it}{}^{psm} = \alpha_0 + \alpha_1 GETC^{psm}{}_{it} + \gamma X^{psm} + \lambda_i + \lambda_t + \mu_{it} \tag{2}$$

In equations (1) and (2), i denotes the city, t denotes the year, CO_2 is the CEs, and *GETC* is a policy dummy variable indicating whether the city is affected by GETC. α_0 is a constant term, and α_1 is the coefficient of focus, which indicates the net effect of GETC on CEs. γ is the coefficient of control variables. λ_i denotes individual fixed effects, and λ_t denotes time fixed effects. μ_{it} denotes the random disturbance term.

The third step is to investigate the mechanism through which GETC reduces CEs. Following the approach of Chen *et al.* (2020), we verify the mediating effect by regressing the mechanism variables on the core explanatory variables.

$$ECI_{it}(ISO_{it}, GTI_{it}) = \chi_0 + \chi_1 GETC_{it} + \phi X + \lambda_i + \lambda_t + \pi_{it} \quad (3)$$

where *ECI* denotes energy consumption intensity, *ISO* denotes industrial structure optimization, and *GTI* denotes green technology innovation. x_0 is the constant term, x_1 is the coefficient of the core explanatory variable, and ϕ is the coefficient of the control variable. π is the random disturbance term.

To test the spatial impact of GETC on CEs, a spatial Durbin model was developed:

$$CO2_{it} = \beta_0 + \beta_1 GETC_{it} + \beta_2 WGETC_{it} + \pi WX + \gamma X + \lambda_i + \lambda_t + \varepsilon_{it} \quad (4)$$

where $\beta_0$is the intercept term. β_1 and α_1 have the same meaning.β_2 is spatial spillover effect. π is the spatial effect of control variables on CE.β_2 is the spatial effect of GETC on CEs. W is the spatial weight matrix, including geographic weight matrix, economic weight matrix and mixed economic-geographic weight matrix. $\varepsilon_{it}$is random error term.

Data sources and description

The explained variable for CEs intensity (CO_2) is obtained by inverting the model based on nighttime lighting data and global power plant emission inventory data. This variable covers global CO_2 emissions from fossil fuel combustion, cement production, and natural gas combustion at a 1 km resolution monthly raster data. The CO_2 emission source data are obtained from the National Institute for Environmental Studies Open Data Inventory for Anthropogenic CO_2 (Oda & Maksyutov, 2016), and the data are parsed using ArcGIS software and matched with Chinese administrative division data to obtain total annual CO_2 emissions for 241 prefecture-level cities in

China from 2003 to 2019. Finally, the carbon intensity data are obtained by taking the logarithm of the ratio of total carbon emissions to GDP.

The core explanatory variable is GETC. If a local government is influenced by the Responsibility Statement and the city sets environmental targets for self-regulation in year *t*, then the city takes the value of 1 in year *t* and subsequent years. Otherwise, it takes the value of 0.

Several control variables are included to exclude the influence of other factors on the results and to ensure the accuracy and reliability of the regression results. Economic development (*ey*) and its squared term (ey^2): Song, (2021) found a non-linear relationship between economic growth and CEs. Therefore, economic development should be added to the model to verify whether there is a CO_2 Kuznets curve between economic growth and CEs. It is measured by using real GDP per capita and its squared term. Industrialization (*indus*) is expressed as the share of value added of the secondary sector in each city (Zhao *et al.*, 2020b). The secondary sector consists of sectors such as industry and construction, and an increase in the share of these sectors will lead to an increase in the use of resources such as fossil fuels, which will aggravate CEs (Bai *et al.*, 2023). Population density (*den*) is measured by taking the logarithm of the number of people per unit administrative area (Li *et al.*, 2022). Because of the agglomeration of public living and production activities, greenhouse gases are emitted. Meanwhile, it also helps to reduce CEs by improving the efficiency of the use of resources such as transport and heating (Qi *et al*., 2022). Anyway, population density has a non-negligible impact on CEs. Foreign direct investment (*fdi*) is measured using the ratio of total foreign investment actually used by each city to GDP (Wenbo & Yan, 2023). FDI has a significant impact on CEs, with the pollution halo hypothesis suggesting that environmentally friendly technological spillovers from FDI can reduce CEs, and the pollution paradise hypothesis suggesting that FDI can exacerbate CEs through an increase in polluting industries (Song *et al.*, 2021).

In addition, Grossman and Krueger, (1995) showed that energy, technology and structure effect are important channels that influence environmental pollution. Therefore, the following are the three mechanisms. energy consumption intensity (*ECI*) is expressed as the ratio of energy consumption to GDP of city (Zhang *et al.*, 2021), and the energy consumption is calculated based on the whole society's electricity consumption, gas and natural gas supply, and liquefied petroleum gas supply converted into tonnes of standard coal (Li *et al.*, 2022). Industrial structure optimization

(*ISO*) is expressed as the ratio of the value added of the tertiary sector to the value added of the secondary sector (Li *et al.*, 2022). Green technology innovation (*GTI*) is measured using the green patent application data of local municipalities. The green patent list published by the World Intellectual Property Organization (WIPO) is used to identify the IPC classification numbers of green patents. Then, the green patent application data of local municipalities are compiled to indicate GTI (Zhang *et al.*, 2020).

Due to data limitations and availability, the empirical analysis is based on 241 cities from 2003 to 2019. All variables related to prices are measured at constant prices with 2003 as the base period. Data related to CEs measurement are obtained from the China City Statistical Yearbook and China City Construction Statistical Yearbook. Carbon dioxide data are from the National Institute for Environmental Studies (NIES) Open Data Inventory for Anthropogenic Carbon Dioxide. Green technology innovation data are obtained from the State Intellectual Property Office based on the IPC classification numbers listed in the list of green patents published by WIPO. Data on GETC are obtained from the work reports of prefecture-level municipal governments. Other data are obtained from the China City Statistical Yearbook.

Descriptive statistics of the variables are presented in Table 1. We divide the sample into two groups based on whether the cities are exposed to GETC or not. We find that the average level of CEs in GRTC cities is 0.785, while the average level of CEs in non-GRTC cities is 0.975, and the maximum value of the former is also smaller than the maximum value of the latter. In the full sample, the average value of CEs is 0.867. The above results indicate that after the cities were exposed to the GETC, there was an important change in the level of CEs in the GETCs compared to the non-GETC cities.

Results

Results of the direct impact of GETC on CEs

Baseline regression analysis

The results with only the core explanatory variable are presented in Column (1) of Table 2. The coefficient for GETC is -0.078 and significant at the

1% level, indicating that GETC reduces local CEs. This supports Hypothesis 1. The results are consistent with the findings of Ouyang *et al.* (2020), who found that mandatory emission reduction policies by the government can reduce CEs. Similarly, setting GETC can encourage local governments to increase their emission reduction efforts, effectively promoting a reduction in CEs. The coefficients for GETC remain significantly negative in Columns (2) through (6) after gradually adding control variables, and the significance level remains at 5%.

Regarding the control variables, the coefficient for economic development (*ey*) on CEs is -0.103 and significant, while the coefficient for ey^2 is 0.002 and also significant. This indicates a nonlinear relationship between the level of economic development and CEs, where low economic development does not aggravate CEs, but as economic development increases, energy consumption and other factors also increase, leading to elevated CEs. This finding is consistent with Nie *et al.* (2019). As local economic development increases, ECI and residential demand also increase, leading to elevated fossil fuel consumption and increased CEs, indicating that the current economic growth in China has not yet been decoupled from CEs. The coefficient for population density (*den*) is significantly negative, indicating that an increase in population density decreases CEs. This finding is similar to that of Qi *et al.* (2022), who found that a large population concentration can increase local public participation in environmental protection, putting pressure on the local government for environmental management and promoting efforts to reduce CEs. The coefficient for the level of industrialization (*indus*) on CEs is significantly negative, indicating that an increase in the level of local industrialization aggravates CEs. This may be due to the resource path dependence of industrialization with a predominantly secondary sector, where large energy consumption drives CEs (Wu *et al.*, 2021). The coefficient for foreign direct investment (*fdi*) on CEs is positive but insignificant. This may be because the ER level needs to be improved, making *fdi* insufficiently clean to take advantage of the clean technology spillover effect of foreign investment.

Estimation based on PSM-DID

Before performing PSM-DID, the applicability of the method is tested. The test results are presented in Table 3, which shows that all control variables are not significantly different after matching, indicating that PSM-

DID is applicable. Table 4 displays results. The coefficient for GETC remains significantly negative, indicating that GETC is effective in reducing local CEs, further supporting the previous results.

Parallel trend test

The event study method is used to analyze the trend of CEs in the year of GETC shocks faced by local governments that set targets and in the period before the shocks occurred. Figure 1 displays the results of the event study method. Year t is the year of the implementation of GETC. The coefficient for GETC on local CEs before the implementation of GETC (t-3, t-2, t-1) is almost 0 and not significant, indicating that there was no significant difference in the trend of change between the treatment and control groups, satisfying the parallel trend test hypothesis. However, the impact coefficient starts to become significantly negative after the implementation of GETC, indicating that GETC does reduce local CEs. The inhibitory effect of GETC on CEs improves in the first two years, but by the third year, it disappears. This suggests that local governments increased their local environmental protection efforts and pollution control levels in the first two years to achieve the targets, resulting in better reductions in CEs. However, over time, the environmental wake-up call and deterrent effect brought by GETC decreases or even disappears.

Placebo test

To test the robustness of the results, a placebo test is conducted by generating a list of treatment groups where GETC are not actually set. A regression analysis is performed 500 times, and the distribution of spurious impact coefficient estimates is observed. Generally speaking, the more the points are concentrated near the zero point of the horizontal axis, it means that the placebo test has been passed. Figure 2 shows that the values of the coefficients are mainly distributed between -0.1 and 0.1 and are approximately normal, with p-values almost always greater than 0.1. The placebo results demonstrate that other unobserved factors do not significantly affect local carbon emission reduction, further supporting the robustness of the results.

The mechanistic test of the indirect effects of GETC on CEs

Table 5 shows that GETC can significantly reduce energy consumption intensity (ECI) and promote industrial structure optimization (ISO) and green technology innovation (GTI). Combining the regression results, it is evident that GETC can reduce local CEs through three paths: reducing ECI, promoting ISO, and increasing GTI. This conclusion verifies the existence of hypotheses 2, 3, and 4. The implementation of GETC can change the ratio of society's investment in clean energy and reduce the consumption of fossil fuels, thereby reducing CEs (Xie *et al.*, 2021). GETC are environmental constraints set by governments at the beginning of the year when they develop their government work reports. Local governments increase their environmental regulatory power and put pressure on local polluting enterprises to fulfill their environmental management tasks and targets for the year, which can either squeeze out local polluting enterprises or force them to optimize and upgrade and carry out GTI locally. Moreover, strict environmental target constraints can raise the entry threshold of polluting enterprises, helping to improve the local industrial structure and reduce CEs (Zhao *et al.*, 2020b).

Further analysis: spatial spillover effects of GETC on CEs

Spatial correlation effect and applicability tests

The previous analysis illustrated the inhibitory effect of GETC on CEs. Therefore, spatial DID is used to test the impact of GETC on local as well as neighboring cities' CEs, that is, the CEs reduction spillover effect of GETC in the implementation process. The results of Moran's I test are presented in Table 6, showing that the spatial Moran indices of CEs are significantly positive. The above results show that there is a significant spatial correlation and spatial aggregation of CEs. In addition, LR tests were conducted, and all p-values were less than 0.01. The Wald test was also conducted to test whether SDM can degenerate into SAR, with p-values < 0.01 indicating that SDM does not degenerate into the spatial lag model (SAR) or spatial error model (SEM). Based on the Hausman test, the fixed-effects spatial Durbin model (SDM) is chosen to estimate the spillover effect, with the specific results shown in Table 7.

Spatial spillover effects of GETC on CEs

Table 8 presents the results of the effect of GETC on CEs under different spatial weight matrices. In Column (1), GETC can significantly reduce local CEs, but the coefficient of GETC on neighboring CEs is -0.011 and not significant. Under the economic weight matrix, there is no significant aggravating effect of GETC on CEs in cities with more similar economic development levels. Under the geographical weight matrix and the mixed weight matrix, there is a significant inhibitory effect of GETC on local CEs, while the coefficients of GETC on neighboring CEs are 2.148 ($p<0.01$) and 0.539 ($p<0.01$), respectively. This suggests that GETC can significantly aggravate the CEs of neighboring cities when considering geographical proximity or mixed economic-geographical proximity. The reason for this result may be that when a local government sets the GETC at the beginning of the year, the government increases the enforcement of environmental regulations to meet annual environmental targets, forcing local backward industries, such as high-carbon polluters, to transform and upgrade (Li *et al.*, 2022) or move out of the local area to neighboring cities to avoid the high costs associated with high-intensity environmental regulations (Dong *et al.*, 2020). However, polluting industries transfer to neighboring areas due to local environmental target constraints, reducing local CEs but worsening the industrial structure and hindering environmental technology upgrading in neighboring cities (Zhao *et al.*, 2020b; Feng *et al.*, 2020), thus aggravating CEs in neighboring cities. This result verifies hypothesis 5. Additionally, GETC is not significant under the economic weight matrix, which may be due to a more similar level of economic development that does not necessarily favor the transfer of polluting industries. Cities with more similar levels of economic development may be geographically distant from each other, and backward polluting industries prefer to move to cities with relatively lower levels of economic development to reduce relocation costs when they move (Dong *et al.*, 2020). Therefore, there is no significant aggravating effect of GETC on CEs in cities with similar economic development.

Heterogeneity analysis

Analysis of city distribution heterogeneity

The baseline regression results suggest that GETC can significantly reduce local CEs. Therefore, this article further explores whether the CEs reduction effect of GETC exists and differs for different cities of China. The environmental governance effects of GETC may vary according to characteristics of city (Hu & Wang, 2020), and the level of CEs varies between cities based on regional economic development (Li *et al.*, 2022), which may result in variation in the inhibitory effect of GETC on CEs by city. Hence, this study examines the CEs reduction effects of GETC in the eastern, central, and western cities of China.

Table 9 shows that GETC in the eastern and central cities can significantly reduce CEs, but it has no significant effect on the reduction of CEs in the west. This result suggests that the inhibitory effect of GETC on CEs varies significantly depending on the spatial distribution of cities. This may be because the east-central city has relatively better economic development than the western city. In cities with higher levels of economic development, residents are more concerned about the living environment, physical and mental health, and environmental quality, which increases pressure on governments to protect the environment and motivates them to increase environmental protection efforts (Gu *et al.*, 2022), thus facilitating the CEs reduction effect of GETC. Economic development in the western city is poorer, and governments tend to focus on the economic aspect of development, making it difficult to achieve low-carbon development effectively.

Heterogeneity analysis of official characteristics

Local government officials act as the makers of government policy, and the setting of environmental targets by the government at the beginning of the year puts a certain intensity of environmental pressure on the local officials primarily responsible. Therefore, to further examine whether the individual characteristics of key government officials have an impact on the CEs reduction effect of GETC, this paper adds in turn to the baseline regression model the intersection term between the secretary's term of office (*sjrq*) and its constraint with GETC (*sjrq × GETI*), the secretary's education (*sjxl*) and its intersection term with GETC (*sjxl × GETC*), the mayor's term of office (*szrq*) and its intersection term with GETC (*szrq* × *GETC*), and the mayor's education (*szxl*) and its intersection term with GETC (*szxl* × *GETC*). In Table 10, the higher the tenure and education of local secretaries and the tenure and education of mayors, the stronger the disincentive effect of GETC on local CEs. This may be because new government officials do not know enough about the local situation and that it takes time for ER policies to be developed and implemented. Local officials who have been in office for a shorter period are more likely to ignore environmental issues to achieve their own political performance (Wang & Lei, 2021). Therefore, key government officials with longer tenure can formulate appropriate environmental governance policies based on local realities when faced with environmental target constraints, thus effectively improving the local CEs situation. In addition, the higher the education of local officials, the more experienced they will be, and local governments will focus more on innovation and improve the productivity of enterprises (Meng *et al.*, 2019). Therefore, local government officials with higher education will incorporate the concept of sustainable development when considering economic development issues, which helps to enhance the local government's attention to environmental target constraints, thus improving the level of emission reduction.

Discussion

The 2022 China Eco-Environmental Protection Work Conference placed "orderly promotion of low-carbon development" at the top of its list. To achieve synergistic promotion in reducing pollution and carbon, local governments must set environmental goals and realize them according to local conditions. Several studies analyzed the impact of ER on CEs (Ouyang *et al.*, 2020; Zhao *et al.*, 2020a; Zhang *et al.*, 2021), but most have used data on local pollution emissions per unit GDP, which may be endogenous. Pollution emissions per unit GDP as ER is a regional integrated level of ER and does not purely reflect the government's environmental protection efforts. A few studies have used other government policies to represent government ER (Qi *et al.*, 2022; Li *et al.*, 2022), avoiding the endogeneity problem. However, this study examines the emission reduction effect brought about by ER from the perspective of a combination of government self-regulation and environmental policy. By investigating the behavior of local governments announcing environmental target constraints in government work reports on their initiative, this study examines whether the GETC may have a non-negligible impact on CEs in addition to affecting pollution control. Therefore, this study explores the direct impact, mechanism of action, spatial impact, and heterogeneity of GETC on CEs in 241 cities in China from 2003 to 2019.

Aşici and Aca (2018) found that strict ER can promote the transformation of the green economic structure. Feng *et al.* (2020) found that ER in China reduces air pollution. Zhang *et al.* (2020) found that the CEs effect of ER becomes more pronounced as ER continues to improve. Existing studies have laid the theoretical foundation and research direction for this article. This study distinguishes itself from existing traditional ER research by considering the government's own environmental target constraint as an environmental policy and finds that the GETC, as a policy advocated by the government to reduce pollution, can also reduce CEs. This result is meaningful and enlightening, demonstrating that governments can achieve the dual utility of reducing pollution and CEs by upgrading their own environmental goals.

Yan *et al.* (2023) studied Chinese firms and found that stricter ER reduces energy consumption. Xie *et al.* (2021) also found that ER can change the structure of energy use and increase the proportion of new energy sources. Moreover, some scholars have found that ER can optimize local industrial structure and promote green technology progress (Yu & Zhang, 2021; Zhao *et al.*, 2020b). Since energy use is the source of pollution and CEs, reducing energy consumption is key to reducing pollution and CEs. ISO and GTI can improve the production process and enhance the environment from the source and end. Therefore, this study finds that GETC reduces CEs through ECI reduction, ISO, and GTI. This finding validates and expands on existing research and highlights the role of energy consumption, industry, and green technology in the reduction process.

Local governments in China engage in competitive behaviors in economic development, and environmental pollution and CEs, as products of the economic development process, are also affected by competitive behaviors. Therefore, it is necessary to examine the impact of environmental protection behaviors between neighboring governments on CEs. It has been found that there is obvious spatially vicious competition between ER among different cities in China, where stronger local ER leads to weaker ER in neighboring cities, resulting in increased pollution and CEs in neighboring cities (Feng *et al.*, 2020; Zhao *et al.*, 2020b). However, it has also been mentioned that as the importance of environmental protection in China increased, governments at all levels began to compete for environmental protection, resulting in healthy competition between cities for environmental protection (Wang & Lei, 2021). The findings of existing studies are inconsistent regarding the interactive behavior of ER in different cities, which may be due to differences in indices and a transformation in government perceptions. Therefore, based on existing studies, this study examines whether there is competitive interaction behavior between cities in GETC behavior. The results show that local GETC can reduce local CEs, but induce bottom-up competitive behavior of neighboring governments, leading to the deterioration of CEs in neighboring cities. The findings also validate the traditional pollution refuge hypothesis.

Finally, China is a vast country, and the level of economic development varies greatly in different cities. Zhang *et al.* (2021) found that ER is less effective in reducing carbon in western China. Hu and Wang (2020) found that there is a threshold for ER on carbon productivity, with the level of ER closest to the threshold in eastern China, while it differs more in the central and western cities. Moreover, there are significant differences in the carbon reduction effects of GETC for different cities. Compared with the eastern and central cities, the effect of GETC on CEs reduction is poor in the western city. Additionally, Zhang *et al.* (2017) mentioned that personal traits such as tenure and education of officials have a significant impact on production decisions. Officials such as local environmental policy makers and GETC are also influenced by the personal characteristics of government officials. This study finds that local government officials with higher education levels and longer tenure will incorporate the concept of sustainable development when considering economic development issues, enhancing the local government's attention to environmental goal constraints. This finding also validates that the personal characteristics of government officials can affect the effectiveness of environmental policies.

Conclusions

The main purpose of this study is to investigate the carbon reduction effects brought about by the combination of government self-restraint and environmental policies. The study examines 241 prefecture-level cities from

2003 to 2019. The results show that GETC can effectively reduce local CEs. However, the inhibitory effect is mainly more effective in the first two years of setting environmental targets, but the effect starts to diminish in the third year. GETC can reduce local CEs through three pathways: reducing ECI, promoting ISO, and GTI. From the perspective of spatial spillover effects, GETC reduces local CEs while aggravating CEs in neighboring cities, indicating a beggar-thy-neighbor effect of GETC in conventional environmental regulation policies. The beggar-thy-neighbor effect mainly occurs in the geographic matrix and the economic-geographic matrix, but not in the economic matrix. From the heterogeneity analysis, local GETC in the eastern and central cities can significantly reduce CEs. The higher the tenure and education of local secretaries and mayors, the stronger the inhibitory effect of GETC on local CEs.

Based on the findings, the following policy implications are proposed:

Firstly, GETC can reduce CEs and promote local low-carbon development. The central government should coordinate with local governments to effectively utilize the advantages of China's administrative system. Local governments should publicly disclose their environmental governance goals to strengthen self-restraint in environmental protection. Moreover, local officials' awareness of environmental protection should be enhanced, long-term development goals should be set, and a sound environmental goal constraint mechanism should be established.

Secondly, effective control of energy consumption is an important way to reduce CEs through GETC, and local governments should clearly disclose energy consumption targets in government work reports according to the actual local development situation. The energy consumption target constraint helps to strengthen public monitoring of local energy consumption and pollution emissions. The social capital-inducing effect of GETC should be actively utilized to direct limited funds to high-tech industries and provide a favorable environment for the cultivation of new industries. This provides a good source of funds for GTI to reduce the high risks that GTI may face in the process.

Thirdly, although GETC can reduce local CEs, it can aggravate neighboring region CEs, indicating a "beggar-thy-neighbor" effect of conventional environmental regulation. The current Chinese environmental policy still has problems such as weak enforcement and lack of coordination. Therefore, it is important to establish a correct concept of sustainable development and guide local governments to set reasonable competition goals and adopt healthy competition to avoid "bottom-up competition" in environmental protection. Furthermore, promoting the target achievement experience and models of cities with better results in reducing emissions by GETC and sharing the experience of carbon reduction for neighboring cities with serious environmental problems should be vigorously promoted.

The conclusions have practical significance for improving the Chinese government assessment system. However, this paper still has some limitations. First, the sample size is not microscopic enough, and enterprises are important subjects of CEs and governance. However, this study only examines the effect of CEs at the region level and does not go into the level of the main subject of CEs. Investigating the CEs reduction of microenterprises in response to GETC can provide more beneficial theoretical support for China's CEs reduction. Therefore, in future studies, the author will focus on the effect of government environmental constraints on pollution control behavior between enterprises. Second, the energy consumption data used in this paper is calculated based on the whole society's electricity consumption, gas and natural gas supply, and liquefied petroleum gas (LPG) supply converted into tonnes of standard coal. Although this data is representative of the extent of energy consumption in China, it is not the official government-published city energy consumption in China. Therefore, in future research, we will look for other methods and data that can measure city energy consumption variables to reduce the error caused by a single research indicator. Finally, this study finds that there is a beggar-thy-neighbor phenomenon in the CEs reduction effect of GETC, which reveals that China's current environmental governance and CEs reduction efforts have achieved some effectiveness, but have not achieved synergistic interregional governance. In future studies, we will further combine the government's economic target constraints and GETC to explore what measures the government can take to avoid the beggar-thy-neighbor phenomenon of environmental governance and CEs reduction.

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Annex

Table 1. Descriptive statistics

Variables (units)	Number of samples	Mean	Standard deviation	Minimum	Maximum
Cities constrained by government environmental targets					
CO_2 (tons of carbon/CNY)	2320	0.785	0.705	0.061	7.606
Cities not constrained by government environmental targets					
CO_2 (tons of carbon/CNY)	1777	0.975	0.775	0.044	8.545
Full sample					
CO_2 (tons of carbon/CNY)	4097	0.867	0.743	0.044	8.55
GETC (-)	4097	0.566	0.496	0	1
ey (10^4 CNY)	4097	2.896	3.476	0	13.47
ey^2 (-)	4097	20.468	84.372	0	181.44
den (100 people/km2)	4097	4.933	35.691	0.047	2278.418
indus (-)	4097	47.131	10.9	1.93	85.92
fdi (-)	4097	0.021	0.028	0	0.78
ISO (-)	4097	0.927	0.599	0.03	19.21
GTI (-)	4097	4.185	1.947	0	10.153
ECI (-)	4097	3.971	1.319	-0.01	7.833

Table 2. Baseline results analysis of the impact of GETC on CEs

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Co_2	Co_2	Co_2	Co_2	Co_2	Co_2
GETC	-0.078***	-0.070**	-0.065**	-0.065**	-0.067**	-0.069***
	(0.029)	(0.027)	(0.027)	(0.027)	(0.027)	(0.026)
ey		-0.039***	-0.101***	-0.106***	-0.108***	-0.103***
		(0.010)	(0.025)	(0.026)	(0.027)	(0.028)
ey^2			0.002***	0.003***	0.003***	0.002***
			(0.0008)	(0.001)	(0.001)	(0.008)
den				-0.0003*	-0.0003*	-0.0003*
				(0.0017)	(0.0017)	(0.0017)
indus						-0.005***
						(0.002)
fdi						0.928
						(0.744)
Constant term	0.714***	0.876***	1.067***	1.081***	1.305***	1.284***
	(0.038)	(0.055)	(0.085)	(0.088)	(0.126)	(0.130)
Time fixed	YES	YES	YES	YES	YES	YES
City fixed	YES	YES	YES	YES	YES	YES
N	4097	4097	4097	4097	4097	4097
R^2	0.231	0.243	0.256	0.256	0.260	0.262

Note: The estimated coefficients in parentheses are robust standard errors of the regression coefficients, and ***, **, and * denote 1%, 5%, and 10% significance levels, respectively.

Table 3. PSM-DID applicability test (common support hypothesis)

Variables	Mean of treatment group	Mean of the control group	Difference	T value	P value
ey	3.639	3.468	0.171	1.6	0.11
ey^2	26.942	24.471	2.471	1.08	0.282
indus	1.050	1.062	-0.012	-0.83	0.409
gov	0.207	0.217	-0.01	-1.48	0.138
den	4.771	4.835	-0.064	-0.57	0.567

Table 4. Results Analysis of the Impact of GETC on CEs under the PSM-DID Method

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Co2	Co2	Co2	Co2	Co2	Co2
GETC	-0.078***	-0.069**	-0.065**	-0.066**	-0.067**	-0.070***
	(0.029)	(0.028)	(0.027)	(0.027)	(0.027)	(0.027)
ey		-0.045***	-0.112***	-0.111***	-0.113***	-0.108***
		(0.010)	(0.030)	(0.031)	(0.031)	(0.032)
ey^2			0.003***	0.003***	0.002**	0.003***
			(0.001)	(0.001)	(0.001)	(0.001)
den				0.004	0.004	0.006
				(0.029)	(0.029)	(0.029)
indus					-0.005***	-0.005***
					()0.002	(0.002)
fdi						0.928
						(0.754)
Constant term	0.714***	0.904***	1.096***	1.076***	1.302***	1.266***
	(0.038)	(0.053)	(0.094)	(0.175)	(0.208)	(0.216)
Time fixed	YES	YES	YES	YES	YES	YES
City fixed	YES	YES	YES	YES	YES	YES
N	4091	4091	4091	4091	4091	4091
R^2	0.231	0.246	0.257	0.257	0.261	0.263

Note: Columns (1)-(6) are progressively added to the control variables in the same order as in Table 2.

Table 5. Mechanisms testing the indirect effects of GETC on CEs

Variables	Energy consumption intensity	Industrial structure optimization	Green Technology Innovation
	ECI	ISO	GTI
GETC	-0.075**	0.070**	0.105*
	(0.038)	(0.032)	(0.062)
ECI			
ISO			
GTI			

Table 5. Continued

Variables	Energy consumption intensity	Industrial structure optimization	Green Technology Innovation
	ECI	ISO	GTI
Constant term	4.904***	2.966***	5.358***
	(0.152)	(0.321)	(0.161)
Control variables	YES	YES	YES
Time fixed	YES	YES	YES
City fixed	YES	YES	YES
N	4097	4097	4097
R^2	0.733	0.356	0.884

Table 6. Moran index results

Geographic matrix		Economic Matrix		Economic-geographic matrix	
Year	Moran index	Year	Moran index	Year	Moran index
2003	0.093***	2003	0.043*	2003	0.066***
2004	0.106***	2004	0.044*	2004	0.070***
2005	0.104***	2005	0.068**	2005	0.071***
2006	0.105***	2006	0.079***	2006	0.080***
2007	0.105***	2007	0.085***	2007	0.081***
2008	0.099***	2008	0.093***	2008	0.071***
2009	0.096***	2009	0.085***	2009	.0.073***
2010	0.108***	2010	0.112***	2010	0.079***
2011	0.099***	2011	0.092***	2011	0.073***
2012	0.107***	2012	0.113***	2012	0.078***
2013	0.105***	2013	0.119***	2013	0.074***
2014	0.109***	2014	0.120***	2014	0.082***
2015	0.108***	2015	0.111***	2015	0.077***
2016	0.116***	2016	0.109***	2016	0.073***
2017	0.071***	2017	0.066**	2017	0.075***
2018	0.119***	2018	0.002*	2018	0.073***
2019	0.075***	2019	0.003*	2019	0.055***

Table 7. Results of the spatial Durbin model applicability test

Inspection Type	Statistical values	P value
LR-spatial-lag	31.56	0.000
Wald-spatial-lag	31.96	0.000
LR-spatial-error	34.84	0.000
Wald-spatial-error	33.91	0.000
Hausman test	-22.43	-

Note: The Hausman test is negative, mainly because the basic assumption of the RE model, Corr(x_it, u_i) = 0, cannot be satisfied. Therefore, FE should be used in this case.

Table 8. Spatial effect of GETC on CEs

Variables	Economic weightmatrix	Geographic weight matrix	Mixed weight matrix
	Co_2	Co_2	Co_2
GETC	-0.077***	-0.084***	-0.079***
	(0.023)	(0.023)	(0.023)
WGETC	-0.011	2.148***	0.539***
	(0.014)	(0.472)	(0.232)
ey	-0.135***	-0.105***	-0.139***
	(0.010)	(0.010)	(0.011)
ey^2	0.003***	0.003***	0.003***
	(0.0003)	(0.001)	(0.0003)
den	-0.0004**	-0.00025	-0.0004**
	(0.0002)	(0.00017)	(0.0002)
indus	-0.004***	-0.006***	0.991***
	(0.001)	(0.001)	(0.283)
fdi	1.122***	1.503***	0.991***
	(0.278)	(0.292)	(0.283)
rho	0.135***	0.798***	0.405***
	(0.029)	(0.045)	(0.054)
Control variable spatial lag term	YES	YES	YES
N	4097	4097	4097
R^2	0.276	0.270	0.269

Table 9. Heterogeneity analysis of cities distribution

Variables	Eastern cities	Central cities	Western cities
	Co_2	Co_2	Co_2
GETC	-0.072**	-0.128**	0.002
	(0.036)	(0.049)	(0.046)
Constant term	0.784***	0.612	1.911***
	(0.124)	(0.736)	(0.567)
Control variables	YES	YES	YES
Time fixed	YES	YES	YES
City fixed	YES	YES	YES
N	1479	1411	1207
R^2	0.226	0.312	0.477

Table 10. Heterogeneity analysis of officer characteristics

Variables	secretary's term Co_2	Variables	secretary's Degree Co_2	Variables	Mayor's term Co_2	Variables	Mayor's Degree Co_2
sjrq×GETC	-0.016** (0.007)	*sjxl×GETC*	-0.075** (0.038)	*szrq×GETC*	-0.026** (0.013)	*szxl×GETC*	-0.130** (0.059)
sjrq	0.016 (0.011)	*sjxl*	0.006 (0.028)	*szrq*	0.016 (0.013)	*szxl*	0.101* (0.057)
GETC	-0.046 (0.040)	*GETC*	-0.026 (0.045)	*GETC*	-0.022 (0.044)	*GETC*	0.017 (0.052)
Constant term	1.337*** (0.177)	Constant term	1.370*** (0.183)	Constant term	1.343*** (0.173)	Constant term	1.297*** (0.193)
Control variables	YES	Control variables	YES	Control variables	YES	Control variables	YES
Time fixed	YES	Time fixed	YES	Time fixed	YES	Time fixed	YES
City fixed	YES	City fixed	YES	City fixed	YES	City fixed	YES
N	2002	N	2002	N	2002	N	2002
R^2	0.216	R^2	0.219	R^2	0.217	R^2	0.218

Figure 1. Parallel trend test chart

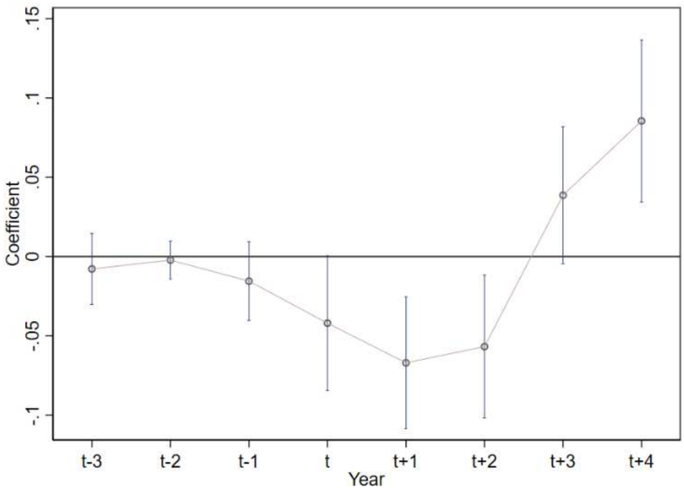

Figure 2. Placebo test