Can national environmental protection supervision and control have a lasting impact on corporate production efficiency? — an empirical study based on the multi-phase difference-in-difference model

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Abstract
National environmental protection supervision and control has become essential means to regulate the environmental behavior of enterprises. Furthermore, the optimization, promotion, and sustainability of relevant policies are key topics of inquiry. Taking the implementation of national environmental protection supervision policies as the time series, this paper studies the impact of national environmental protection supervision and control on corporate production efficiency. It uses the multi-phase difference-in-difference (DID) method and explores the sustainability of said policies. Results indicate that, first, national environmental protection supervision and control can considerably enhance corporate production efficiency, and green technology innovation plays a vital role as an intervening variable. Second, national environmental protection supervision and control can only boost the increase in corporate production efficiency in the short term, and the impact will no longer be noticeable in the third year. This paper provides a decision-making basis for constantly boosting and revising national environmental protection supervision and control policies and stimulating green technology innovation.

Keywords National environmental protection supervision and control · Green technology innovation · Corporate production efficiency · Multi-phase difference-in-difference method · Policy persistence · Lasting impact

Introduction
Since the twenty-first century, with the rapid development of the world economy, a large amount of energy has been consumed, resulting in the imbalance between economy and environment (Iram et al., 2019; Chen and Chen, 2021; Pirmana et al., 2021). As the largest developing country in the world today, China faces even more severe challenges. According to data published by the BP World Energy Statistical Yearbook 2020, China consumed 3.39 billion tons of energy in 2019, making it the largest energy consumer and carbon emitter in the world. Among its industries, heavy polluting and energy-consuming industries accounted for over 60% of China’s total energy consumption. Therefore, how to reduce energy consumption while enhancing corporate production efficiency is a problem that a number of scholars are concerned about (Guo et al., 2019; Wang et al., 2019a, 2021c). Confronted with the difficulties of economic development and energy conservation and emission reduction, many countries have proposed to carry out environmental protection supervision and control policies to regulate enterprises. Since 2013, China has become the...
main representative in such efforts, proposing to intensify the reform of civilized systems, gradually improve its eco-environmental protection policies, and encourage enterprises to achieve environmental governance and green development through green technology innovations. Among them, green technology innovation plays an important role as the country’s main regulatory means. Therefore, an important way to achieve high-quality economic development is by exploring whether environmental protection supervision and control can induce enterprises to conduct green innovation and achieve green technology progress, thereby increasing China’s corporate production efficiency and reducing pollutant emissions.

Environmental protection supervision and control inevitably affect the behavior and decision-making processes of enterprises (Peng et al., 2019; Du and Li, 2020; Nikolaos et al., 2021). A variety of actors implement environmental protection supervision and control. This paper takes national environmental protection supervision and control policies as its main research object and governments as their implementers. Because these policies are the main means for governments to implement supervision, they are of symbolic significance. Therefore, this paper takes the implementation of national environmental protection supervision and control policies as the time series.

Traditional environmental protection supervision and control policies are affected by a series of phenomena, such as “government-enterprise cooperation,” “formalism,” and the “one-size-fits-all” approach (Huang et al., 2019; Yang et al., 2020), resulting in policy outcomes that are not as good as expected. Enterprises do not fundamentally enhance production efficiency and achieve energy conservation and emission reduction through the path of improving their own green technology levels; thus, the environmental situation has not been fundamentally improved. To solve the “failure” of local governments in environmental governance and facilitate the sustainable development of enterprises, national environmental protection supervision and control policies that conform to the characteristics of China’s environmental governance have been officially introduced (Xiang and Gevelt, 2020; Li et al., 2020). The specific national environmental protection supervision and control policy discussed in this paper is the first round of five batches of environmental protection supervision and control actions implemented in 31 provinces under the supervision of the Ministry of Environmental Protection of the PRC between January 1, 2016 and September 15, 2017.

In the previous studies, the study on national environmental protection supervision and control policies focuses more on the exploration of macro-level influence and the study of effectiveness. Jia and Chen (2019) found that environmental protection supervision and control policies can enhance urban air quality, while Zeng et al. (2021) reported that these policies have a negative impact on China’s capital market. However, few studies have been conducted on whether such a policy can improve corporate production efficiency, whether it can realize this path by forcing enterprises to achieve green technology innovations, and the duration of the time effect produced by the policy.

Therefore, the sustainable effect of national environmental protection supervision and control policies on enterprises has become the focus of current research. Taking green technology innovation as the intervening variable, this paper constructs an action mechanism model via the multi-phase difference-in-difference (DID) method to sort out the path of the national environmental supervision protection and control policy’s influence on corporate production efficiency, and then uses this as the basis for examining the persistence of the policy. At the same time, this work not only provides theoretical guidance and suggestions for the next round of national environmental protection supervision and control but also serves as a reference for measures that can be taken to ensure the economic development and environmental protection of other developing countries.

Compared to the existing literature, the main theoretical contributions of this paper are as follows: (1) Using a multi-phase DID model, this paper explores the effectiveness and temporal effect of national environmental protection supervision and control policies on corporate production efficiency. It clarifies the internal relationship between national environmental protection supervision and control policies and production efficiency and supplements the study of the temporal aspect of the policies’ effects on enterprises. Furthermore, it studies the differentiated presentation of green technology innovation as an intervening variable in the model, which enriches the study of the heterogeneity of green technology innovation in the relationship between the policies in question and production efficiency. (2) By testing the temporal effect of national environmental protection policies, this paper finds that the environmental governance represented by national environmental protection supervision and control can quickly achieve short-term goals. This effect can be maintained for 2 years. Therefore, China needs to carry out regular actions and constantly strengthen environmental protection supervision. Moreover, regarding the intermediary effect of green technology innovation, this paper finds that national environmental protection supervision and control policies will cause some distortion to green technology innovation. China thus needs to proactively guide enterprises to choose green invention innovation with a high technical level.

The rest of the paper is structured as follows: Part two reviews the existing literature on national environmental supervision and control, green technology innovation, and corporate production efficiency; summarizes the time effect of action mechanism and policies; and proposes the
corresponding research hypotheses. Part three introduces the method model and data source, while part four presents the empirical results. Finally, part five presents the research conclusions, policy recommendations, and future prospects.

**Literature review and theoretical hypotheses**

The problem of environmental pollution is of utmost importance. As the main driving force behind economic development, enterprises are not only the main sources of pollution but also important participants in environmental governance. Enterprises mainly seek to maximize profits and, as a result, often overlook environmental problems. Because of this, governments usually interfere with their production decisions. At present, most countries have formulated environmental protection policies to curb pollution and achieve sustainable development. As shown in Table 1, the study of the impact of governmental behavior on corporate environmental governance has received extensive attention from scholars worldwide. However, different countries have different environmental governance systems. Regarding the impact of environmental regulation on production efficiency, there is still no consensus in the literature. According to neoclassical economics, strict regulation can alleviate the adverse impact of economic activities on the environment. However, the internalization of environmental externalities will force enterprises to change optimal production decisions, thus increasing their costs. This is not conducive to the enhancement of productivity and competitiveness (Ambec et al. 2013). Porter and Linde (1995) disagreed with the neoclassical view and proposed Porter's hypothesis. An example of this hypothesis is found in Alessandro (2017) who studied German and Italian chemical enterprises and concluded that environmental regulations can improve enterprise productivity. We believe that the possible reason for these contrasting results is that in a specific institutional environment, regulation is affected by factors such as the mode of economic development and the consumption structure of different countries and regions, which creates a deviation in the regulatory effect. Moreover, different policy tools also have different impacts. The characteristics of environmental policies will affect corporate behavior and thus have different impacts on productivity.

China’s national environmental protection supervision and control policies came into being in this context. Faced with higher administrative oversight, enterprises may incur higher costs; however, this forces them to carry out green technology innovation and obtain compensation for environmental costs (Saunila et al., 2018). Truly achieving the win–win result of economic value and environmental benefit by helping local governments complete environmental assessments is a vital way of overcoming the fierce conflict between China’s rapid economic growth and environmental pollution (Tang et al., 2020). Therefore, green technology innovation makes the government and enterprises encourage each other. Local governments are also motivated to mobilize enterprises toward green innovation through this system (Kemp, 2011). When studying the implementation of national environmental protection supervision and control policies, scholars mainly focus on its institutional characteristics, operating mechanism, and implementation impact. In other words, they focus on the impact of the policies from a macro point of view. Not enough attention is paid to the interaction between government and enterprises, while the businesses most closely affected by the policies are overlooked. Existing research found that national environmental protection supervision and control policies have a positive effect on air quality (Lin et al., 2021) and can significantly reduce the concentration of PM2.5 and PM10 (Wang et al., 2021b; Tan and Mao, 2021). Chong and Sun (2020) used game theory to systematically analyze the strategic changes and emission reduction effects caused by these policies. From a macroeconomic perspective, Zeng et al. (2021) found that the policies would create a negative reaction in China’s capital market; however, according to Nie et al. (2020), they would enhance the overall energy and environmental efficiency of its cities. Little research has been done on the temporal effect of the policies, that is, whether they are effective for a long time and whether they can bring economic benefits to micro-enterprises by improving their efficiency. The study of green technology innovation as an intervening variable is particularly rare (Zhang and Li, 2020). Therefore, taking listed industrial enterprises as a sample, this paper deeply studies the economic benefits of national environmental protection supervision and control from the

**Table 1** Environmental protection behaviors of governments in some countries/organization

| Country/organization | Measures                            | Documents                                      |
|----------------------|-------------------------------------|------------------------------------------------|
| European Union       | Emissions trading system            | Calel and Dechezleprêtre (2016)               |
| America              | Implicit pollution tax              | Shapiro and Walker (2015)                     |
| Pakistan             | Integrated energy plan              | Hu et al. (2020); Imran et al. (2019)         |
| India                | Supreme court action plan           | Greenstone and Hanna (2014)                   |
| Canada               | Environmental bill of rights        | Victorial (2021)                              |
perspective of enterprises at the micro level, explores the impact mechanism of this policy on corporate production efficiency and the time effect it produces, and studies its intermediary role in the above relationship from the perspective of green technology innovation. The main objectives of this study are as follows: (1) to enrich the relevant literature on the relationships among national environmental protection supervision and control, green technology innovation, and corporate production efficiency, and (2) to provide a reference value for improving environmental protection policies and energy conservation and emission reduction, thus providing maximum guarantee for the realization of environmental and economic benefits after the second round of national environmental protection supervision and control.

Based on the goals stated above, the content of this paper is divided into two main parts. Part one discusses the process of constructing the mechanism model of the effect of national environmental protection supervision and control on corporate production efficiency. Part two presents research on the persistence of national environmental protection supervision and control.

**Construction of the mechanism model based on national environmental protection supervision and control on corporate production efficiency**

**National environmental protection supervision and control policy and corporate production efficiency**

Economists represented by Porter believe that environmental policies can improve the productivity of enterprises. Porter and Van (1995) put forward the influential Porter hypothesis through case study that appropriate environmental regulation can produce higher productivity through innovation incentives, efficiency improvement, and internal redistribution. The implementation of national environmental protection supervision and control policies has strengthened local governments’ ability to enforce environmental control (Wang et al., 2021a), prompting enterprises to adjust the input ratio of production factors (He and Geng, 2020). Under the supervision of the environmental protection supervision and control group, enterprises usually need to pay large fines for their pollutant discharge behaviors and bear higher production costs. At this time, some heavy-polluting enterprises could not bear the increasing cost of regulations. Based on the “compliance cost effect,” non-compliant companies are thus driven out of the market (Zhou et al., 2021). According to the potter hypothesis of product compensation theory, due to reasons such as the replacement of raw materials, packaging to reduce makes the product cost is reduced, or because the product is easy to recycle or split and higher resale or scrap value, thus make the compliance enterprises through the sale of environmentally friendly products enjoy the more market share and revenue. To maintain long-term development and to maintain market presence while also reducing pollutant emissions at the source, enterprises must increase their resource utilization efficiency and enhance clean production capacity, thus enhancing their corporate production efficiency. In addition, enterprises are also affected by the barrier effect produced by environmental regulations, that is, the government sets barriers to the enterprises trying to enter the market through environmental regulations, thus ensuring that only the most capable ones survive in the market (Zhou et al., 2021). According to the process compensation theory of Porter hypothesis, enterprises usually take the initiative to install more advanced energy-using pollution control equipment to optimize their production processes. Prudent production management leads to reduced downtime, reduced consumption through recycling of inputs, full utilization of by-products, lower energy consumption, and lower waste disposal costs, thus increasing resource productivity and improving enterprise productivity. Although the cost of pollution control has increased, the high entry threshold will reduce the intensity of competition in the industry. After the elimination of backward enterprises with high pollution and high energy consumption, the remaining enterprises can obtain long-term monopoly profits (Hussain et al., 2020), thus forming a virtuous cycle. Therefore, the barrier effect of environmental regulations optimizes the main structure of the remaining enterprises, which not only reduces environmental damage but also helps enhance the overall production efficiency of the enterprises. Related to this, the following hypothesis is proposed:

**Hypothesis 1**: With other conditions remaining constant, national environmental protection supervision and control policies will increase corporate production efficiency.

**The mediating effect of green technology innovation**

To study the implementation effect of national environmental protection supervision and control policies in China, this paper selects the conventional green technology innovation of intervening variables (Yousaf, 2021; Sun et al., 2021b). Green technology innovation refers to the activities through which enterprises can achieve win–win economic and environmental benefits through innovations in production and organizational structure, guided by the aim of increasing resource utilization rate and reducing energy consumption, which is the bridge connecting the environment and the economy (Huang and Li, 2018; Wang et al., 2020; Jirakraisiri et al., 2021). National environmental protection supervision and control policies put pressure on enterprises to protect the environment through the action of local governments. Aiming at value creation, enterprises usually choose to implement environmental strategies to obtain the
compensation of environmental costs (Oliver, 1991). This is an active environmental tactic with green technology innovation as its main approach. The dual value contribution distinguishes green innovation from other forms of innovation (Saunila et al., 2018). This innovation not only enables enterprises to obtain cost compensation but also helps the government to complete the assessment of local regions. According to the product compensation theory and process compensation theory of Porter hypothesis, reasonable environmental regulation can promote the technological innovation of enterprises’ products and production management, offset the pollution control cost, and produce “innovation compensation effect,” so as to improve the productivity and competitiveness of enterprises. Through active research and development of environmental friendly products and advanced energy-using pollution-control equipment, optimizing the production process, from the source to reduce pollutant emissions, waste disposal costs down, so that enterprises enjoy the more market share and profit, improve the efficiency of resource utilization, promote clean production ability, so as to enhance the enterprise of the production efficiency. Therefore, when national environmental protection supervision and control increases the cost of corporate environmental governance, it also stimulates green innovation based on the compensation of environmental costs (Hart, 1995), thus promoting the improvement of enterprise productivity. The compensation effect of this form of green technology innovation will be more obvious because its dual externalities determine the characteristics of the internalization of environmental costs (Saunila et al., 2018). Therefore, management usually changes its competitive strategy in the face of the constraints of national environmental regulation to internalize costs and meet standards. Compared to a terminal governance strategy, which is a passive response to environmental regulation, a green innovation strategy can proactively respond to governmental requirements without causing additional costs and bring enterprises higher returns on investment (Pan et al., 2021). Jiao et al. (2020) believe that green technology is the core factor in increasing corporate production efficiency. Through green technology innovation, the entire production process—including traditional production processes and pollution-control technologies can be innovatively improved (Pan et al., 2021). Doing so reduces the pollution control cost and confiscation cost, which in turn, is conducive to the formation of scale effect and enhancement of corporate productivity.

Green technology innovation can be divided into green utility patents and green invention patents. According to the provisions of China’s Patent Law, a green invention patent refers to an innovative design with outstanding substantive characteristics and significant progress, while a utility patent is limited to the innovative design of the shape, construction, or combination of a product. Thus, the degree of creativity of invention patents is significantly higher than that of utility patents. In the face of sudden environmental protection supervision and control, the compensation for green innovation usually ends at the upper limit of the administrative penalty when the local government’s environmental protection incentive system is not perfect and is not classified based on the quality of corporate green patents. This can easily lead to enterprises finding ways to meet green technology innovation standards only to cope with environmental supervision. Therefore, to verify whether national environmental protection supervision and control policies will distort corporate green technology innovation, we take green utility patents, which represent a lower level of green technology and a higher level of green invention patents, as an intervening variable to study whether enterprises will choose strategic or substantive innovation to improve corporate productivity under the pressure of environmental protection inspectors. Therefore, the following hypotheses are proposed:

**Hypothesis 2:** With other conditions remaining constant, national environmental protection supervision and control policies increase corporate production efficiency by facilitating corporate green technology innovation.

**Hypothesis 3:** With other conditions remaining constant, national environmental protection supervision and control policies increase corporate production efficiency by facilitating corporate green utility patents.

**Hypothesis 4:** With other conditions remaining constant, national environmental protection supervision and control policies cannot increase corporate production efficiency by facilitating corporate green invention patents.

**Persistence test of national environmental protection supervision and control policy**

As a kind of movement-type governance, national environmental supervision and control policies break the conventional hierarchical management process, and the key element lies in whether it can maintain long-term effectiveness and persistence. Zhao (2017) holds that the advantage of movement-type governance lies in its efficiency, strength, quick results, and ability to mobilize all resources in a certain area to achieve a goal in a short time. In the face of the environmental pollution behavior of enterprises, national environmental supervision and control group will maximize the allocation of resources to promote enterprises, thus solving the problem in a short time (Wang, 2016). However, emergency environmental governance also ends with the departure of the national environmental supervision and control group, and the typical characteristic of “expedience” gradually appears. This kind of movement-type policy may not be able to
build a long-term mechanism for environmental governance, as it prefers a short-term emergency response. In other words, the inevitable departure of the supervision team means that environmental protection measures are only temporary.

Based on the existing literature, the effects of national environmental protection supervision and control on corporate production efficiency can be divided into short- and long-term effects. It is generally believed that the short-term effect lasts for 2 to 3 years, while the long-term effect lasts for more than 5 years (Wang et al., 2019b; Hu and Zhou, 2021). With the continuous development of the second and third rounds of national environmental supervision and control actions in the future, the short-term impact on enterprises will become a normal constraint. Thus, the economic benefits brought to enterprises may show repeated governance and rebound with environmental governance, thereby indicating a cyclical upward trend as a whole. As a proven policy effect evaluation method, the multi-phase DID method can obtain the net benefit of policy implementation by eliminating individual and time differences as well as exploring the lasting time effect of the policy through the dynamic trend test. Therefore, the following hypothesis is proposed:

**Hypothesis 5**: With other conditions remaining constant, national environmental protection supervision and control policies have a short-term effect on the increase in corporate production efficiency.

### Research design

#### Data sources

In this paper, the listed industrial enterprises of Shanghai and Shenzhen A-shares in the first round of the national environmental protection supervision and control between 2013 and 2019 were selected as the research objects to identify the effects before and after the policy. Sample screening was processed as follows by drawing on the practice of Feenstra (2014): (1) only the observed values of all listed industrial enterprises between 2013 and 2019 were retained, (2) samples with abnormal financial conditions (also known as ST and *ST enterprises) were eliminated, and (3) samples with missing values of key variables were omitted. After a series of screening and data processing, we finally obtained unbalanced panel data of 12,745 observed values. Data on green technology innovations came from the Incopat patent database, the marketization index data came from the China Provincial Marketization Index Report (2018), and the rest of the enterprise-level data came from CSMAR. The descriptive statistics of all the specific variables used in this paper are shown in Table 2.

| Variable | Obs  | Mean | Std. Dev | Min  | Max  |
|----------|------|------|----------|------|------|
| Tfp_lp   | 12,745 | 15.584 | 0.990 | 12.517 | 19.058 |
| Tfp_op   | 12,745 | 14.399 | 0.772 | 10.424 | 17.945 |
| Gpatent  | 12,745 | 0.352 | 0.809 | 0 | 6.874 |
| IGpatent | 12,745 | 0.249 | 0.666 | 0 | 6.719 |
| UGpatent | 12,745 | 0.206 | 0.585 | 0 | 5.347 |
| Debt     | 12,745 | 0.400 | 0.342 | -0.195 | 31.466 |
| Size     | 12,745 | 22.068 | 1.256 | 16.161 | 28.636 |
| ROA      | 12,745 | 0.045 | 1.003 | -30.959 | 108.365 |
| TobinQ   | 12,745 | 2.178 | 2.948 | 0.153 | 192.705 |
| Capital  | 12,745 | 2.332 | 4.584 | 0.114 | 289.885 |
| Market   | 12,745 | 8.222 | 1.730 | -0.23 | 1 |

#### Time series of China’s environmental protection supervision and control

China’s national environmental management system is mainly derived from the establishment of its environmental protection supervision and control mechanism. This system uses the selected environmental protection supervision and control group as the representatives to conduct environmental supervision in various provinces and cities on behalf of the government, thereby facilitating the implementation of environmental protection supervision and control with the help of national authority. The Ministry of Environmental Protection of China launched the implementation of the first round of five batches of environmental protection supervision and control actions in 31 provinces between January 1, 2016 and September 15, 2017. Figure 1 shows the timeline of environmental regulatory actions, while the specific implementation situation is shown in Table 3.

#### Variable selection

**Explained variable: corporate production efficiency**

Referring to the research by Levinsohn and Petrin (2003), this paper used total factor productivity (TFP) to measure corporate production efficiency and the LP method and Cobb–Douglas production function to estimate corporate TFP. The specific calculation model is shown below:

\[
\ln Y_{it} = \delta_0 + \delta_1 \ln K_{it} + \delta_2 \ln L_{it} + \delta_3 \ln M_{it} + \mu_i + \nu_t + \epsilon_{it} \tag{1}
\]

In the equation, yield (Y) is measured by the natural logarithm of annual operating income, capital (K) is measured by the natural logarithm of net fixed assets, and labor (L) is measured by the natural logarithm of the number of employees. In addition, intermediate input
**Table 3** Specific implementation of the first round of national environmental protection supervision and control policy

| Batch of inspectors | Time                  | Number of inspectors | Inspected areas                                      |
|---------------------|-----------------------|----------------------|------------------------------------------------------|
| Pilot               | 2016.1.1—2016.1.31   | 1                    | Hebei                                                |
| First batch         | 2016.7.12—2016.8.19  | 8                    | Inner Mongolia, Heilongjiang, Jiangsu, Jiangxi, Henan, Guangxi, Yunnan, Ningxia |
| Second batch        | 2016.11.24—2016.12.30| 7                    | Beijing, Shanghai, Hubei, Guangdong, Chongqing, Shaanxi, Gansu |
| Third batch         | 2017.4.24—2017.5.28  | 7                    | Shanxi, Anhui, Tianjin, Hunan, Fujian, Liaoning, Guizhou |
| Fourth batch        | 2017.8.7—2017.9.15   | 8                    | Jilin, Zhejiang, Shandong, Hainan, Sichuan, Tibet, Qinghai, Xinjiang |

Data source: Xinhua news, [http://www.xinhuanet.com/politics/2017-11/07/c_1121916536.htm](http://www.xinhuanet.com/politics/2017-11/07/c_1121916536.htm)
(M) is measured by the natural logarithm of the operating cost of the enterprise plus the sales, management, and financial expenses of the enterprise minus the depreciation and amortization of the enterprise in the current period, as well as the cash paid to and for the employees. To ensure that the empirical conclusion of this paper was not affected by variable measurement, the enterprise TFP measured using the OP method was selected as an explained variable for empirical research.

**Explanatory variable: national environmental protection supervision and control policies**

Referring to the study of Wang et al. (2021b), the virtual variable was used to indicate whether or not the listed industrial enterprises accepted national environmental protection supervision and control. When and only when the international environmental protection supervision and control group begins to supervise a province, the value of listed industrial enterprises of the heavily polluting industry in the province is 1, and the other value is 0.

**Intervening variable: green technology innovation**

Referring to the study of Liu et al. (2020), the number of green patent applications made by an enterprise was selected to measure the level of its green innovation. The classification list of green patents was determined based on the list of green patents released by the World Intellectual Property Organization (WIPO). In this paper, the numbers of applications of green invention patents and green utility patents were obtained from the Incopat patent database. The total number of an enterprise’s green patent applications was obtained by adding the numbers of the two types of patents. To eliminate the right-biased distribution of application data for green patents, this paper took the natural logarithm as the intervening variable by adding 1 to the total number of applications of green patents, the number of applications of green invention patents, and the number of applications of utility patents.

**Control variables**

Referring to the study of Wang et al. (2021b), the following control variables were selected: firm size (size), that is, the natural logarithm of total assets, financing capacity (debt), that is, the asset–liability ratio of an enterprise, profitability (Roa), that is, the net interest rate of the total assets of an enterprise, investment opportunity (TobinQ), that is, the Tobin’s Q value of an enterprise, operating capacity (capital), that is, the capital intensity of an enterprise, the ratio of total assets to operating income, and marketization index (market).

**Model building**

National environmental protection supervision and control can be regarded as an emergency, and a good quasi-natural experiment due to the strong randomness of whether industrial enterprises in different regions will be affected by environmental protection inspectors. The national environmental protection supervision and control group gradually conducted comprehensive inspections in 31 provinces in China between 2016 and 2017. The traditional DID method does not meet the requirements of the same time for policy implementation due to the different times for listed industrial enterprises in various provinces to accept an inspection. Thus, to study the impact of corporate production efficiency under national environmental protection supervision and control policies, this paper constructs a benchmark regression model. The multi-stage DID method is used to deal with the difference of policy implementation time of the treatment group (Jia and Chen, 2019; Nie et al., 2020; Lin et al., 2021).

\[ Y_{it} = \beta_0 + \beta_1 CEPI_{it} + \lambda X_{it} + \delta_i + \eta_t + \mu_{it} \]  

(2)

In the model, i in the subscript represents the listed industrial enterprises, t represents the year, Y_{it} represents the corporate production efficiency of enterprise i in year t, CEPI_{it} is the DID item, and X_{it} is the control variable, including firm size, debt-to-asset ratio, net interest rate of total assets, Tobin’s Q value, capital intensity, and marketization index. In addition, it also controls for firm fixed effects (\delta_i) and time fixed effects (\eta_t), where \mu_{it} is a random disturbance term. This paper constructs two dummy variables: the dummy variables for the experimental and control groups and the policy time dummy variables. For the dummy variables for the experimental and control groups, according to the “Environmental Protection Inspectors Program (Trial),” the processing group includes industrial enterprises in the pollution industry, such as mining, thermal power, chemical engineering, metallurgy, petrifaction, textile, coal, and pharmaceuticals. The control group consists of the other industrial enterprises. For the policy time dummy variables, when the central environmental protection group inspects a province, the value of the year is 1; otherwise, it is 0.
Empirical test and analysis of results

Action mechanism model test

Benchmark regression analysis

According to model (2), this paper uses the multi-phase DID model to test the impact of national environmental protection supervision and control on corporate production efficiency. It also controls for corporate fixed effects and time fixed effects. The benchmark regression results are shown in Table 4. As can be seen, the explained variables are corporate production efficiency measured by the LP method and corporate production efficiency measured by OP method. Columns (1) and (2) reveal that the coefficients of national environmental protection supervision and control are both significantly positive at 5%, indicating that national environmental protection supervision and control can boost the improvement of corporate production efficiency. Compared to traditional environmental regulations, movement-type national environmental protection supervision and control increases the supervision of local governments over enterprises and urges the latter to make up for the cost of pollution control by increasing their production efficiency. This finding shows that the national environmental protection supervision and control system gives full play to the role of government guidance and provides an important direction for exploring and achieving economic and environmental benefits. Therefore, Hypothesis 1 was verified.

Mediating effect test of green technology innovation

To test the intermediary mechanism of national environmental protection supervision and control affecting corporate production efficiency, the mediating effect model was constructed as follows:

\[
Y_{it} = \beta_0 + \beta_1 CEPI_{it} + \lambda X_{it} + \delta_i + \eta_t + \mu_{it} \tag{3}
\]

\[
Patent_{it} = \beta_0 + \beta_2 CEPI_{it} + \lambda X_{it} + \delta_i + \eta_t + \mu_{it} \tag{4}
\]

\[
Y_{it} = \beta_0 + \beta_3 CEPI_{it} + \theta Patent_{it} + \lambda X_{it} + \delta_i + \eta_t + \mu_{it} \tag{5}
\]

In the model, Patent_{it} represents the green technology innovation of an enterprise. Referring to the study of Dong and Wang (2019), the total number of applications of green patents (Gpatent), the total number of applications of green utility patents (UGpatent), and the total number of applications of green invention patents (IGpatent) were used in the current study to measure the level of green technology progress. The specific test procedure is as follows: First, in the main model of national environmental protection supervision and control and corporate production efficiency, we ensured that the results were statistically significant and met the prerequisite for the existence of mediating effect. Then, we added green technology innovation to the benchmark model, after which model (4) was built, paying attention to whether \( \beta_2 \) was significant. Finally, national environmental protection supervision and control and green technology innovation were used as explanatory variables to construct model (5), after which regression was carried out with corporate production efficiency to observe the significance of \( \beta_3 \) and \( \theta \). If the effect of explanatory variables on explained variables is still significant after the addition of intervening variables, it means that there is a partial mediating effect; if the effect of explanatory variables becomes non-significant, it means that there is a complete mediating effect; if the intervening variables are non-significant, it means that there is no obvious mediating effect.

In Table 5, column (1) presents the benchmark regression results, while column (2) indicates the regression results of model (4) when using the total number of applications of green patents to measure the green technology innovation level. Here, the coefficient of CEPI is significantly positive, indicating that national environmental protection supervision and control can significantly drive industrial enterprises in heavy pollution industries to carry out green innovation activities, thus improving the level of green technology. Column (4) presents the regression results when using green

| Table 4 Benchmark regression results |
|------------------------------------|
|                                    |
| (1) Tfp_{lp}                       |
|                             |
| CEPI 0.034**                    |
| (2.33)                          |
| Size 0.534***                   |
| (23.96)                         |
| Debt 0.209***                   |
| (3.19)                          |
| Roa 0.205***                    |
| (3.00)                          |
| TobinQ 0.015***                 |
| (3.57)                          |
| Capital −0.016***               |
| (−2.59)                         |
| Market 0.015                     |
| (0.94)                          |
| Firm fixed effect Yes            |
| Year fixed effect Yes            |
| _cons 3.581***                  |
| (7.23)                          |
| N 12,745                        |
| \(R^2\) 0.534                   |
| ![t statistics in parentheses, *^p<0.1, **^p<0.05, ***^p<0.01](t statistics in parentheses, *^p<0.1, **^p<0.05, ***^p<0.01) |

\(t\) statistics in parentheses, \(^*^ p<0.1, ^{**} p<0.05, ^{***} p<0.01\)
utility patents to measure the level of green technology progress. As can be seen, the coefficient of CEPI is significantly positive at 1%. In comparison, that of CEPI is insignificant when column (5) measures the level of corporate green technology innovation with green invention patents as the index. This indicates that national environmental protection supervision and control forces enterprises to implement green innovation to a certain extent. However, when there are no supporting incentive measures and no green patent quality evaluation system is established, enterprises often carry out low-level utility green innovation activities to put environmental protection inspectors off, while green invention patents, which are highly technical, remain insignificantly promoted.

Columns (3), (5), and (7) represent the results of model (5) regression, using national environmental protection supervision and control and green technology innovation as the explanatory variables. The coefficients of national environmental protection supervision and control and green technology innovation in columns (3) and (5), respectively, are significantly positive, but the green technology innovation coefficient of column (7) is insignificant. It should be noted that if $\beta_2$ or $\theta$ has a non-significant coefficient, the bootstrap method should be further used to test whether the indirect

### Table 5 Mediating effect test of green technology innovation

| Variable | Tfp_{lp} (1) | Gpatent (2) | Tfp_{lp} (3) | UGpatent (4) | Tfp_{lp} (5) | IGpatent (6) | Tfp_{lp} (7) |
|----------|--------------|-------------|--------------|--------------|--------------|--------------|--------------|
| CEPI     | 0.034**      | 0.032*      | 0.034**      | 0.041***     | 0.034**      | 0.004        | 0.034**      |
|          | (2.33)       | (1.76)      | (2.30)       | (2.85)       | (2.30)       | (0.23)       | (2.33)       |
| Gpatent  |              |             |              | 0.011**      |              |              |              |
|          |              |             |              | (2.07)       |              |              |              |
| UGpatent |              |             |              |              | 0.011*       |              |              |
|          |              |             |              |              | (1.81)       |              |              |
| IGpatent |              |             |              |              |              | 0.009        |              |
|          |              |             |              |              |              | (1.42)       |              |
| Size     | 0.534***     | 0.056***    | 0.533***     | 0.0251**     | 0.534***     | 0.049***     | 0.534***     |
|          | (23.96)      | (3.46)      | (23.90)      | (2.05)       | (23.94)      | (3.83)       | (23.91)      |
| Debt     | 0.209***     | 0.019       | 0.209***     | 0.022        | 0.209***     | 0.010        | 0.209***     |
|          | (3.19)       | (0.60)      | (3.19)       | (0.82)       | (3.19)       | (0.42)       | (3.19)       |
| Roa      | 0.205***     | 0.009       | 0.205***     | 0.013        | 0.205***     | 0.005        | 0.205***     |
|          | (3.00)       | (0.30)      | (3.00)       | (0.51)       | (3.00)       | (0.22)       | (3.00)       |
| TobinQ   | 0.015***     | −0.002      | 0.015***     | −0.002       | 0.015***     | −0.001       | 0.015***     |
|          | (3.57)       | (−1.06)     | (3.56)       | (−1.34)      | (3.57)       | (−0.64)      | (3.57)       |
| Capital  | −0.016***    | −0.001***   | −0.016***    | −0.001***    | −0.016***    | −0.016***    | −0.016***    |
|          | (−2.59)      | (−3.16)     | (−2.59)      | (−2.56)      | (−2.59)      | (−2.99)      | (−2.59)      |
| Market   | 0.015        | 0.021       | 0.015        | 0.008        | 0.015        | 0.020        | 0.015        |
|          | (0.94)       | (0.88)      | (0.92)       | (0.43)       | (0.93)       | (1.02)       | (0.93)       |
| Firm fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Year fixed effect | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $N$      | 12,745       | 12,745      | 12,745       | 12,745       | 12,745       | 12,745       | 12,745       |
| $R^2$    | 0.534        | 0.074       | 0.534        | 0.068        | 0.534        | 0.043        | 0.534        |

$t$ statistics in parentheses, * $p<0.1$, ** $p<0.05$, *** $p<0.01$}

### Table 6 Parallel trend test

| Variable | TFP_{lp} |
|----------|----------|
| Pre_4t   | 0.009 (0.35) |
| Pre_3t   | 0.010 (0.49) |
| Pre_2t   | −0.016 (−0.95) |
| Current_4t | 0.004 (0.28) |
| After_{14}t | 0.040** (2.31) |
| After_{24}t | 0.062*** (3.09) |
| After_{34}t | 0.040 (1.62) |
| Size     | 0.534*** (23.99) |
| Debt     | 0.210*** (3.19) |
| Roa      | 0.206*** (3.00) |
| TobinQ   | 0.015*** (3.56) |
| Capital  | −0.016*** (−2.59) |
| Market   | 0.016 (0.98) |
| Firm fixed effect | Yes |
| Year fixed effect | Yes |
| $N$      | 12,745 |
| $R^2$    | 0.535 |

$t$ statistics in parentheses, * $p<0.1$, ** $p<0.05$, *** $p<0.01$
effect is significant (Wen and Ye, 2014). The times of bootstrap sampling are 500, 1000, and 2000, and 95% confidence intervals contain 0. The conclusion drawn is the same as the conclusion of the step method regression, that is, when the invention green patent is used as an intervening variable, the result is non-significant, and the conclusion is robust. This indicates that national environmental protection supervision and control helps enhance corporate production efficiency by promoting the level of green technology in enterprises in which green technology mainly depends on green utility patents. Given that the creation of green utility patents is easier than that of invention patents, enterprises generally carry out less difficult innovation activities to maximize profits. Although green invention patents must invest a great deal of manpower and material resources, their economic benefits are long term and huge. Thus, finding ways to guide enterprises to conduct substantive innovation in the future is key to high-quality development. In summary, Hypotheses 2, 3, and 4 are tenable.

**Policy persistence test**

The use of the multi-phase DID model needs to meet the parallel trend hypothesis, that is, the gap trend between the explained variables of the experimental and control groups before being affected by the policy should be stable. Referring to Beck et al. (2010), we took the year before the implementation of national environmental protection supervision and control policies as the benchmark. Then, we added dummy variables with that year as the limit and replaced them in model (2) to test the effect of national environmental protection supervision in different periods and control
policies on corporate production efficiency. The following regression equation was constructed:

\[ Y_t = \beta_0 + \beta_1 \text{Pre}_{t-1} + \beta_2 \text{Pre}_{t-2} + \beta_3 \text{Current}_{t-1} + \beta_4 \text{After}_{t-1} + \beta_5 \text{After}_{t-2} + \beta_6 \text{After}_{t-3} + \text{X}_{t} + \delta_t + \eta_t + \mu_t \]  

(6)

In the equation, \( \beta_1 \) represents the effect of the \( \tau \) period before treatment, and \( \beta_2 \) represents the effect of the \( \tau \) period after treatment. The definitions of the other variables are the same as above. The regression results are shown in Table 6.

The parallel trend test results in Table 6 are dynamically reflected in Fig. 3. According to Table 6, the regression coefficient is insignificant and obviously satisfies the parallel trend hypothesis. In the first and second years after the implementation of the national environmental protection supervision and control, it was significantly positive at significance levels of 5% and 1%, respectively. This promoting effect continued to increase until the third year. As the effectiveness of the policy does not exceed 3 years, Hypothesis 5 is deemed tenable. This result can be seen more clearly and intuitively in Fig. 2. As can be seen, before policy implementation, it basically fluctuates up and down near the value of 0 and is insignificant. After policy implementation, the marginal effect line tilts rapidly to the upper right; the effect shows an increasing trend and also becomes increasingly stronger. This may be attributed to the fact that enterprises increase their production efficiency by carrying out green innovation activities under the pressure of environmental protection supervision and control, thus achieving the goals of energy conservation and emission reduction. However, the R&D of green patents requires sufficient time, so the policy effect may not be effective in the current period, but the effect will gradually become significant in the next year.

In addition, as a new movement-type environmental governance policy, national environmental protection supervision and control covers a short period in effect, because a “tripartite co-governance” environmental governance model—with the government, enterprises, and the public as the main body—is not perfect. In relation to this, the government is also aware of the problem of the short-term effects of the policy. Given that environmental protection inspectors must become a long-term management mechanism, the second round of national environmental protection supervision and control was announced at the end of 2019 to be gradually launched in 2020. Its goal was to enhance the influence of environmental protection supervision and control and to facilitate improvements in corporate production efficiency.

**Model robustness test**

**Propensity score matching (PSM) processing**

In this paper, the PSM method was used to reduce the systematic differences between the experimental and control groups. The logit model and nearest neighbor matching method were also used to match the two kinds of enterprises. Figure 3 presents a comparison chart of the propensity score kernel density functions before and after year-on-year matching between the experimental and control groups. As can be seen, after the completion of the nearest neighbor matching, the characteristic variables of the two groups are relatively close, the matching effect is rational, and the selection deviation of the sample is well solved. Table 7 presents the PSM-treated regression results for corporate production efficiency. As can be seen, the regression results treated by PSM are consistent with the benchmark regression results, indicating that national environmental protection supervision and control can facilitate the improvement of corporate production efficiency and that the regression results are robust.

**Placebo test**

(1) Placebo test of policy implementation time.

The implementation time for national environmental protection supervision and control was advanced by 2 years, and the regression was conducted again. The results in column (1) of Table 8 show that the coefficient of CEPI is insignificant, which is inconsistent with the original benchmark regression results. In other words, it does not have a significant impact on the increase in corporate production efficiency, thus verifying the assumption of randomness of policy implementation time.

(2) Replacement of the explained variables.

The corporate production efficiencies of the explained variables were re-measured using the OLS method and the fixed effects method. Columns (2) and (3) of Table 8
respectively represent the regression results of replacing the explained variables. Results show that they are consistent with the original benchmark results, indicating that the promoting effect of central environmental protection inspectors on corporate production efficiency still exists and that it does not depend on the choice of explained variables.

(3) Placebo test of randomly assigned experimental group.

In this paper, the experimental group was randomly assigned from the whole sample through self-help sampling. To improve the validity of the test, the random process was repeated 1000 times. Then, the probability density distribution of the regression coefficient estimate and the scatter distribution of the $P$-values were plotted, as shown in Fig. 4. As can be seen, the estimated coefficients are mostly concentrated around zero, and the $P$-values of most estimated values are greater than 0.1, which means that they are insignificant at the 10% level. This indicates that the regression results are unlikely to be obtained by chance. Thus, the national environmental protection supervision and control aimed at boosting corporate production efficiency is unlikely to be affected by other policies or random factors.

**Heterogeneity analysis**

**Heterogeneity test within enterprises—enterprise size**

This paper divides enterprises based on tertiles of total assets and studies the impact of national environmental protection supervision and control on large, medium, and small enterprises. The regression results are presented in Table 9. National environmental protection supervision and control has a significant positive impact on large industrial enterprises; the impact on small and medium enterprises (SMEs), on the contrary, is not significant. The reason for this difference may be that large enterprises have strong financial and talent support and can thus conduct green technology innovation, thereby increasing their production efficiency and achieving the win–win result of environmental and economic benefits. In contrast, SMEs have financial

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**Table 8** Placebo test results

| Variable | (1) Tfp_lp | (2) Tfp_ols | (3) Tfp_fe |
|----------|------------|------------|------------|
| CEPI     | $-0.005$  | $0.03^{***}$ | $0.036^{***}$ |
| Size     | $0.536^{***}$ | $0.816^{***}$ | $0.749^{***}$ |
| Debt     | $0.200^{***}$ | $0.276^{***}$ | $0.259^{***}$ |
| Roa      | $0.189^{***}$ | $0.289^{***}$ | $0.273^{***}$ |
| TobinQ   | $0.015^{***}$ | $0.016^{***}$ | $0.016^{***}$ |
| Capital  | $-0.015^{***}$ | $-0.024^{***}$ | $-0.024^{***}$ |
| Market   | $0.016$ | $0.008$ | $0.010$ |
| Firm fixed effect | Yes | Yes | Yes |
| Year fixed effect | Yes | Yes | Yes |
| $N$       | 11,053 | 12,745 | 12,745 |
| $R^2$     | 0.536 | 0.722 | 0.701 |

$t$ statistics in parentheses, $^* p<0.1$, $^{**} p<0.05$, $^{***} p<0.01$

**Table 9** Heterogeneity analysis—enterprise size

| Variable | Large enterprises (1) | Medium enterprises (2) | Small enterprises (3) |
|----------|------------------------|------------------------|-----------------------|
| CEPI     | $0.036^*$              | $0.012$                | $0.012$               |
| Size     | $0.470^{***}$          | $0.502^{***}$          | $0.503^{***}$         |
| Debt     | $0.018$                | $0.240^{**}$           | $0.240^{**}$          |
| Roa      | $1.175^{***}$          | $0.217^*$              | $0.217^*$             |
| TobinQ   | $0.038^{***}$          | $0.007^{***}$          | $0.007^{***}$         |
| Capital  | $-0.010$               | $-0.026^*$             | $-0.026^*$            |
| Market   | $-0.001$               | $0.000$                | $0.000$               |
| Firm fixed effect | Yes | Yes | Yes |
| Year fixed effect | Yes | Yes | Yes |
| $N$       | 4248                   | 4248                   | 4249                  |
| $R^2$     | 0.517                  | 0.323                  | 0.350                 |

$t$ statistics in parentheses, $^* p<0.1$, $^{**} p<0.05$, $^{***} p<0.01$
constraints that make them unable to withstand the risks of R&D failure. In this case, managers are often unwilling to carry out technological reforms, which affect SMEs’ sustainable development.

**External heterogeneity test of enterprises—green finance level**

In essence, green finance involves guiding the transformation to green production by using financial means and optimizing the allocation of regional resources to achieve sustainable development. This paper selects four indicators of green finance: green credit, green investment, green insurance, and environmental protection support from the government. The paper uses the entropy method to measure the green finance level. The data for each year and region comes from the CSMAR, the China Statistical Yearbook, the Statistical Yearbook of each province, and the China Insurance Yearbook. According to the size of the green finance index in the areas where the enterprises are located, green finance can be divided into three levels: high, medium, and low. The regression results are shown in Table 10. For enterprises in areas with a high green finance level, national environmental protection supervision and control can increase production efficiency and achieve energy conservation and emission reduction; on the contrary, the policies have no significant impact on enterprises in areas with low and medium green finance levels. The reason for this may be that areas with a high green finance level have a more developed green financial system. When enterprises in these areas are confronted with environmental protection supervision and control, they can develop cleaner production projects and increase investment in green innovation with multiple types of financial support, such as green credit and investment, to enhance efficiency and reduce environmental damage. In areas with a low green finance level, the government and the financial sector have failed to guide the flow of funds from high-polluting and energy-intensive industries to green ones. As a result, enterprises cannot perceive the environmental dividend and thus have little enthusiasm to save energy and reduce emissions.

**Research conclusions and policy recommendations**

**Conclusions**

With the constant change of national environmental conditions, the implementation effect of environmental protection policies will gradually decline. Therefore, this paper takes the implementation of the national environmental protection regulatory policy as the time series to test the effectiveness and temporal effect of the policy. It is found that national environmental protection supervision and control can only boost the increase in corporate production efficiency in the short term, and the impact will no longer be noticeable in the third year. This paper finds that environmental protection policies need to be formulated and perfected according to China’s actual situation and will continue to be optimized and improved with the changes of the times.

This paper uses the data of listed industrial enterprises and adopts a multi-phase DID model to test the impact of national environmental supervision on corporate production efficiency. Based on the mechanism model, it is found that: First, previous literature studies have mainly verified the effectiveness of environmental policies (Pan et al., 2021; Wang, 2021), but this paper not only verifies that environmental protection supervision and control policies can facilitate the improvement of corporate production efficiency in China but also tests the temporal

| Variable       | Tfp_l1p          |
|---------------|------------------|
|               | High green finance level (1) | Medium green finance level (2) | Low green finance level (3) |
| CEPI          | 0.084**          | 0.000                     | 0.030                      |
|               | (2.46)           | (0.01)                    | (1.37)                     |
| Size          | 0.482****        | 0.557****                 | 0.57****                   |
|               | (11.17)          | (13.61)                   | (13.30)                    |
| Debt          | 0.124            | 0.124                     | −0.123                     |
|               | (1.24)           | (0.99)                    | (−1.15)                    |
| Roa           | 0.425****        | 0.491**                   | 0.173                      |
|               | (3.67)           | (2.19)                    | (1.27)                     |
| TobinQ        | 0.017***         | 0.021***                  | 0.012**                    |
|               | (2.64)           | (5.00)                    | (2.48)                     |
| Capital       | −0.009*          | −0.064****                | −0.013**                   |
|               | (−1.86)          | (−2.75)                   | (−1.99)                    |
| Market        | −0.041           | 0.042**                   | 0.003                      |
|               | (−0.44)          | (2.16)                    | (0.12)                     |
| Firm fixed effect | Yes            | Yes                      | Yes                        |
| Year fixed effect | Yes           | Yes                      | Yes                        |
| N             | 4293             | 4332                     | 4120                       |
| R²            | 0.458            | 0.571                     | 0.507                      |

*t statistics in parentheses, *p <0.1, **p <0.05, ***p <0.01
effect of policy, that is, it still maintains a positive effect for a period of time after supervision and control, which is supported by the robustness test. Second, the positive role of green technology innovation of conventional intervening variables in the existing literature research results has also been well verified in China (Yang and Wang, 2021; Meng et al., 2020). National environmental supervision and control can increase corporate production efficiency by facilitating corporate green technology innovation, thereby indicating that the compensation effect of environmental protection supervision and control on corporate green innovation is greater than the effect of compliance costs. In turn, this will improve the green technology level of polluting enterprises in a short time and achieve a win–win situation of economic and environmental benefits. Third, green technology was divided into a high level of green invention patents and a low level of green utility patents based on the quality. Results show that national environmental supervision and control mainly boosts the innovation of green utility patents to increase corporate production efficiency, while the effect of green invention patents is not that noticeable. This indicates that enterprises at this stage tend to carry out less difficult strategic innovations and are satisfied with the “standards” of green innovation activities while striving to meet the requirements of environmental regulation and maximizing profits simultaneously. The persistence test based on national environmental protection supervision and control policies found that national environmental protection supervision and control cannot continuously facilitate the enhancement of corporate production efficiency. The test results show that the policy effect can be maintained for 2 years and that the effect is no longer significant in the third year. Moreover, referring to the existing literature on the research and analysis of firm heterogeneity and regional heterogeneity (Hu et al., 2021), we find that national environmental protection supervision and control policies have different effects on enterprises with different individual characteristics and in different regions. The policies have a significant positive effect on the production efficiency of large enterprises, but they have no significant effect on SMEs. For enterprises in areas with a high green finance level, national environmental protection and supervision policy can considerably improve their production efficiency, but for enterprises in areas with a lower green finance level, the effect is non-significant.

Policy recommendations

First, the intermediary role of green technology innovation should be emphasized, the motivation for green technology innovation must be boosted, national environmental supervision and control policies must be strictly implemented, and the increase of corporate production efficiency must be promoted (Zhang and Li, 2020; Liu et al., 2021). On the one hand, the government should establish supporting incentive measures, give full play to the guiding role of financial subsidies and tax incentives to fully release environmental dividends, and encourage enterprises to conduct the R&D of high-quality green technologies. On the other hand, it must establish a perfect green technology quality evaluation system, accurately measure the quality of green technologies, and take this as the standard of incentive policies, thus achieving a win–win situation of environmental protection and production efficiency improvement.

Second, there is a need to constantly optimize the normalized construction of national environmental supervision and control policies and establish a long-term mechanism of environmental protection supervision and control strategy (Wang et al., 2021b; Tan and Mao, 2021). As shown by this study’s results, the environmental protection supervision and control group left after completing the first round of inspection, and the follow-up effect was uncertain. To strengthen the economic and environmental benefits brought about by environmental protection supervision and control, the group tasked with carrying out this duty must conduct spot checks on environmental protection from time to time. Then, the results of national environmental supervision and control should be taken as one of the main indicators for the assessment and promotion of local officials in the future. In this way, the government can establish a strict long-term mechanism of national environmental supervision and control while simultaneously ensuring the continuous development of a movement-type environmental governance system.

Third, with the cyclical effect of the policy, the government should constantly optimize and improve the details of its ongoing national environmental supervision and control policies. For instance, corresponding measures should be introduced in view of the differentiation problems in the process of supervision. With the successive development of the second and third rounds of the national environmental protection supervision and control movement, policymakers must pay close attention to the actual results and “tailor” the policies as needed to maximize their efficacy.

Future prospects

The global spread of the COVID-19 pandemic has had an impact on the global economy and has sounded an alarm for climate change. Now, more than ever, human beings realize that the environment and economy are inextricably linked with each other. To deal with the adverse impact of the pandemic while maintaining their vitality, enterprises need to increase their production efficiency to retain their respective
positions in the market. To restore the economy, the government must also propose to gradually improve the vitality of enterprises. However, whether enterprises must maintain their vitality at the expense of the environment is worthy of deep consideration. Therefore, with the launch of the second round of national environmental protection supervision and control action, our team will continue to explore whether maintaining corporate vitality in the context of the COVID-19 pandemic can lead to environmental degradation. This will play a guiding role in global economic recovery and environmental protection in the future.

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**Declarations**

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