Journal of Innovation & Knowledge 9 (2024) 100458

Journal of Innovation & Knowledge

https://www.journals.elsevier.com/journal-of-innovation-and-knowledge

Government environmental protection subsidies and corporate green innovation: Evidence from Chinese microenterprises

Feng Han[a,*], Xin Mao[a], Xinyu Yu[a], Ligao Yang[b]

[a] School of Economics, Nanjing Audit University, PR China
[b] School of Economics and Management, Changsha University of Science & Technology, PR China

ARTICLE INFO

Article History:
Received 6 December 2022
Accepted 30 December 2023
Available online 5 January 2024

Keywords:
Government environmental subsidies
Corporate green innovation
Government intervention
Externalities
Signal effect

JEL:
H23
O31
O38
O32

ABSTRACT

This paper explores the impact of government environmental protection subsidies on corporate green innovation using panel data of listed companies from 2007 to 2019. The results show that such subsidies can significantly promote corporate green innovation, and the results are robust. Financing constraints, research and development (R&D) willingness, and resource allocation efficiency are important variables for government environmental protection subsidies to promote corporate green innovation. Further analysis shows that compared with industrial policies at the provincial level, the key supportive industrial policies at the central level have a more obvious reinforcing effect on government environmental subsidies to promote enterprise green innovation. Furthermore, government environmental subsidies in the eastern, middle, and western regions benefit the promotion of enterprise green innovation, and the promotional effect is stronger in the middle and western regions. Compared with state-owned enterprises, government environmental subsidies have a more obvious promotional effect on promoting green innovation of non-state-owned enterprises. This paper provides strong theoretical inspiration for better playing the positive incentive role of government intervention with the help of government environmental protection subsidies.

Introduction

Today's world faces serious challenges, such as environmental pollution, climate change, and declining biodiversity, and environmental governance has become an urgent global issue. After promoting the Kyoto Protocol and the Eco-Innovation Plan, the United Nations and the European Union have further proposed the 17 Sustainable Development Goals (for People, for Planet), the Post-2015 EU and Global Development Framework, and the Paris Agreement, incorporating ecological protection, sustainable development, and addressing climate change into their long-term development strategies. The Chinese government attaches great importance to ecological and environmental protection and has made environmental protection a basic state policy. The green transformation is China's basis and source of motivation to solve its resource, environmental, and ecological problems. In 2020, China announced its targets of peaking CO_2 emissions by 2030 and achieving carbon neutrality by 2060. These targets reflect China's determination and efforts to promote green and low-carbon development and actively respond to global climate change. General Secretary Xi Jinping has also stressed the importance of green development at important meetings. In his report to the 20th National Congress of the Communist Party of China in 2022, he proposed "accelerating the green transformation of the development mode" and "promoting the formation of a green and low-carbon mode of production and lifestyle."

Against this backdrop, green innovation has received unprecedented attention. The pace of China's efforts to promote industrial transformation, enhance energy utilization efficiency, and develop and promote green and low-carbon technologies will be significantly accelerated. Green innovation, also known as sustainable innovation, environmental innovation, and eco-innovation, refers to enterprises introducing new ideas, behaviors, products, and processes to reduce their environmental impact or achieve specific ecological sustainable development goals.

However, many enterprises lack the motivation to innovate and realize green transformation. On the one hand, the low level of green innovation technology in most enterprises in China and the high

* Corresponding author at: Nanjing Audit University, No.86 Yushan West Road, Jiangpu Street, Pukou District, Nanjing, China.
E-mail address: hanfeng@nau.edu.cn (F. Han).

https://doi.org/10.1016/j.jik.2023.100458

proportion of traditional resource inputs have led to the unsatisfactory environmental performance of enterprises. On the other hand, green innovation requires enterprises to invest substantial upfront costs and bear the risks brought about by the uncertainty of innovation. The government's environmental regulations also increase enterprises' production and operation costs. Some enterprises, especially private enterprises, cannot take the initiative to choose green transformation due to the cost pressure. Bi, Huang and Wang (2016) argued that compared with traditional innovation, green innovation has a significant positive externality of knowledge spillover and a negative externality of environmental protection. That is, when the cost of innovation is higher than the cost of emission, firms will have an incentive to emit rather than to innovate. Therefore, firms cannot achieve Pareto-optimal efficiency, leading to inefficient resource allocation (Bai, Song, Jiao & Yang, 2019). The government must take timely and effective measures to control this externality (Wu, 2017). Generally, government subsidies effectively mitigate market failures in R&D activities and address innovation externalities to drive green innovation. They can guide the direction of green R&D, compensate for the lack of funds for green innovation, and reduce the risk when firms urgently require green innovation to comply with environmental laws and regulations (Bai et al., 2019; Bi et al., 2016; Li, Liao, Wang & Huang, 2018).

Nevertheless, few scholars have conducted in-depth research on the impact mechanism of government environmental subsidies on corporate green innovation, which provides an entry point for this study. It is necessary to break away from the previous literature limited to exploring the direct relationship between government subsidies and enterprise innovation and further explore the related conduction path and influence mechanisms. A detailed study determining whether and how government environmental subsidies can promote enterprise green innovation by emphasizing green development will have essential theoretical inspiration and practical significance for enhancing enterprise green innovation, building a green innovation industrial system, and promoting green development transformation.

Compared with the existing literature, the possible marginal contributions of this paper are mainly reflected in the following aspects. (1) From the perspective of the research object, this paper focuses on the government environmental protection subsidies and confirms that this governmental behavior has a motivating effect on the green innovation of enterprises, which provides empirical evidence for the local government to promote the green innovation of enterprises by playing the role of "positive incentives" of the government environmental protection subsidies. (2) From the perspective of the research mechanism, this paper synthesizes and analyzes the influence mechanism of government environmental protection subsidies on enterprise green innovation from financing constraints, R&D willingness, and resource allocation efficiency, which provides a new theoretical analysis framework for the subsequent related research. (3) Different from previous studies that used the number of green patent applications or authorizations to measure green innovation of enterprises, this paper uses the number of cited green patents of enterprises (excluding self-citations) to measure the level of corporate green innovation. (4) From the perspective of the further analysis and heterogeneity tests, it reveals the reinforcing role of central industrial policies and provincial industrial policies in the process of government environmental protection subsidies' influence on enterprise green innovation, which can provide new perspectives for the subsequent research on industrial policies. In addition, the influence of enterprise location and property rights heterogeneity on the green innovation enhancement effect of government environmental subsidies is also explored. In conclusion, this paper expands the existing literature on government environmental subsidies and corporate green innovation and helps to deepen the theoretical understanding of the role of government environmental subsidies in intervening in market failure.

Theoretical background and research hypotheses

Theoretical background

As innovation subjects, firms play an essential role in achieving environmental performance by producing, operating, and promoting green innovation products and practices (Lee & Min, 2015). Xu, Liu and Shang (2021) showed that firms' increased research and development (R&D) investment positively affects green innovation performance, and ESG (environmental, social, and governance) performance increases the number of patents for green inventions. Wei, Li, Liu and Du (2022) found that as the main body of enterprise strategic decision-making and resource allocation, top managers of enterprises are the leading promoters of green innovation. Li, Shi, Han and Zeng (2023) examined the complex impact of new energy industry agglomeration on green innovation efficiency from the perspective of spatial mismatch of R&D resources. Han and Mao (2023) argued that enterprises could realize intelligent transformation through human capital, R&D expenditures, information-sharing effects, and the mediating role of factor allocation efficiency to promote green innovation in enterprises.

Government environmental subsidies are a series of policies led by the Ministry of Finance and local governments at all levels to help enterprises conduct environmental protection equipment and environmental protection process improvement as a kind of governmental behavior. Scholars generally believe government subsidies can effectively compensate enterprises for R&D expenses and pollution control costs in green technological innovation, positively incentivizing enterprise green innovation (Bai et al., 2019; Feldman & Kelley, 2006). Hu (2001) conducted empirical research on data from China's high-tech enterprises, showing that the stronger the government subsidies, the more significant the improvement of enterprises' innovation performance. Liu, Zhao and Wang (2020) conducted an empirical analysis using panel data from 30 provinces and cities in China from 2009 to 2017; their results showed that government subsidies positively affect green process innovation.

However, some literature suggests that the influx of government subsidies can reduce entrepreneurs' risk-taking spirit and inhibit innovation performance (Boldrin & Levine, 2004; Wallsten, 2000). Furthermore, local governments' "promotion tournaments" can easily lead to subsidy cheating and rent-seeking by enterprises, resulting in policy failures and waste of public resources (Jiang et al., 2022). Consistent conclusions on whether government environmental subsidies can effectively promote green innovation in enterprises have not yet been obtained. Therefore, the relationship between government environmental subsidies and green innovation needs more evidence to support.

Research hypotheses

Government environmental subsidies and corporate green innovation

Green innovation aims to reduce environmental pollution and conserve natural resources and energy (Saunila, Ukko & Rantala, 2018). As green innovation technologies and knowledge have the spillover characteristics of public goods, green R&D activities inevitably encounter market failure and underinvestment (Tassey, 2004). Government environmental subsidies can facilitate green innovation, which satisfies the traditional theoretical view of market failure and government intervention (Xia, Gao, Wei & Ding, 2022). Environmental subsidies are a policy tool used by governments to support firms in conducting high-quality green innovation R&D activities and to reduce market failures caused by green technology spillovers. First, by directly providing financial support to enterprises that meet the

conditions for green innovation, government environmental protection subsidies can alleviate the cost of introducing advanced green technologies and equipment and stimulate the enthusiasm of enterprises for green innovation. Second, the government can guide the direction of green innovation, improve its quality and efficiency, and realize the healthy development of enterprise green innovation by issuing environmental protection subsidies to specific projects. Third, government environmental subsidies can solve the problem of externalities of green innovation. The spillover effect of green technology innovation is more significant than general innovation. Intermediate products embedded with advanced green technologies from upstream industries can greatly enhance green innovation capabilities and reduce pollution emissions from downstream industries (Bai et al., 2019). Finally, government environmental protection subsidies can also alleviate the adverse effects of resource constraints on enterprise green innovation R&D activities (Dimos & Pugh, 2016), reduce the R&D risks borne by enterprises (Takalo, Tanayama & Toivanen, 2013), and guide the resource elements to realize rational allocation (Liu, 2019). Based on the above analysis, this paper proposes the following hypothesis:

Hypothesis 1. Government environmental subsidies can significantly promote enterprise green innovation.

Government environmental subsidies, financing constraints, and corporate green innovation

Compared with traditional innovation, green innovation has large inputs, high risks, and high uncertainty and also has the characteristics of double externalities of the economy and the environment; therefore, green innovation faces more serious financing constraints (Ebrahimi & Mirbargkar, 2017; Polzin, 2017). Gupta and Barua (2018) showed that financing constraints have become a constraint on corporate green innovation enhancement shackles. Firms need help obtaining bank loans to promote green innovation and face significant cost changes, such as the high expense of disposing of hazardous waste. Government environmental subsidies can alleviate the financing constraints of enterprises and make up for their financial shortfalls in the implementation of innovation activities, thus narrowing the gap between the social benefits of green innovation and the benefits of enterprises and encouraging enterprises to conduct green innovation R&D activities (Huang, Liao & Li, 2019). On the one hand, government subsidies can provide direct innovation compensation, alleviate the pressure of internal financing required for enterprise innovation activities, and overcome enterprises' financial bottlenecks in realizing green innovation expectations. Government environmental protection subsidies directly invest funds into projects and enterprises involved in green environmental protection. This investment supports and incentivizes relevant enterprises to allocate funds and personnel for advanced environmental protection materials, energy saving and emission reduction, renewable energy, and other green innovations, forming the most direct and effective compensation for green innovation and R&D.

On the other hand, government environmental subsidies enhance the external financing ability of green R&D projects through signaling and certification effects, and they improve the efficiency of enterprise green innovation. Based on the signaling theory, the government uses environmental subsidies as a signal of favorable investment to external investors, helping enterprises to label themselves as recognized by the government. This situation facilitates enterprises to obtain more external financing for higher-quality green innovation (Lerner, 1996; Li, Chen, Gao & Xie, 2019; Wu, 2017). At the same time, because government environmental subsidies can be regarded as government-issued credit endorsement, they increase the trust of external investors in the enterprise, reduce information asymmetry, and enhance the enterprise's ability to obtain external financing, thereby diversifying and stabilizing R&D capital investment (Häussler, Harhoff & Müller, 2012; Meuleman & Maeseneire, 2012). Recipient enterprises are the key targets of government support and attention, which can reduce the risk assessment of external investors on enterprises' green innovation; thus, enterprises can form a more stable expectation of the effectiveness of green innovation and the quality of green products as well as the repay ability of credit funds, and increase the degree of trust of external investors. Ultimately, government environmental subsidies can bring direct capital inflow to enterprises, send positive signals to stakeholders (Takalo & Tanayama, 2010), and strive for more capital inflow from the outside world, thus alleviating the financing constraints enterprises face and enhancing enterprise green innovation. Based on the above analysis, this paper proposes the following research hypothesis:

Hypothesis 2. Government environmental subsidies will promote corporate green innovation by alleviating financing constraints.

Government environmental subsidies, R&D willingness, and corporate green innovation

Government environmental protection subsidies can also increase the willingness of enterprises to carry out green innovation. Enterprises obtaining government environmental protection subsidies indicate that they can drive the flow of special funds to the field of green innovation, enhance the reputation and share of enterprises in the market of green products, and compensate for the risk of poor performance caused by the externalities of innovation (Hewitt-Dundas & Roper, 2010); these advantages can enhance firms' willingness to engage in high-quality green innovation. First, Bai et al. (2019) argue that government R&D subsidies allocated to energy-intensive firms trigger a competitive mechanism among firms, stimulating green innovations to compete for more lucrative environmental subsidies. Facing external pressure to be more responsible for the environment and the market demand for green products, enterprises will be more active in conducting high-quality green innovation to improve their competitive advantages (Lin, Zeng, Ma & Qi, 2014). Enterprises can reduce the negative impact on the environment through green innovation to comply with relevant environmental laws and regulations, establish a positive social image as socially responsible and considerate of the masses, and take social responsibility as the core concept of enterprise management. Such enterprises can then implement green strategies to strengthen social interactions with the outside world and seize the potential green market (Huang & Li, 2017) to improve corporate performance (Wei, Shen, Zhou & Li, 2017). Second, some enterprises' willingness to innovate is not strong enough due to the high innovation risk; however, the financial support brought by government subsidies can help enterprises avoid risks through innovation incentives and certification effects, which can help increase enterprises' willingness to implement green innovation (Jiang et al., 2022). Government environmental subsidies can release the affinity signal of the relationship between enterprises and the government, enabling enterprises to obtain more policy support, such as tax breaks, loan preferences, and priority approvals. This situation can also increase enterprises' willingness to innovate and improve the level of green innovation (Wu, 2017). Finally, the incentive signals released by government environmental protection subsidies help enterprises to establish a supporting green innovation system and cultivate a normalized awareness of green development according to the project standards of environmental protection subsidies. Such enterprises then incorporate the social responsibility of protecting the environment into their corporate strategies, promote green production methods, and actively carry out green innovation and R&D activities. Based on the above analysis, this paper proposes the following research hypothesis:

Hypothesis 3. Government environmental protection subsidies can promote corporate green innovation by enhancing corporate R&D willingness.

Government environmental subsidies, resource allocation efficiency, and corporate green innovation

According to the theory of government intervention, it is difficult to rely solely on the market economic system to realize green innovation and achieve the optimal social output. Therefore, the government must correct the functional distortion of the market mechanism on the optimal allocation of resources to correct the market failure of the market mechanism on enterprise green innovation (Guo, Xia, Zhang & Zhang, 2018). On the one hand, the lack of a green innovation market compensation mechanism distorts the price of green innovation factors. Enterprises will be more inclined to capital-intensive, high-energy consumption, high output value of the heavy chemical industry or low-level processing industry, and a large amount of capital into the high-pollution and high-energy-consuming industries, resulting in the continuous deterioration of environmental pollution. As a supplement to the market compensation mechanism, government environmental protection subsidies can play a substitute role, especially when the market compensation mechanism is unsound and imperfect. The non-R&D subsidies in government environmental protection subsidies can provide financial security for enterprises to purchase green technology materials and equipment and introduce emerging technologies. This approach reduces enterprise production costs and indirectly incentivizes enterprises to transfer resources to green innovation activities, actively absorbing new technologies and striving to transform them into independent innovation.

On the other hand, government environmental protection subsidies create a rational flow and allocation of human resources factors, guiding the flow of human resources factors to green technologies and new industries with good prospects for future development in line with the government's support. The signaling effect of government environmental protection subsidies forms a continuous inflow of funds, attracting high-end innovative talents to enter the enterprise by providing more security and stability and accumulating high-quality technical talents for enterprise green innovation (Acharya, Baghai & Subramanian, 2014). Furthermore, intelligent and precise production occurs, reducing unnecessary waste in production activities, easing labor allocation distortion, and realizing highly efficient enterprise green innovation. Furthermore, the government can provide timely expert guidance and institutional support for the problems enterprises face in green innovation from stage supervision and results transformation. Government environmental subsidies bring more external monitoring and assistance to enterprises. Furthermore, the constraints of legitimacy pressure force enterprises to fulfill government contracts more strictly, implement green innovation strategies, and reduce uncertainty and resource allocation distortion in green innovation (Marquis & Qian, 2014). Based on the above analysis, this paper proposes the following research hypothesis:

Hypothesis 4. Government environmental subsidies can promote corporate green innovation by optimizing the efficiency of resource allocation and thus promote green innovation.

In summary, the theoretical model of this paper is constructed, which is shown in Fig. 1.

Methods and data

Model setting

Panel benchmark regression model

This paper's research objective is to examine the effect of government environmental protection subsidies on enterprise green innovation and reveal the mechanism and characteristics of its influence on green innovation. Combined with the previous theoretical

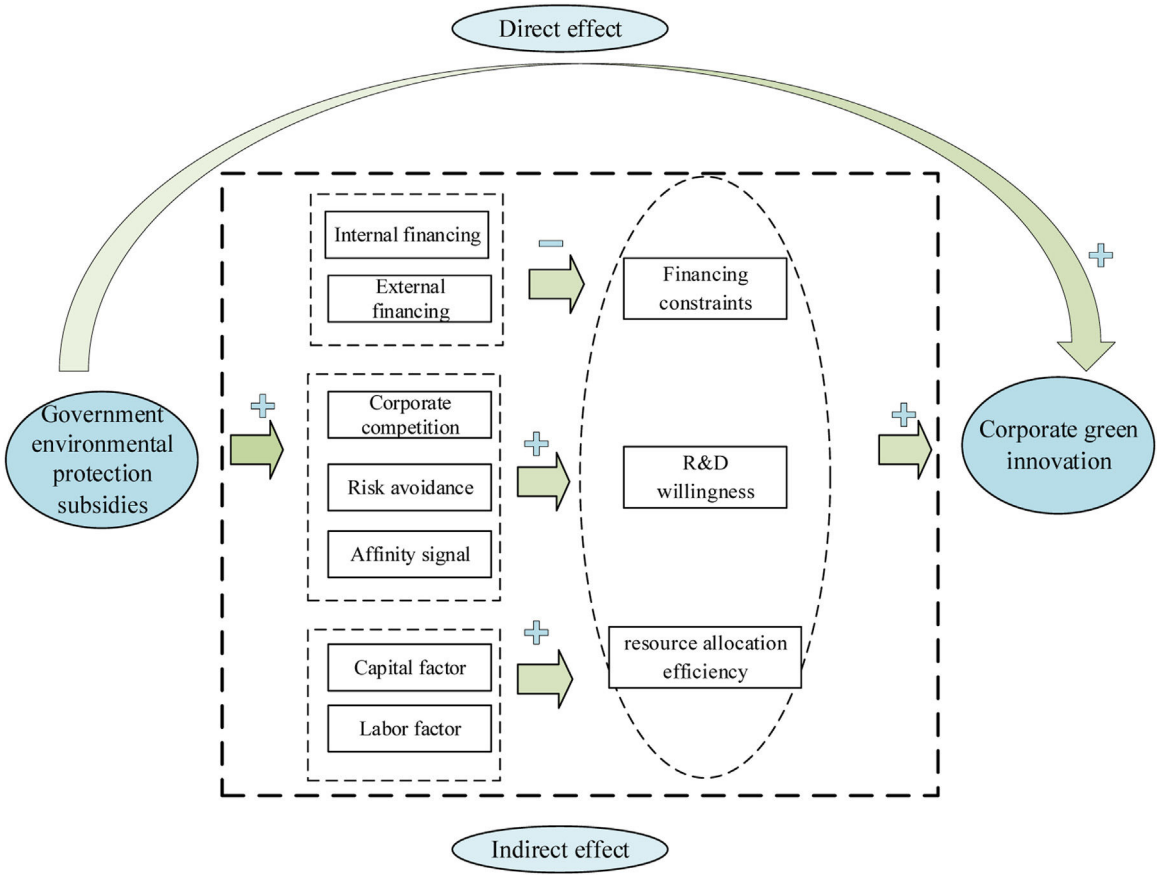

Fig. 1. Theoretical analysis framework.

analysis, this paper sets up the following measurement model to verify the effect of government environmental protection subsidies on enterprise green innovation:

$$\ln Green_{it} = \alpha_0 + \alpha_1 \ln Subsidy_{it} + \beta X + \lambda_i + \mu_t + \varepsilon_{it} \quad (1)$$

Here, $Green_{it}$ denotes the green innovation capability of firm i in year t. $Subsidy_{it}$ denotes the government environmental protection subsidies received by firm i in year t. X is the set of control variables, including *FirmAge, liability, Asset, FinancialLeverage, ReturnOnAssets*, and *TobinQ;* α and β are coefficients and coefficient vectors to be estimated. λ_i and μ_t are firm and year fixed effects, respectively, and ε_{it} is a random disturbance term. The econometric model, including control variables, is as follows:

$$\ln Green_{it} = \alpha_0 + \alpha_1 \ln Subsidy_{it} + \beta_1 FirmAge + \beta_2 liability + \beta_3 Asset + \beta_4 FinancialLeverage + \beta_5 ReturnOnAssets + \beta_6 Tobin + \lambda_i + \mu_t + \varepsilon_{it} \quad (2)$$

where β_1–β_6 denote the coefficients of the effects of each control variable on corporate green innovation.

Mechanism testing model

This paper introduces three mechanism variables (financing constraints, R&D willingness, and resource allocation efficiency) based on the baseline regression to carry out the mechanism test. This approach allows us to verify the mechanism of government environmental protection subsidies that promote enterprise green innovation by alleviating financing constraints, enhancing R&D willingness, and optimizing resource allocation efficiency based on theoretical analysis. The specific mechanism test model is as follows.

$$M_{it} = \Theta + \theta_0 \ln Subsidy_{it} + \phi_\tau \sum_{\tau=1}^{\varpi} W_{it} + \eta_i + \upsilon_t + \zeta_{it} \quad (3)$$

Here, Θ is a constant term. M represents various mechanism variables, including financing constraints, R&D willingness, and resource allocation efficiency. W is the set of control variables consistent with the baseline regression model. θ_0 and ϕ are coefficients and coefficient vectors to be estimated, and ϖ is the number of control variables; η_i and υ_t are firm fixed effects and year fixed effects, respectively, and ζ_{it} is a random disturbance term.

Variable selection and indicator measurement

The dependent variable is enterprise green innovation (ln*Green*). Whether green technological innovation results can be rapidly disseminated, promoted, and applied determines the influence and recognition of green innovation and its value in promoting enterprises' green development. An essential technological breakthrough will inevitably be recognized, promoted, and applied by more and more economic agents, generating greater social and economic value. Therefore, compared with the mere number of green patent applications or authorizations, the citation status of enterprise green patents better reflects the extent to which green innovations are recognized, accepted, promoted, and disseminated. This approach helps measure the impact, innovation value, and innovation quality of enterprise green innovations. The green patent citation data is divided into two parts: the number of citations for green patents applied for and the number of citations granted. Each part contains the number of citations per year (cumulative) and the number of citations per year (cumulative), excluding self-citations. Among them, the number of citations excluding self-citations is the number of citations of the patents in the corresponding year excluding parent companies, subsidiaries, joint ventures, and associates within the group. This paper uses the logarithmic value of the cumulative number of citations in each year of green patents applied by listed companies (excluding self-citations) plus one to measure corporate green innovation. For robustness, this paper also uses the following proxy variables for corporate green innovation: the cumulative number of citations in each year of the applied green patents (ln*green1*); the number of citations in each year of the applied green patents excluding self-citations (lngreen2); the number of citations in each year of the authorized green patents excluding self-citations (ln*green3*); the number of green inventions independently applied in the same year (ln*green4*); the number of green utility models independently applied in the same year (ln*green5*).

The independent variable is government environmental subsidies (ln*Subsidy*). This paper uses the natural logarithm of the total amount of government environmental subsidies announced by listed companies to measure. Government subsidies are transfer payments, i.e., government funds are transferred to enterprises directly or indirectly. Government environmental subsidies take the form of cash grants (including special allocations, government interest rates, and fee subsidies), tax exemptions or rebates, and in-kind subsidies (including the allocation of land and equipment at no cost and the supply of land and equipment at a low cost). Specifically, this paper selects the logarithmic amount of the sum of environmental protection-related grants under the government grants line item in the notes to the financial statements of listed companies as a measure of government environmental protection grants.

Control variables: This paper selects variables closely related to green innovation for control, including the following six control variables. The *FirmAge* variable is measured by the logarithmic value of subtracting the current year from the listed year. The *liability* variable is measured by the ratio of total liabilities at the end of the year to total assets at the end of the year. The *Asset* variable is the ratio of net fixed assets and net inventories to total assets. The *FinancialLeverage* variable is the ratio of total financial liabilities at the end of the year to total assets. The *ReturnOnAssets* variable is measured as the ratio of net profit to total assets at the end of the period. The *TobinQ* variable is measured by the firm's market capitalization ratio to total assets.

Several mechanism variables are included, beginning with (1) financing constraints. This paper refers to the research idea of Kaplan and Zingales (1997) to calculate the KZ index of the degree of financing constraints of listed companies. The larger the KZ index, the higher the financing constraints faced by listed companies and the lower the financing efficiency. (2) In this paper, the logarithm of the amount of R&D investment is used to measure R&D willingness. (3) This paper adopts the logarithm of total factor productivity of enterprises to measure the resource allocation efficiency, following Olley and Pakes (1992).

Data sources

This paper's annual green patent citation data of listed enterprises are mainly based on the green patent classification number standard published by the World Intellectual Property Office. These data are obtained by comprehensively and systematically screening and sorting the patents from the State Intellectual Property Office and Google Patent. The data of listed enterprises are obtained from the China Stock Market and Accounting Research database. After merging and matching, the unbalanced panel data of more than 20,000 enterprise samples from 2007 to 2019 are finally collated. Table 1 shows the descriptive statistics of the variable data.

Analysis of empirical results

Benchmark regression

Heterogeneity may exist across firms and years, and these heterogeneities are often difficult to observe and measure. The results of the Hausman test show that estimation using a fixed effects model is

Table 1
Descriptive statistical analysis of variables.

Variable	Mean	SD	Min	Max
ln*Green*	1.2685	0.6277	0.0000	5.0499
ln*green1*	1.2691	0.6278	0.0000	5.0499
ln*green2*	0.3813	0.5095	0.0000	4.2195
ln*green3*	0.3634	0.4975	0.0000	4.1897
ln*green4*	2.6543	1.8058	0.0000	7.7790
ln*green5*	1.7333	1.5918	0.0000	6.3099
ln*Subsidy*	14.6294	2.0287	5.7991	20.9701
FirmAge	2.6232	0.4464	0.0000	3.3673
liability	0.5559	0.2247	0.0145	10.4953
Asset	0.3407	0.1458	0.0000	0.9542
FinancialLeverage	0.3756	0.2211	0.0000	0.9874
ReturnOnAssets	0.0278	0.1079	−7.7001	0.6243
TobinQ	1.4739	0.8589	0.7154	56.6643
financing constraints	1.1618	1.7306	−11.3445	11.7108
R&D willingness	20.5239	2.1126	7.4085	25.0252
resource allocation efficiency	2.0345	0.1209	1.4069	2.3477

more appropriate than a random effects model. Thus, this paper uses the panel fixed effects model to estimate Eqs. (1) and (2); Table 2 presents the regression results.

Column (1) reports the results of government environmental subsidies on firms' green innovation without considering control variables and fixed effects. The coefficient on government environmental subsidies (ln*Subsidy*) is significantly positive at the 1% level, indicating a significant positive relationship between government environmental subsidies and firms' green innovation. Column (2) reports the results of the effect of government environmental subsidies on firm green innovation, controlling only for firm and year fixed effects. The coefficient of government environmental subsidies is significantly positive. That is, without considering other factors, government environmental subsidies have a significant role in promoting enterprise green innovation. This result indicates that the government will prompt enterprises to conduct green innovation activities through financial subsidies, policy subsidies, tax breaks, and other environmental subsidy policies. This situation will encourage enterprises to invest funds and resources into the green innovation field they were reluctant to before to enhance the level of enterprise green innovation. Finally, this paper gradually considers the effects of control variables and fixed effects in columns (3) and (4). The results indicate that the coefficients of the government's environmental protection subsidies are still significantly positive and relatively stable, suggesting that after controlling for firm characteristics, government environmental subsidies can significantly promote the development of corporate green innovation. The estimation results in Table 2 preliminarily indicate that government environmental subsidies significantly promote enterprise green innovation; thus, hypothesis 1 is proved.

Table 2
Regression results of the impact of government environmental protection subsidies on corporate green innovation.

Variable	(1)	(2)	(3)	(4)
ln*Subsidy*	0.0076***	0.0089***	0.0060***	0.0115***
	(4.6428)	(3.3347)	(3.8846)	(4.0165)
FirmAge			0.4754***	0.0802***
			(53.7841)	(5.6733)
liability			−0.1198***	−0.1196***
			(−5.1585)	(−2.8921)
Asset			−0.2069***	−0.0731*
			(−7.2575)	(−1.7177)
FinancialLeverage			−0.1177***	−0.1060***
			(−6.0152)	(−3.7036)
ReturnOnAssets			−0.2993***	−0.1716**
			(−8.9488)	(−2.3762)
TobinQ			−0.0211***	−0.0033
			(−5.3341)	(−0.4434)
_cons	1.0550***	1.0993***	0.1102***	1.0029***
	(43.2410)	(28.0020)	(3.1277)	(19.1619)
Hausman test		21.70		5305.45
		[0.0000]		[0.0000]
Firm FE	No	Yes	No	Yes
Year FE	No	Yes	No	Yes
N	25,734	25,734	25,381	25,381
R^2	0.0020	0.0124	0.3849	0.0192

Notes:.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$; t-values are in parentheses of columns (2) and (4); z-values in parentheses of columns (1) and (3); p-values are in square brackets.

Robustness test

Considering the possible problems of extreme values, variable measures, and endogeneity in the regression results, this paper conducts the following robustness tests.

(1) Consider the problem of extreme values of the sample: This paper analyzes regression after winsorizing and truncating extreme values of the core explanatory variable to eliminate the influence of extreme values on the regression results. Columns (1) and (2) of Table 3 show the regression results after winsorizing and truncating at 2.5% of the core explanatory variable, respectively. A comparison with the benchmark regression results shows that the coefficient of the effect of government environmental protection subsidies on corporate green innovation decreases slightly after excluding the extreme values of the sample; however, it is still significantly positive, indicating that the baseline regression results are robust. In other words, government environmental protection subsidies significantly promote corporate green innovation.
(2) Consider different measures of corporate green innovation: There are other indicators mentioned above can be used to measure corporate green innovation. At the same time, Zhou et al. (2023) argue that patent data can accurately identify the advantages of green technologies, and green patents can reflect the green innovation ability of enterprises. Therefore, this paper uses the following alternative indicators to measure enterprise green innovation: the cumulative number of citations in each year of the applied green patents (ln*green1*); the number of citations in each year of

Table 3
Robustness test I.

Variable	(1) Winsor=0.025	(2) Trim=0.025
ln*Subsidy*	0.0098***	0.0061**
	(3.7347)	(2.5064)
FirmAge	0.0757***	0.0784***
	(6.1857)	(7.2531)
liability	−0.1028***	−0.0853**
	(−2.6397)	(−2.3398)
Asset	−0.0600	−0.0445
	(−1.4498)	(−1.1187)
FinancialLeverage	−0.1099***	−0.0969***
	(−4.0052)	(−3.7120)
ReturnOnAssets	−0.1402**	−0.0999
	(−2.0717)	(−1.5408)
TobinQ	−0.0048	−0.0033
	(−0.6715)	(−0.4776)
_cons	1.0328***	1.0372***
	(20.6544)	(21.6154)
Firm FE	Yes	Yes
Year FE	Yes	Yes
N	25,381	24,473
R^2	0.0149	0.0127

Notes:.
*$p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$; t-values are in parentheses.

Table 4
Robustness test II.

Variable	(1) lngreen1	(2) lngreen2	(3) lngreen3	(4) lngreen4	(5) lngreen5
ln*Subsidy*	0.0119***	0.0097***	0.0083***	0.0193***	0.0217***
	(4.1708)	(5.3246)	(5.3831)	(3.5740)	(4.3523)
FirmAge	0.0770***	−0.0674***	0.0065	−0.3454***	−0.4493***
	(5.4750)	(−7.3008)	(0.9092)	(−12.3050)	(−19.7155)
Liability	−0.1185***	0.0867***	0.1023***	1.9385***	2.7662***
	(−2.8662)	(3.7245)	(4.8172)	(21.7325)	(32.3412)
Asset	−0.0718*	−0.1176***	−0.0832***	0.3788***	0.2744***
	(−1.6868)	(−4.7587)	(−3.5984)	(4.9282)	(3.4848)
FinancialLeverage	−0.1067***	−0.0168	−0.0501***	−2.3807***	−1.8590***
	(−3.7316)	(−0.9943)	(−3.1740)	(−43.7874)	(−33.8663)
ReturnOnAssets	−0.1734**	0.1524***	0.0403	1.4848***	1.3628***
	(−2.4039)	(3.4411)	(0.9818)	(9.9261)	(7.5016)
TobinQ	−0.0036	0.0118**	0.0114**	−0.1085***	−0.1983***
	(−0.4951)	(2.3985)	(2.3281)	(−6.1979)	(−11.5106)
_cons	1.0054***	0.4037***	0.2249***	2.8259***	1.9864***
	(19.2173)	(12.4411)	(7.2667)	(24.3108)	(19.1900)
Firm-FE	Yes	Yes	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes	Yes	Yes
N	25,381	25,381	25,380	23,781	23,781
R^2	0.0189	0.2084	0.2085	0.2495	0.2130

Notes:.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$; t-values are in parentheses.

the applied green patents, excluding self-citations (lngreen2); the number of citations in each year of the authorized green patents excluding self-citations (ln*green3*); the number of green inventions independently applied in the same year (ln*green4*); the number of green utility models independently applied in the same year (ln*green5*). These indicators are then regressed. The results shown in Table 4 show that the government environmental protection subsidy coefficient is still significantly positive after replacing the enterprise green innovation measurement indicators, indicating that the core findings of this paper remain robust.

(3) Considering endogeneity issues: This paper further uses the lagged variable, instrumental variable, and two-stage least squares methods to test the model and alleviate the possible endogeneity problem. Regarding instrumental variable selection, this paper utilizes the lagged one period of government environmental subsidies and the mean value of government environmental subsidies received by other firms in the industry as instrumental variables, respectively. This instrumental variable satisfies the relevance and exclusion criteria. Regarding relevance, the government environmental protection subsidies received by other enterprises in the same industry are relevant to the government environmental protection subsidies received by this enterprise. Competition exists among enterprises in the industry, which prompts enterprises to imitate each other in green transformation. In terms of exclusion, government environmental subsidies received by other firms in the same industry should not directly affect the green innovation of this firm.

Table 5 reports the results of the tests after considering endogeneity issues. Column (1) reports the estimation results using the lagged variable method, where the significance and sign of the coefficient on government environmental subsidies do not change. Column (2) reports the results of the instrumental variable test using the mean value of government environmental subsidies received by other firms in the industry as an instrumental variable. The coefficient of government environmental subsidies is still significant and positive at the 1% level, and the Hausman test rejects the original hypothesis that all the explanatory variables are exogenous; thus, the instrumental variable method's estimation is reasonable. Column (3) reports the results of a two-stage least squares regression using the core explanatory variables lagged by one period and the mean value of government environmental subsidies received by other firms in the industry as instrumental variables. Furthermore, the coefficient on government environmental subsidies is still significantly positive. The Kleibergen−Paap rk LM statistic rejects the under-identification test, and the Kleibergen−Paap rk Wald F rejects the test of weak instrumental variables. These results indicate that the selection of instrumental variables is reasonable, and the Hansen test has a

Table 5
Robustness test III.

Variable	(1) Lagged variable method	(2) Instrumental variable method	(3) 2SLS
l.ln*Subsidy*	0.0139***		
	(4.1946)		
ln*Subsidy*		0.0256***	0.0257***
		(6.4937)	(2.6935)
FirmAge	0.0891***	1.0629***	0.1677***
	(5.0681)	(84.4562)	(3.1013)
liability	−0.1070**	−0.1340***	−0.1357**
	(−2.1468)	(−4.7734)	(−2.1178)
Asset	−0.1114**	−0.0354	0.0291
	(−2.2362)	(−0.9404)	(0.3203)
FinancialLeverage	−0.1519***	−0.1425***	−0.2339***
	(−4.5064)	(−4.9172)	(−3.6904)
ReturnOnAssets	0.1094	−0.2137***	−0.0643
	(1.4947)	(−6.3635)	(−1.1262)
TobinQ	−0.0090	−0.0224***	0.0018
	(−1.1288)	(−5.0769)	(0.2055)
_cons	1.0963***	−1.6778***	
	(16.8082)	(−23.0320)	
Hausman test		37.9600	
		[0.0000]	
Kleibergen-Paap rk LM			563.4750
			[0.0000]
Kleibergen-Paap rk Wald F			381.0420
Hansen test			1.3910
			[0.2383]
Firm-FE	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes
N	18,757	25,343	11,229
R^2	0.0259		0.0009

Notes:.
*$p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$; t-values are in parentheses; p-values are in square brackets.

Table 6
Mechanism tests of the impact of government environmental protection subsidies on corporate green innovation.

Variable	(1) Financial constraints	(2) R&D willingness	(3) Resource allocation efficiency
ln*Subsidy*	−0.0446***	0.1608***	0.0166***
	(−9.2163)	(21.9231)	(38.6556)
FirmAge	0.0052	−0.2909***	0.0050***
	(0.2516)	(−9.0865)	(2.7014)
liability	5.2862***	2.9109***	0.2543***
	(71.7946)	(23.2496)	(29.8915)
Asset	0.7970***	−0.0928	0.0365***
	(12.0065)	(−0.6800)	(4.8406)
FinancialLeverage	1.0200***	−3.4572***	−0.1378***
	(22.3401)	(−44.6120)	(−27.6153)
ReturnOnAssets	−7.4618***	3.6282***	0.4135***
	(−20.2880)	(14.1763)	(20.1661)
TobinQ	0.1767***	−0.6635***	−0.0347***
	(10.1627)	(−29.1131)	(−22.6756)
_cons	−1.6654***	18.6670***	1.6855***
	(−15.4267)	(133.7916)	(204.3295)
Firm-FE	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes
N	25,124	24,321	24,199
R^2	0.6221	0.4248	0.4701

concomitant probability greater than 10%, thus accepting the original hypothesis that all instrumental variables are valid. The above results indicate that government environmental subsidies can significantly promote corporate green innovation after considering the endogeneity issue and estimating using the lagged variable method, instrumental variable method, and two-stage least squares method.

Mechanism test and further analysis

Mechanism test

The benchmark regression only briefly analyzes the impact of government environmental protection subsidies on corporate green innovation and does not verify the mechanism path of its implications. Therefore, this paper constructs a mechanism test model, i.e., regression of Eq. (3); the results are shown in Table 6. The results of the mechanism test verify the mechanism of government environmental subsidies to promote the development of corporate green innovation by alleviating financing constraints, enhancing R&D willingness, and optimizing resource allocation efficiency. Column (1) of Table 6 reports the mechanism test results for the financing constraint channel. The coefficient of government environmental protection subsidies is significantly negative, indicating that government environmental protection subsidies directly alleviate the financing constraints of enterprises and thus help enterprises in green innovation. Government environmental protection subsidies can help enterprises alleviate financing constraints by providing them with direct capital inflow and helping them attract market capital through the signal effect.

In addition to affecting financing constraints, government environmental subsidies may also affect firm green innovation by influencing firms' willingness to conduct R&D and resource allocation efficiency. Columns (2) and (3) of Table 6 report the test results after replacing the mechanism variables with R&D willingness and resource allocation efficiency, respectively. As shown, enhancing R&D willingness and optimizing resource allocation efficiency are also important channels for government environmental subsidies to promote green innovation of enterprises. On the one hand, the government environmental protection subsidies reduce the risk of green R&D and provide incentives for enterprises to seize the green market, enhancing the willingness of enterprises to green innovation. On the other hand, the government environmental protection subsidies will also be used as a powerful tool to make up for the shortcomings of the market mechanism and guide the flow of resources toward meeting social development needs. This situation is conducive to optimizing the efficiency of resource allocation and thus promoting the green innovation of enterprises to enhance and ultimately achieve green development.

Further analysis

The previous section examined the impact of government environmental subsidies on corporate green innovation; however, the effect of government environmental subsidies on corporate green innovation may also show differences with the heterogeneous characteristics of industrial policies and enterprises. Therefore, this paper discusses the dimensions of industrial policy, the region's heterogeneity, and enterprise property rights of enterprises to reveal some regular characteristics of government environmental subsidies affecting green enterprise innovation.

(1) Further analysis based on industrial policy: As an essential factor in enterprises' production and operation environment, industrial policy has an important impact on the green innovation activities of enterprises. Industrial policy is the main government intervention to realize specific economic development goals by guiding industrial development. Different policies are needed because the situation of the same industry in various fields of social reproduction often differs. Furthermore, industrial policy is implemented using economic, administrative, legal, and disciplinary means. It suggests that the government's attitude toward the relevant industries affects their development prospects, i.e., industries supported by policy priorities may be treated more favorably, and the facilitating effect of government environmental subsidies on enterprise green innovations may be strengthened. This paper examines the role of policy support and other influences by constructing relevant dummy variables and introducing interaction terms with government environmental subsidies into the measurement Eq. (2) for estimation. Specifically, this paper uses the industrial policy database in China Research Data Services, which extracts the relevant industries and planning contents mentioned in the five-year plan outline, summarizes the relevant industrial policies of the central government and provinces, and establishes the corresponding dummy variables. Enterprises belonging to the

Table 7
Further analysis considering industrial policies.

Variable	(1)	(2)	(3)	(4)
ln*Subsidy*	−0.0010	0.0028	−0.0011	0.0023
	(−0.1938)	(0.7171)	(−0.2553)	(0.5433)
Provincial policy	−0.2707***			
	(−3.1371)			
ln*Subsidy* × *Provincial policy*	0.0156***			
	(2.6958)			
Provincial national policy		−0.2925***		
		(−4.0449)		
ln*Subsidy* × *Provincial national policy*		0.0171***		
		(3.4418)		
Central policy			−0.3050***	
			(−3.8171)	
ln*Subsidy* × *Central policy*			0.0176***	
			(3.2756)	
Provincial and central policy				−0.2338***
				(−2.9692)
ln*Subsidy* × *Provincial and central policy*				0.0128**
				(2.4073)
FirmAge	0.0779***	0.0786***	0.0761***	0.0783***
	(5.5103)	(5.5516)	(5.3597)	(5.5280)
liability	−0.1264***	−0.1142***	−0.1225***	−0.1148***
	(−3.0523)	(−2.7661)	(−2.9665)	(−2.7919)
Asset	−0.0707*	−0.0527	−0.0775*	−0.0835**
	(−1.6623)	(−1.2255)	(−1.8203)	(−1.9652)
FinancialLeverage	−0.1011***	−0.1052***	−0.1027***	−0.1026***
	(−3.5375)	(−3.6802)	(−3.5929)	(−3.5886)
ReturnOnAssets	−0.1785**	−0.1587**	−0.1800**	−0.1721**
	(−2.4895)	(−2.2172)	(−2.5156)	(−2.4116)
TobinQ	−0.0037	−0.0002	−0.0029	−0.0026
	(−0.5039)	(−0.0271)	(−0.4025)	(−0.3497)
_cons	1.2250***	1.1398***	1.2331***	1.1714***
	(14.5996)	(17.0447)	(16.4634)	(16.3686)
Firm-FE	Yes	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes	Yes
N	25,374	25,374	25,374	25,374
R^2	0.0204	0.0209	0.0210	0.0208

Notes:.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$; t-values are in parentheses.

key support industries are assigned the value of 1, and enterprises not obtaining them are assigned the value of 0.[1] *Provincial policy* denotes key support industries in provincial industrial policy, *Provincial national policy* denotes national key support industries in provincial industrial policy, *Central policy* denotes key support industries in central industrial policy, and *Provincial and central policy* denotes both provincial and central key support industries. Table 7 reports the green innovation enhancement effect of government environmental subsidies under the interaction term of introducing the above four dummy variables with government environmental subsidies. Based on the coefficients of the interaction terms, columns (1)–(4) show that the government's key supportive industrial policies are conducive to promoting the positive effect of government environmental subsidies on firms' green innovation.

Comparing the coefficients of the interaction terms in columns (1) and (3) shows that the effect of government environmental protection subsidies on the enhancement of enterprise green innovation is stronger in the central-level key support industries. The reason may be that under China's current system, the central government plays the role of overall regulation. Being listed as a key support industry by the central government means that a firm can obtain more resources and will receive strong support from all levels of government; thus, its environmental protection subsidies have a more significant effect on the promotion of green innovation in enterprises. The coefficient of the interaction term between national key-supported industries and government environmental subsidies in column (2) is larger than that for the interaction term between provincial key-supported industries and government environmental subsidies in column (1). Additionally, the coefficient of the interaction term between the industries with the same provincial and central key-supported industries and government environmental subsidies in column (4) is significantly positive. These results again verify that the industrial policy at the central level implies more substantial policy effects, which may be because, on the one hand, central planning takes into account the reality of local industrial development. On the other hand, local governments will actively respond to the central policy to obtain support from the central government, which is more conducive to strengthening the role of government environmental protection subsidies in promoting enterprise green innovation.

(2) Analysis based on regional heterogeneity: Considering that the economic development status of different regions and the intensity of local government's policy requirements for green development differ, heterogeneity may arise in the role of government environmental protection subsidies in promoting green innovation of enterprises. Therefore, this paper takes the central region as the standard, introducing the product of government environmental protection subsidies and the dummy variables of the eastern region (*east*) and the western region (*west*). The regional dummy variables (*east* and *west*) set the value of the dummy variable as one and the rest as zero. Column (1) of Table 8 reports the

Table 8
Heterogeneity analysis based on the regions and property rights of enterprises.

Variables	(1) Regional heterogeneity	(2) Heterogeneity of property rights
ln*Subsidy*	0.0091***	0.0115***
	(3.0482)	(3.9858)
ln*Subsidy* × *west*	0.0067***	
	(4.2291)	
ln*Subsidy* × *east*	0.0023*	
	(1.8731)	
ln*Subsidy* × *SOE*		0.0002
		(0.2000)
FirmAge	0.0757***	0.0799***
	(5.2912)	(5.6233)
liability	−0.0946**	−0.1208***
	(−2.3122)	(−2.9381)
Asset	−0.0759*	−0.0723*
	(−1.7871)	(−1.7078)
FinancialLeverage	−0.0990***	−0.1050***
	(−3.4569)	(−3.5522)
ReturnOnAssets	−0.1451**	−0.1731**
	(−2.0064)	(−2.3940)
TobinQ	0.0010	−0.0032
	(0.1329)	(−0.4296)
_cons	0.9899***	1.0039***
	(18.8529)	(19.2949)
Firm-FE	Yes	Yes
Year-FE	Yes	Yes
N	25,381	25,381
R^2	0.0212	0.0192

Notes:.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$; t-values are in parentheses.

[1] Specifically, each five-year planning document has a chapter dedicated to industrial development, and this paper will be entitled "key development industries," "key support industries," "pillar industries," "priority industries," as well as "bigger and stronger," "vigorously develop," "efforts to cultivate" and so on the words to guide the industry are regarded as the next five years as a key support industry labeled, or else regarded as a non-focus on the industry.

regression results, showing that the estimated coefficient of the interaction term between the western region and government environmental subsidies is significantly positive at the 1% level. Furthermore, the estimated coefficient of the interaction term between the eastern region and government environmental subsidies is significantly positive at the 10% level. When both dummy variables take zero at the same time, the estimated coefficient of the core explanatory variable (which denotes the role of government environmental protection subsidies in the central region in influencing firms' green innovation) is significantly positive at the 1% level.

The finding suggests that the role of government environmental subsidies in promoting green innovation exists significantly among enterprises in the eastern, central, and western regions; however, the role of government environmental subsidies in the eastern region is weaker than that in the central and western regions. The reason may be that the degree of marketization in the eastern region is relatively high, and the government environmental protection subsidies are insufficient to promote green innovation in enterprises compared with the central and western regions, which are lagging in economic development. Enterprise financing in the central and western regions is still behind the eastern regions; thus, the government environmental protection subsidies can provide stronger policy and financial support for green innovation activities in the central and western regions.

(3) Analysis based on property rights heterogeneity: State-owned enterprises (SOE) undertake more local employment and other economic and social functions than non-SOEs. Thus, SOEs are more likely to receive government subsidies; however, the higher the proportion of state-owned property rights in an enterprise, the worse the effect of government subsidies on enterprise innovation (Bai, 2011). Under the same government subsidy conditions, the innovation enhancement effect in non-SOEs is significantly higher than in SOEs. To maintain their personal incentive gains, administrative positions, etc., SOE managers are reluctant to invest in high-risk innovation projects and bear the risk of innovation failure; therefore, the role of government environmental subsidies in promoting corporate green innovation may not be significant in SOEs. Therefore, this paper introduces a dummy variable for enterprise property rights (*SOE*), set to one for SOEs and zero for non-SOEs.

The results in column (2) of Table 8 show that the estimated coefficient of the interaction term between SOEs and government environmental subsidies is insignificant. In contrast, when the dummy variable is zero, the estimated coefficient of the core explanatory variable, which represents the role of government environmental subsidies for non-SOEs in influencing firms' green innovation, is significantly positive at the 1% level. SOEs enjoy government subsidies before emphasizing green development; thus, the government subsidies from firms' green innovation have little incentive effect on firms' green R&D investment. At the same time, the management of SOEs will consider the political risks associated with project failure and will be reluctant to invest in green innovation projects even if they receive environmental grants. Non-SOEs enjoy relatively few government grants before the emphasis on green development and transformation; therefore, government environmental grants from green innovations are a greater incentive. At the same time, managers from non-SOEs also want to establish contact with the government and are willing to conduct R&D following the requirements of green development construction after receiving government subsidies.

Conclusions and suggestions

Conclusions

This paper summarizes how government environmental protection subsidies affect corporate green innovation through theoretical analysis. We analyze the role of government environmental protection subsidies in affecting corporate green innovation by using the data of Chinese listed companies from 2007 to 2019. The findings show that government environmental protection subsidies significantly promote corporate green innovation, and this conclusion remains robust after considering the sample extreme value problem, considering other corporate green innovation indicators, and dealing with endogeneity. The results of the mechanism test indicate that financing constraints, R&D willingness, and resource allocation efficiency play a significant mediating role in the process of government environmental subsidies affecting enterprise green innovation. Further analysis shows that government environmental subsidies' role in promoting enterprise green innovation will be strengthened in industries that receive government policy support. Furthermore, the effect of industrial policy at the central level is more pronounced. The role of government environmental subsidies in promoting enterprise green innovation is not restricted by region; however, the effect of promotion in the central and western regions is more significant than that in the eastern region. Finally, the effect of government environmental subsidies to promote enterprise green innovation mainly exists in non-SOE.

Suggestions

The research in this paper is conducive to deepening the theoretical understanding of the impact of government environmental protection subsidies on corporate green innovation, expanding policy support, and other related research. The results can also help the government implement the positive advantages of environmental protection subsidies through positive incentives to promote corporate green innovation, achieve green development, and provide useful policy insights.

First, the positive incentive role of government environmental protection subsidies should be emphasized. This paper's results indicate that government environmental subsidies can significantly promote enterprise green innovation. Therefore, the government should clarify its functional positioning, establish a perfect green development incentive system, and increase the financial support for enterprise energy saving, emission reduction, and green innovation projects. The method of government subsidies should also be improved to increase the role of government subsidies in promoting green innovation. The government should implement more targeted guidance and incentive policies, such as increasing subsidy policies' depth and breadth, based on carefully considering ecological and environmental protection requirements. These policies can be implemented to respond to the level of green innovation and the different stages of R&D of enterprises, as well as in the light of their actual situation. At the same time, enterprises should change the direction of green innovation and improve the level of green innovation promptly. They should take the initiative to seek government environmental protection subsidies to meet the inputs of the green innovation process according to the requirements of the relevant documents on issuing government environmental protection subsidies. Furthermore, enterprises should expand their green technological innovation chain by increasing capital, intellectual and equipment inputs, and increase the supply of high-quality products that meet ecological and environmental standards in the change of production methods.

Second, the government should establish an effective information platform with enterprises to realize the openness, transparency, and

sharing of government subsidy and enterprise environmental information. This approach will allow the government to avoid the asymmetry of information between the government and enterprises caused by weak supervision, an incomplete legal system, and a lack of transparency in the subsidy process. Enterprises should also take the initiative to establish a reasonable information disclosure mechanism, allowing external investors to evaluate and invest in enterprises based on the development status of technological innovation and enterprise performance, thus solving the problem of enterprise financing constraints. The government should also support enterprises in green innovation technology and knowledge to stimulate their green innovation potential. Moreover, the government should strengthen publicity efforts to deepen the national green innovation development concept. Through the propaganda and interpretation of various guidelines and policies, enterprises can improve their understanding of the direction, objectives, and requirements of national green innovation development and spontaneously adjust the means of green technology development to adapt to social and environmental economic development. Enterprises should also take the initiative to understand the overall national development policy, conform to the requirements of the times, grasp the market development trend, and promote green innovation, research, and development of practical, efficient, and environmentally friendly green products. Furthermore, the government should set up a team of experts to review enterprises' innovative projects or achievements, improve screening capabilities, and subsidize enterprises in echelons according to the difficulty and value of green innovation. Additionally, the review of the government's environmental subsidy program should be enhanced to reduce enterprises' rent-seeking possibilities. The government should establish a monitoring system to track the flow of subsidized funds to ensure they are used for green innovation. Enterprises should also establish a scientific and effective internal monitoring system to eliminate corruption and waste and ensure government environmental subsidies are effectively used.

Third, the empirical results indicate that industrial policy at the central level is more conducive to strengthening the role of government environmental subsidies in promoting green innovation. Therefore, the central government should flexibly utilize industrial policy to promote green innovation and the development of green industries. In formulating industrial policy, local governments should cooperate with the overall layout of the central industrial policy and actively respond to the implementation of the central industrial policy. Such policies should be adapted to local conditions, giving full consideration to the actual situation of the local community and further refinement of the industrial policy. Thus, an industrial policy aligned with the local realities maximizes resource allocation function to strengthen the government's environmental protection subsidies to promote enterprise green innovation. The government should also avoid homogenizing administrative directives and not subsidize environmental protection for all enterprises without discrimination but should implement a differentiated subsidy policy. The government should also consider the regional and property rights differences of enterprises and realize the precise positioning of the target of subsidies. A reasonable government subsidy intensity interval should be set, and the mechanism should be optimized. Enterprises should grasp the policy benefits of green innovation, design enterprise R&D planning in line with the industrial policy issued by the government as much as possible, and reasonably utilize the government's R&D subsidy resources. These practices can lead enterprises to conduct high-quality green innovation.

Declaration of Competing Interest

The authors declare no competing interests.

Acknowledgement

This research was funded by the National Natural Science Foundation of China [Grant No. 72073071], the Qing Lan Project of Jiangsu Province [Grant No. D202062045], and the Postgraduate Research & Practice Innovation Program of Jiangsu Province [Grant No. KYCX22_2109].

References

Acharya, V. V., Baghai, R. P., & Subramanian, K. V. (2014). Wrongful discharge laws and innovation. *The Review of Financial Studies, 27*(1), 301–346. doi:10.1093/rfs/hht009.

Bai, J. (2011). Are government R&D subsidies in China? Evidence from large and medium enterprises. *China Economic Quarterly, 10*(4), 1375–1400. doi:10.13821/j.cnki.ceq.2011.04.009.

Bai, Y., Song, S., Jiao, J., & Yang, R. (2019). The impacts of government R&D subsidies on green innovation: Evidence from Chinese energy-intensive firms. *Journal of Cleaner Production, 233*, 819–829. doi:10.1016/j.jclepro.2019.06.107.

Bi, K., Huang, P., & Wang, X. (2016). Innovation performance and influencing factors of low-carbon technological innovation under the global value chain: A case of Chinese manufacturing industry. *Technological Forecasting and Social Change, 111*, 275–284. doi:10.1016/j.techfore.2016.07.024.

Boldrin, M., & Levine, D. K. (2004). Rent-seeking and innovation. *Journal of Monetary Economics, 51*(1), 127–160. doi:10.1016/j.jmoneco.2003.07.006.

Dimos, C., & Pugh, G. (2016). The effectiveness of R&D subsidies: A meta-regression analysis of the evaluation literature. *Research Policy, 45*(4), 797–815. doi:10.1016/j.respol.2016.01.002.

Ebrahimi, P., & Mirbargkar, S. M. (2017). Green entrepreneurship and green innovation for SME development in market turbulence. *Eurasian Business Review, 7*(2), 203–228. doi:10.1007/s40821-017-0073-9.

Feldman, M. P., & Kelley, M. R. (2006). The ex-ante assessment of knowledge spillovers: Government R&D policy, economic incentives and private firm behavior. *Research Policy, 35*(10), 1509–1521. doi:10.1016/j.respol.2006.09.019.

Guo, Y., Xia, X., Zhang, S., & Zhang, D. (2018). Environmental regulation, government R&D funding and green technology innovation: Evidence from China provincial data. *Sustainability, 10*(4), 940. doi:10.3390/su10040940.

Gupta, H., & Barua, M. K. (2018). A framework to overcome barriers to green innovation in SMEs using BWM and Fuzzy TOPSIS. *Science of the Total Environment, 633*, 122–139. doi:10.1016/j.scitotenv.2018.03.173.

Han, F., & Mao, X. (2023). Impact of intelligent transformation on the green innovation quality of Chinese enterprises: Evidence from corporate green patent citation data. *Applied Economics*, 1–18. doi:10.1080/00036846.2023.2244256.

Häussler, C., Harhoff, D., & Müller, E. (2012). *To be financed or not…-The role of patents for venture capital-financing*. ZEW-Centre for European Economic Research Discussion Paper.

Hewitt-Dundas, N., & Roper, S. (2010). Output additionality of public support for innovation: Evidence for Irish manufacturing plants. *European Planning Studies, 18*(1), 107–122. doi:10.1080/09654310903343559.

Hu, A. G. (2001). Ownership, government R&D, private R&D, and productivity in Chinese industry. *Journal of Comparative Economics, 29*(1), 136–157. doi:10.1006/jcec.2000.1704.

Huang, J. W., & Li, Y. H. (2017). Green innovation and performance: The view of organizational capability and social reciprocity. *Journal of Business Ethics, 145*(2), 309–324. doi:10.1007/s10551-015-2903-y.

Huang, Z., Liao, G., & Li, Z. (2019). Loaning scale and government subsidy for promoting green innovation. *Technological Forecasting and Social Change, 144*, 148–156. doi:10.1016/j.techfore.2019.04.023.

Jiang, Z., Xu, C., & Zhou, J. (2023). Government environmental protection subsidies, environmental tax collection, and green innovation: Evidence from listed enterprises in China. *Environmental Science and Pollution Research, 30*, 4627–4641. doi:10.1007/s11356-022-22538-3.

Kaplan, S. N., & Zingales, L. (1997). Do investment-cash flow sensitivities provide useful measures of financing constraints? *The Quarterly Journal of Economics, 112*(1), 169–215. doi:10.1162/003355397555163.

Lee, K. H., & Min, B. (2015). Green R&D for eco-innovation and its impact on carbon emissions and firm performance. *Journal of Cleaner Production, 108*, 534–542. doi:10.1016/j.jclepro.2015.05.114.

Lerner, J. (1996). The government as venture capitalist: The long-run effects of the SBIR program. NBER working paper. https://doi.org/10.3386/w5753

Li, L., Chen, J., Gao, H., & Xie, L. (2019). The certification effect of government R&D subsidies on innovative entrepreneurial firms' access to bank finance: Evidence from China. *Small Business Economics, 52*(1), 241–259. doi:10.1007/s11187-018-0024-6.

Li, T., Shi, Z., Han, D., & Zeng, J. (2023). Agglomeration of the new energy industry and green innovation efficiency: Does the spatial mismatch of R&D resources matter? *Journal of Cleaner Production, 383*, 135453. doi:10.1016/j.jclepro.2022.135453 2023.

Li, Z., Liao, G., Wang, Z., & Huang, Z. (2018). Green loan and subsidy for promoting clean production innovation. *Journal of Cleaner Production, 187*, 421–431. doi:10.1016/j.jclepro.2018.03.066.

Lin, H., Zeng, S. X., Ma, H. Y., & Qi, G. Y. (2014). Can political capital drive corporate green innovation? Lessons from China. *Journal of Cleaner Production, 64*, 63–72. doi:10.1016/j.jclepro.2013.07.046.

Liu, E. (2019). Industrial policies in production networks. *The Quarterly Journal of Economics, 134*(4), 1883–1948. doi:10.1093/qje/qjz024.

Liu, J., Zhao, M., & Wang, Y. (2020). Impacts of government subsidies and environmental regulations on green process innovation: A nonlinear approach. *Technology in Society, 63*, 101417. doi:10.1016/j.techsoc.2020.101417.

Marquis, C., & Qian, C. (2014). Corporate social responsibility reporting in China: Symbol or substance? *Organization Science, 25*(1), 127–148. doi:10.1287/orsc.2013.0837.

Meuleman, M., & De Maeseneir, W. (2012). Do R&D subsidies affect SMEs' access to external financing? *Research Policy, 41*(3), 580–591. doi:10.1016/j.respol.2012.01.001.

Olley, S., & Pakes, A. (1992). The dynamics of productivity in the telecommunications equipment industry. *NBER Working paper*. https://doi.org/10.3386/w3977

Polzin, F. (2017). Mobilizing private finance for low-carbon innovation—A systematic review of barriers and solutions. *Renewable and Sustainable Energy Reviews, 77*, 525–535. doi:10.1016/j.rser.2017.04.007.

Saunila, M., Ukko, J., & Rantala, T. (2018). Sustainability as a driver of green innovation investment and exploitation. *Journal of Cleaner Production, 179*, 631–641. doi:10.1016/j.jclepro.2017.11.211 2018.

Takalo, T., & Tanayama, T. (2010). Adverse selection and financing of innovation: Is there a need for R&D subsidies? *Journal of Technology Transfer, 35*(1), 16–41. doi:10.1007/s10961-009-9112-8.

Takalo, T., Tanayama, T., & Toivanen, O. (2013). Market failures and the additionality effects of public support to private R&D: Theory and empirical implications. *International Journal of Industrial Organization, 31*(5), 634–642. doi:10.1016/j.ijindorg.2013.02.002.

Tassey, G. (2004). Policy issues for R&D investment in a knowledge-based economy. *The Journal of Technology Transfer, 29*(2), 153–185. doi:10.1023/B:JOTT.0000019536.59816.ae.

Wallsten, S. J. (2000). The effects of government-industry R&D programs on private R&D: The case of the small business innovation research program. *The RAND Journal of Economics, 31*(1), 82–100. doi:10.2307/2601030.

Wei, J., Li, Y., Liu, X., & Du, Y. (2022). Enterprise characteristics and external influencing factors of sustainable innovation: Based on China's innovation survey. *Journal of Cleaner Production, 372*, 133461. doi:10.1016/j.jclepro.2022.133461.

Wei, Z., Shen, H., Zhou, K. Z., & Li, J. J. (2017). How does environmental corporate social responsibility matter in a dysfunctional institutional environment? Evidence from China. *Journal of Business Ethics, 140*(2), 209–223. doi:10.1007/s10551-015-2704-3.

Wu, A. (2017). The signal effect of government R&D subsidies in China: Does ownership matter? *Technological Forecasting and Social Change, 117*, 339–345. doi:10.1016/j.techfore.2016.08.033.

Xia, L., Gao, S., Wei, J., & Ding, Q. (2022). Government subsidy and corporate green innovation-Does board governance play a role? *Energy policy, 161*, 112720. doi:10.1016/j.enpol.2021.112720.

Xu, J., Liu, F., & Shang, Y. (2021). R&D investment, ESG performance and green innovation performance: Evidence from China. *Kybernetes, 50*(3), 737–756. doi:10.1108/K-12-2019-0793 2021.

Zhou, K., Tao, Y., Wang, S., & Luo, H. (2023). Does green finance drive environmental innovation in China? *Emerging Markets Finance and Trade, 59*(8), 2727–2746. doi:10.1080/1540496X.2023.2190847.