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Original Research

Government Subsidy and Enterprise Green Innovation: Evidence from Chinese Enterprises

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Abstract

Green innovation is significant in realizing enterprises' green transformation and high-quality economic development. Using the data of China's Shanghai and Shenzhen A-share listed companies from 2009 to 2019, this study divides enterprise green innovation into substantive and strategic innovations and analyzes the impact of government subsidies on green innovation and the mediating role of R&D investment. The research results show that: (1) Government subsidies promote enterprises' substantive and strategic green innovation, with the impact on substantive innovation being more significant. (2) Government subsidies can help stimulate enterprises to increase R&D investment, promoting green innovation. R&D investment is an important intermediary between government subsidies and enterprise green innovation. (3) R&D investment has a more significant mediating effect on the green innovation of state-owned enterprises, large enterprises, non-polluting industries, and enterprises in non-carbon emission trading pilot areas. Therefore, the government should formulate differentiated subsidy policies according to enterprises' internal and external conditions and improve the carbon emission trading system. In contrast, enterprises should actively adapt to policy changes and rationally use policy resources.

Keywords: government subsidies, green innovation, R&D investment

Introduction

China is a big resource-consuming country. Extensive economic development in the past has put a lot of pressure on the environment, and it can hardly meet the requirements of sustainable development. Regarding industrial development, there are also problems of high pollution and high emissions [1]. With the continuous and in-depth development of the economy, the importance of ecological civilization construction has become increasingly prominent. In 2018, General Secretary Xi Jinping proposed at the National Conference on Ecological and Environmental Protection to accelerate the formation of a green development model, significantly reduce pollutant emissions from the source, and regard green development as a fundamental strategy to solve environmental pollution problems and improve the quality of the ecological environment. Vigorously promoting green technology innovation is the fundamental path to achieving

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green development. Unlike traditional technological innovation, green technological innovation adopts new low-carbon technologies and new green concepts to achieve economic benefits while significantly reducing environmental pressure [2].

Well-known domestic and foreign companies, such as Siemens and BYD, have achieved a win-win situation regarding environmental and economic benefits through green technology innovation and have become one of the world's top 100 sustainable development companies. As a breakthrough in economic transformation and development, green innovation plays a key role in improving economic quality, efficiency, and green development. However, the research and development cycle of green innovation is long, and the cost is high. Without institutional incentives, enterprises often lack enthusiasm for green innovation.

So, achieving harmonious coexistence between ecological civilization construction, economic development, and strong financial support is indispensable. Government fiscal expenditure is an important source of funds to promote the construction of ecological civilization and sustainable economic development, and government subsidies, as the main part of fiscal expenditure, have an important impact on enterprises' green innovation behavior.

Previous literature has focused on government subsidies and green innovation. This paper also innovates based on this and puts forward the problems China faces while pursuing green development and ecological civilization construction. It mainly faces the following three problems: (1) Difficulties in green innovation: The long research and development cycle and high cost of green technology innovation may become a challenge for enterprises in green innovation. (2) Lack of incentives: Without institutional incentives, enterprises may lack incentives for green innovation, resulting in insufficient investment in environmental protection. (3) Lack of government support: To realize the harmonious coexistence of ecological civilization construction and economic development, strong support from the government is needed, especially in finance. Some suggestions are given to promote green technology innovation at the government, enterprise, and social levels. The comprehensive implementation of these measures will help promote sustainable economic development and improve environmental quality. The innovation of this article lies in dividing enterprise innovation into two parts: strategic innovation and substantive innovation. Multiple heterogeneity methods were selected to describe the impact of government subsidies and green innovation on enterprises in as much detail as possible.

Literature Review

The literature review focuses on the impact of government subsidies on green innovation, the impact of government subsidies on different types of enterprises, the factors influencing green innovation in enterprises, and the relationship between government subsidies, research and development investment, and green innovation in enterprises. This analysis aims to sort out and summarize existing research results, providing a foundation for subsequent research.

Research on the Impact of Government Subsidies on Green Innovation

With the increasingly prominent role of government R&D subsidies in promoting green innovation in enterprises, the academic community is increasingly exploring their effects. Although Qi and Guo pointed out differences in academic views on the impact of government subsidies on corporate innovation effectiveness, this topic undoubtedly attracted widespread attention [3].

On the one hand, some studies have shown that government subsidies can motivate enterprises to engage in green innovation. For example, Li (2021) [4] pointed out that government subsidies can directly and indirectly improve green innovation in various regions. Yan (2019) [5], Tian and Liu (2021) [6], and Zhao et al. (2021) [7] also confirmed the positive impact of government subsidies on enterprise green innovation. Ye (2021) [8] found that government subsidies promote green innovation mainly by relieving restrictions on green utility model patents and reducing environmental externalities. Government subsidies can alleviate the financing difficulties of private enterprises, large enterprises, and enterprises with low R&D investment [9]. Dimos et al. (2016) [10] found through meta-analysis that government R&D subsidies can alleviate market failures and improve the R&D activities of subsidized enterprises. Wang et al. (2021) [11] revealed through their research on listed companies that government subsidies play a mediating role between green development and research and development expenditures, promoting green innovation. Tian and Liu (2019) [12] found that government subsidies significantly increase green R&D investment in the pharmaceutical industry. Wu et al. (2021) [13] used listed companies as an example to point out that government subsidies stimulate R&D enthusiasm.

Gao Xia et al. (2022) [14] used fuzzy set analysis and found that government subsidies are crucial for regional green technology innovation. Muscleman et al. (2012) [15] found in a comparative study that subsidized small and medium-sized enterprises are more likely to obtain external financing and sustain innovation. Liu (2023) [16] used A-shares as a sample to confirm that government subsidies positively impact green innovation performance and indirectly affect research and development investment. Jiang and Chen (2022) [17] believe that government subsidies directly promote green innovation in listed companies, and ESG is mediating. Based on the theory of

information asymmetry, Liu et al. (2022) [18] showed that subsidies significantly impact green innovation in enterprises with high social responsibility. Zhang and Chen (2022) [19] found that government subsidies enhance green technology innovation and positively interact with environmental regulations. Gu and Jiang (2022) [20] pointed out that subsidies are the key to promoting green technology innovation in heavily polluting industries.

On the other hand, some studies believe that government subsidies can solve market failure problems in R&D innovation activities, such as knowledge spillover and non-excludability [21]. Sun and Wang (2017) [22] took high-tech enterprises as an example and found that government subsidies and R&D investment were significantly positively correlated with innovation performance. Wang and Zhang (2019) [23] found that a high innovation subsidy rate can promote enterprises' green innovation evolution speed.

Some other scholars have found that government subsidies may inhibit the innovation motivation of enterprises, forming an inverted U-shaped relationship. Mao and Xu (2016) [24] state that excessive government subsidies reduce enterprises' risk appetites, while moderate subsidies can enhance risk tolerance. Shi and Li (2021) [25] found a U-shaped relationship between the scale of government subsidies and enterprise innovation capabilities. Still, this relationship only applies to large enterprises with strong intellectual property protection capabilities. Zhang and Zhao (2022) [26] proposed that government subsidies have a significant U-shaped effect on the green innovation of heavily polluting enterprises. Zhang et al. (2018) [27] analyzed the data of high-technological enterprises in Zhong Guan Cun. They concluded that although government subsidies have increased the innovation investment and patent applications of enterprises, they have also led to a "crowding out effect", that is, the decline in the independent innovation capabilities of subsidized enterprises. Liu et al. (2019) [28] believe that environmental regulation and government innovation subsidies do not linearly affect enterprises' green product innovation. Government subsidies may reduce enterprises' R&D investment, affecting innovation behavior. Busom (2000) [29] and Kaiser (2006) [30] believed that excessive government subsidies would reduce the scale of R&D investment in large state-owned enterprises. Wang et al. (2022) [31] used agency theory to analyze listed manufacturing companies and found that excessive government R&D subsidies may encourage companies to engage in unnecessary donation behavior, which weakens the positive impact of subsidies on green innovation. Yi et al. (2021) [32] found that sustained government R&D funding support for high-tech enterprises can exacerbate dependence on government resources, leading to a shift in resource focus and ultimately reducing innovation efficiency. Lu et al. (2022) [33] constructed a dynamic game model based on peer effects between government subsidies and enterprise R&D investment, revealing the difficulties enterprises may face under high subsidies.

Research on the Impact of Government Subsidies on Different Types of Enterprises

From the perspective of resource acquisition and information transmission, Yang et al. (2015) [34] found that, compared with state-owned enterprises, government subsidies have a greater effect on promoting the innovation performance of private enterprises, and the promotion effect of government subsidies is more significant in regions with a lower level of factor distortion. Wang (2015) [35] studied China's high-tech enterprises, considered differences in ownership and regions, and concluded that government subsidies affect R&D investment and innovation activities differently. Sun et al. (2017) [36] found that government R&D subsidies have a greater impact on private enterprises with weak market conditions. Tong and Wu (2023) [37] observed that the larger the enterprise size, the stronger the innovation promotion effect of government subsidies. Pless (2022) [38] pointed out that small businesses benefit more from government subsidies. Based on provincial data, Li et al. (2022) [39] found that R&D subsidies increased R&D investment in small and non-state-owned enterprises, while large and state-owned enterprises were less affected. Research by Luo (2019) [40] found that the relationship between enterprise size and the effectiveness of R&D subsidies presents a dual threshold. Afcha et al. (2022) [41] used Spain as an example to demonstrate the impact of R&D personnel quality-determining subsidies on innovation, analyzed the manufacturing industry, and found that government subsidies impact manufacturing at different technological levels.

Research on the Influencing Factors of Enterprise Green Innovation

There are also many uncertain factors in enterprises improving their innovation capabilities, such as R&D funds and transnational scale. Therefore, many scholars have incorporated the influencing factors of green innovation into other research fields. Executives' backgrounds aid high-tech firms in accessing innovation subsidies and boosting R&D funds [42]. Green bond pricing influences corporate green innovation [43]. Environmental regulations have variable effects on green innovation, with environmental subsidies impacting green patents [44]. Emission trading policies encourage green innovation, especially among non-state-owned enterprises [45]. Digitalization significantly promotes green tech innovation in polluting industries [46]. Executives' green awareness positively impacts enterprise green innovation and production [47]. Low-carbon city policies enhance green tech innovation in high-carbon emission companies, supporting the "Porter Hypothesis" [48]. Patent applications reflect enterprise

innovation behavior and green credit improves innovation capabilities [49].

Financing is a significant obstacle to green innovation. Guo (2019) [50] pointed out that environmental administrative penalties have a dual impact on green innovation: mild penalties have no effect; severe penalties suppress green innovation; and local environmental regulations have limited and diminishing effects. Fan et al. (2020) [51] found that command-based environmental regulations have no significant impact on green innovation initially, but exceeding the threshold can promote green transformation. Tao et al. (2021) [52] observed that the environmental target responsibility system has improved the level of green innovation but has affected the quality of innovation. Li et al. (2021) [53] analyzed the central environmental inspection and found that its positive effect exceeded the cost, promoting green innovation in heavily polluting enterprises. Zhang et al. (2021) [54] analyzed media reports and believed negative reporting motivates companies to strengthen innovation. According to research by Guan et al. (2018) [55] and Hou et al. (2021) [56], stakeholders and market pressures are positively promoting the green transformation of enterprises.

Research on Government Subsidies, R&D Investment, and Green Innovation in Enterprises

Government subsidies not only have a direct effect on enterprises' green innovation behavior but may also have an indirect effect on R&D investment in their innovation process. Enterprise R&D investment includes private R&D investment and government-subsidized R&D investment [57]. Li et al. (2018) [58] pointed out that R&D investment is a positive intermediary between environmental regulation and green technology innovation capabilities. Research by Zhang et al. (2018) [59] shows that government R&D funding and enterprise R&D investment can promote innovation performance. They used a pairing method to examine the relationship between government subsidies and R&D investment based on a sample of Spanish companies. Still, their research further distinguished the company's size and the industry's technical level. Xiong et al. (2020) [60] believe that R&D investment is the core of enterprise innovation, and under different influencing factors, there will be regional and industry heterogeneity. Wang and Zhou (2018) [61] found that industrial support policies promote R&D investment and innovation in wind power enterprises, with R&D investment partially mediating the impact of policies on innovation performance. The signaling effect of government subsidies can improve enterprises' innovation performance, and R&D investment plays an intermediary role in this process. The model analysis by Mei and Luo (2020) [62] shows that fiscal subsidies positively correlate with enterprises' innovation performance, especially in non-state-owned enterprises, where R&D investment plays a mediating role. Liu, Shen, and He (2021) [63] believe that pre-subsidy directly and indirectly promotes innovation performance through research and development investment, while post-subsidy directly promotes but has a limited impact on research and development investment.

To sum up, the impact of government subsidies on enterprise green innovation is moderated by various factors, including enterprise ownership, regional characteristics, environmental regulations, and executive background. However, due to the different samples and measurement methods used in different studies, the research results of micro-enterprise entities may vary. When discussing the relationship between government subsidies and enterprises' green innovation, it is necessary to comprehensively consider factors of multiple dimensions and conduct analysis in combination with specific situations. Therefore, further research is needed on the direct relationship between government subsidies and enterprise green innovation. This paper discusses the impact of government subsidies on enterprises' green innovation from the micro level and explores whether R&D investment plays an intermediary role in the process of government subsidies on enterprises' green innovation based on the data of Shanghai and Shenzhen A-share listed companies from 2009 to 2019. This study can enrich the relevant literature on enterprise green innovation and contribute a certain theoretical basis to stimulate enterprise green innovation and improve economic development benefits.

Theoretical Analysis and Research Hypothesis

The Impact of Government Subsidies on the Green Innovation of Enterprises

Green innovation can not only bring economic value but also alleviate the negative impact on the environment. According to Li and Zheng (2016) [64], microenterprises will adopt two different innovative behaviors in the face of macro policies. One is the substantive innovation behavior adopted to promote technological progress to gain a competitive advantage, and the other is the strategic innovation behavior adopted to meet government requirements and regulatory purposes. The research also shows that government subsidies significantly impact strategic green innovation more than substantive green innovation [65]. Aghion et al. (2009) [66] believed that enterprises' green innovation activities have double externalities, which affect their innovation efficiency. According to the theory of externalities, externalities will lead to market failure, leading to an unreasonable allocation of resources and affecting the optimal allocation of social resources. Because enterprises may produce environmental pollution in production, green innovation requires higher input costs and faces greater risks, so it has negative externalities.

To achieve the optimal allocation of resources, externalities need to be internalized. That can be achieved through the Coase theorem, that is, by negotiating clear property rights. Another way is government intervention, including government subsidies, sewage charges, and other measures. A Pareto optimal state of social resources is achieved by equalizing economic actors' private costs (benefits) with the social costs (benefits). According to information transmission theory, when there is information asymmetry, the party with superior information will send credible signals to the inferior party to facilitate the conclusion of the transaction. The government's subsidy behavior is also a kind of information transmission. It can convey to the outside world that enterprise innovation has a certain investment value and is recognized by the government, thereby increasing the financing willingness of other parties.

In addition, the government subsidy also represents a policy orientation, indicating that the government believes that the company has broad development prospects in the field of R&D. This signal will increase the investment scale and confidence of investors and is beneficial to the green innovation of enterprises. According to innovation theory, governments can promote innovation and economic growth by formulating appropriate innovation policies. Some scholars believe that larger enterprises have more obvious advantages in R&D and innovation, and as market leaders, they can also provide guarantees for the innovation output of enterprises. However, some scholars believe that enterprises face high risks and long cycles in the process of technological innovation, which may lead to market failure. Therefore, government intervention is needed to stimulate enterprises' enthusiasm for innovation. Based on the above research, the following hypotheses can be put forward:

H1: Government subsidies have a direct effect on promoting both substantial green innovation and strategic green innovation.

The Mediating Effect of R&D Investment between Government Subsidies and Green Innovation in Enterprises

The innovation activities of enterprises can be analyzed from the perspective of R&D investment. From a micro level, R&D investment reflects the commitment of enterprises to their future development, encapsulating both their aspirations and the practical challenges they face, such as funding constraints. Government subsidies play a critical role in this ecosystem, serving not just as a recognition of an enterprise's potential for development but also as a crucial financial boost to stimulate further investment in innovation. They offer a significant avenue for enterprises to secure external financing with reduced cost, enabling them to allocate internal funds more effectively according to their development plans.

Xiong et al. (2016) [67], from the perspective of the enterprise life cycle, found that government subsidies positively correlate with the R&D intensity of "start-up enterprises", and an "inverted U-shaped" correlation with growth-stage enterprises has a certain motivating effect. Wang and Wang (2020) [68] found that government subsidies not only alleviate the problem of enterprises' financing difficulties but also increase the intensity of enterprises' R&D investment. However, under the two threshold variables of debt financing and equity financing, the relationship between government subsidies and R&D investment is "U" shaped only when the financing structure is reasonable. Dong et al. (2016) [69] selected regional innovation data from 2010 to 2014. They found a complete mediating effect between government investment and regional innovation performance in enterprises' R&D investments. The government can promote innovation performance in the public R&D sector by investing in and subsidizing green innovation.

Enterprise R&D is not only a form of investment behavior but also benefits from the "knowledge spillover" effect, which provides the latest guidance or technical support in related fields, thereby reducing R&D costs. Government subsidies and support not only help enterprises reduce R&D opportunity costs and alleviate the pressure of sunk costs but also enhance their willingness to innovate, further encouraging them to expand their R&D investments. This enables companies to reassess high-risk, high-cost projects with more financial confidence. Consequently, enterprises receiving government subsidies can afford to experiment with and invest in new technologies and innovative projects while maintaining financial stability. In summary, from the perspective of knowledge spillovers, government investment and subsidies in green innovation positively impact public R&D departments and enterprises. Zulficarf and Thapa (2018) [70] believe financing issues have become an important obstacle to green innovation. From the perspective of financing constraints, government subsidies will make it easier for enterprises to obtain external financing, and external financing can enable enterprises to increase effective R&D activities. Investment in R&D activities is necessary for enterprises to carry out green innovation. Under the incentive of subsidies, enterprises will have stronger R&D motivation and invest more funds in green innovation. Therefore, this paper proposes the following assumptions:

H2: R&D investment mediates between government subsidies, enterprise substantive innovation, and strategic innovation.

Materials and Methods

Data

This paper uses China's Shanghai and Shenzhen A-share listed companies from 2009 to 2019 as a research

sample. The enterprise green patent data comes from the China Issues Research Database (CNRDS). Song et al. (2022) [45] explain the reliability of the research conclusions, referring to the data processing method. This paper has carried out the following processing on the data: (1) remove the financial industry and S.T. and P.T. listed companies; (2) remove companies that have been delisted midway; and (3) the main variables have been shrink-tailed by 1%. Through the above processing, 18041 sample observations were finally obtained.

Dependent Variable

This paper refers to Li and Zheng (2016) [64], who divide the green innovation behavior of enterprises into substantive green innovation and strategic green innovation. Substantive green innovation refers to high-level innovation that can enhance the innovation ability of enterprises and achieve sustainable social development. Green invention patents have a long R&D cycle and high technical content, so the number of green invention patent applications (GreInvia) measures a company's substantive innovation. Utility model patents have low technical content and relatively loose review standards. They are usually a strategic behavior of "seeking support". Therefore, the number of green utility model patent applications (GreUmia) measures enterprise strategic green innovation.

Independent Variables

The key independent variable in this paper is the government subsidy (Gov). According to previous studies, it is measured by the logarithm of the government subsidy in the notes to each company's financial statements. The intermediary variable is the R&D investment intensity of enterprises. To control the influence of other factors on the green innovation behavior of enterprises, this paper selects a series of control variables, including enterprise size (Size), enterprise age (Age), asset-liability ratio (Lev), return on assets (ROA), cash flow (Cashflow), operating income growth rate (Growth), Tobin's Q value (TobinQ), the shareholding ratio of the largest shareholder (Top1), and also introduces the time dummy variable year (Year). The names, symbols, and descriptions of the main variables used in this paper's empirical research are shown in Table 1.

Model Specification

To verify the impact of government subsidies on enterprise green innovation and the specific mechanism, this paper constructs a regression model in two steps. At the same time, to reduce endogenous problems, this paper used lagged government subsidies.

First, this paper establishes a benchmark regression model with government subsidies as the core explanatory variable to verify the direct impact of government subsidies on enterprise green innovation.

Table 1. Definition and description of main variables.

Variable	Variable explanation	Variable symbol	Variable specification
Explained variable	Number of green invention patent applications	GreInvia	The natural logarithm of the number of green invention patent applications in the current period
	Number of green utility model patent applications	GreUmia	The natural logarithm of the number of green utility model patent applications in the current period
Explanatory variables	Government subsidies	Pubsubs	The natural logarithm of the subsidy received in the current period
Mediator variable	R&D investment intensity	RD	R&D expenditure/operating income
Control variable	Company Size	size	Natural logarithm of total annual assets
	business age	Age	ln (year of the year - year of establishment of the company + 1)
	Assets and liabilities	Lev	Total liabilities at the end of the year divided by total assets at the end of the year
	Return on Assets	ROA	Net profit/average balance of total assets
	cash flow	Cashflow	Net cash flow from operating activities divided by total assets
	Operating Income Growth Rate	Growth	(Operating income of the current year/Operating income of the previous year)-1
	Tobin's Q	TobinQ	(tradable market value + number of non-tradable shares × net assets per share + book value of liabilities) / total assets
	Shareholding ratio of the largest shareholder	Top1	Number of shares held by the largest shareholder/total number of shares
	Years	Year	Time dummy variable

$$Innovation_{i,t}\left(\text{GreInvia}_{i,t}, \text{GreUmia}_{i,t}\right) = \beta_0 + \beta_1 Pubsub_{i,t-1} + \varepsilon_{i,t} \quad (1)$$

$$Innovation_{i,t}\left(\text{GreInvia}_{i,t}, \text{GreUmia}_{i,t}\right) = \alpha_0 + \alpha_1 Pubsub_{i,t-1} + \alpha_2 Control_{i,t} + \varepsilon_{i,t} \quad (2)$$

Model (1) directly investigates the impact of government subsidies on enterprises. *i* represents individual enterprises, *t* represents years, *Control* represents control variables, and *ε* indicates the error term.

The second step is to test the intermediary role of R&D investment between government subsidies and enterprises.

$$RD_{i,t} = \gamma_0 + \gamma_1 Pubsub_{i,t} + \gamma_2 Control_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$Innovation_{i,t}\left(\text{GreInvia}_{i,t}, \text{GreUmia}_{i,t}\right) = \varphi_0 + \varphi_1 Pubsub_{i,t-1} + \varphi_2 RD_{i,t} + \varphi_3 Control_{i,t} + \varepsilon_{i,t} \quad (4)$$

The above models (2) - (4) investigate the intermediary role of R&D investment levels in government subsidies on enterprises' green innovation. *i* represents individual enterprises, *t* represents the year, *Control* represents the control variable, and *ε* represent the error term. First, test model (2). If the coefficient α_1 is significant, then continue to test (3) and (4). If α_1, γ_1 and φ_2 are all significant, and φ_1 is also significant, R&D has a partial mediation effect. If $\varphi_1$is not significant however, this indicates that R&D has a complete mediation effect.

Results

Descriptive Statistics

Table 2 shows the descriptive statistical analysis results of the main variables. It can be seen from Table 2 that the average number of green invention patent applications by enterprises is 0.57, the minimum value is 0, and the maximum value is 6.82, indicating that there are large differences in the number of green invention patent applications among enterprises. The average number of green utility model patent applications by enterprises is 0.60, and there is also a large gap between the minimum and maximum values. Some listed companies have not applied for green invention and utility model patents, reflecting that China's overall level of green innovation is still low. The minimum value of R&D investment is also 0, indicating that some enterprises do not pay enough attention to green innovation and do not invest enough in R&D. The average value of government subsidies is 2.290, and the range of subsidies is from 0 to 8.357, indicating that many enterprises have received financial support from the government.

Benchmark Regression Model

The regression results in Table 3 show that government subsidies significantly positively impact the number of green invention patents and utility model patents, indicating that government subsidies can motivate enterprises to carry out strategic green innovation and substantive green innovation. However, the impact coefficient of government subsidies on green invention patents of enterprises is greater than that of utility model patents, which shows that government subsidies are more inclined to encourage enterprises

Table 2. Descriptive statistics.

Variable	Observations	Average	Standard deviation	Minimum value	Maximum value
Lev	18041	0.400	0.209	0.008	3.919
ROA	18041	0.046	0.072	-1.872	0.669
Cashflow	18041	0.044	0.073	-1.938	0.661
Growth	18041	0.404	15.157	-0.985	1878.372
TobinQ	18041	2.111	1.537	0.153	56.813
Top1	18041	0.349	0.147	0.022	0.891
GreInvia	18041	0.570	0.941	0	6.820
GreUmia	18041	0.602	0.942	0	6.387
Pubsubs	18041	2.290	1.394	0	8.357
RD	18041	0.042	0.053	0	1.694
Size	18041	21.985	1.271	17.879	28.341
Age	18041	2.739	0.398	0.693	4.127

to carry out substantive green innovations rather than just increasing the number of utility model patents. Suppose an enterprise produces some utility model patents with low technological content, small competitive advantages, and no substantial innovation results. In that case, it may be detrimental to the enterprise's long-

Table 3. Baseline regression results.

	(1)		(2)	
Variable	GreInvia	GreUmia	GreInvia	GreUmia
Pubsubs	0.263 *** (0.008)	0.230 *** (0.008)	0.130 *** (0.008)	0.080 *** (0.008)
Size			0.263 *** (0.011)	0.250 *** (0.011)
Cashflow			-0.770 *** (0.123)	-0.722 *** (0.108)
Lev			0.0681 (0.046)	0.449 *** (0.046)
Firm			-0.190 *** (0.023)	-0.231 *** (0.023)
Age			0.5335 *** (0.117)	0.721 *** (0.108)
ROA			0.7335 *** (0.119)	0.622 *** (0.109)
Top1			-0.446 *** (0.055)	-0.220 *** (0.054)
TobinQ			0.031 *** (0.006)	0.007 (0.004)
Year	YES	YES	YES	YES
Note: The statistics are in brackets ***, **, and *, representing significance at 1%, 5%, and 10%, respectively.				

Table 4. Mediating effect test results.

Variable	(1)		(2)	(3)	
	GreInvia	GreUmia	RD	GreInvia	GreUmia
Pubsubs	0.130 *** (0.008)	0.080 *** (0.008)	0.007*** (18.09)	0.109 *** (13.26)	0.071 *** (8.88)
RD				2.869 *** (9.31)	1.301 *** (6.71)
Size	0.263 *** (0.011)	0.250 *** (0.011)	-0.005 *** (-9.71)	0.278 *** (26.09)	0.257 *** (23.59)
Cashflow	-0.770 *** (0.123)	-0.722 *** (0.108)	-0.027 *** (-2.32)	-0.694 *** (-6.30)	-0.687 *** (-6.54)
Lev	0.0681 (0.046)	0.449 *** (0.046)	-0.071 *** (-20.42)	0.274 *** (5.53)	0.542 *** (11.39)
Firm Age	-0.190 *** (0.023)	-0.231 *** (0.023)	-0.017 *** (-11.43)	-0.141** (-5.92)	-0.209 *** (-8.88)
ROA	0.5335 *** (0.117)	0.721 *** (0.108)	-0.086 *** (-6.73)	0.781 *** (6.42)	0.833 *** (7.54)
Top1	-0.446 *** (0.055)	-0.220 *** (0.054)	-0.036 *** (-12.72)	-0.343 *** (-6.26)	-0.173 *** (-3.18)
TobinQ	0.031 *** (0.006)	0.007 (0.004)	0.005*** (4.98)	0.018 *** (3.47)	0.008** (0.17)
year	YES	YES	YES	YES	YES

Note: The statistics are in brackets ***, **, and *, representing significance at 1%, 5%, and 10%, respectively.

term development and make it difficult to obtain the government's and society's recognition and support. Therefore, by strengthening the supervision and guidance of enterprises' green innovation, the government restrains the speculative behavior of enterprises and makes enterprises invest more in substantive innovation activities under the incentive of government subsidies.

Table 4 shows the test results of whether the impact of government subsidies on enterprises' green innovation plays a role through the intermediary variable of R&D investment. First, the regression coefficient of government subsidies in the model (1) is significantly positive, indicating a significant correlation between government subsidies and enterprises' green innovation, and can thus further test the existence of mediation effects. Second, the regression coefficient of government subsidies in the model (2) is 0.0036, which is positive at the 1% significance level, indicating that the increase in government subsidies will encourage enterprises to increase the intensity of R&D investment. Finally, the regression coefficients of government subsidies and R&D investment in a model (3) are both positive at a significant level of 1%, reflecting the direct impact of government subsidies on the number of green invention and utility model patent applications by enterprises and the mediating impact of R&D investment on green innovation by enterprises. Specifically, R&D investment plays a partial intermediary role between government subsidies and enterprise substantive innovation and strategic innovation. The indirect effect of government subsidies on enterprises' substantive green innovation through R&D investment is 0.020, and the total effect is 0.130. The mediation effect accounts for 15.4%. The indirect effect of government subsidies on strategic green innovation through R&D investment is 0.009, the total effect is 0.080, and the mediation effect accounts for 11.3%. Therefore, Hypothesis 2 was verified.

Robust Test

Through regression analysis, this paper verifies the positive impact of government subsidies on enterprise green innovation and the mediating role of enterprise R&D investment in it. To improve the reliability of the research, we carried out a robust test in the following two aspects:

Replacement of Enterprise Green Innovation Indicators

We use the authorized numbers of green invention patents (GreInvig) and utility model patents (Greumig) as proxy indicators to conduct another regression analysis. Table 5 shows the regression results. Consistent with the previous findings, government subsidies positively affect enterprises' substantive innovation strategies, indicating that enterprises receiving government subsidies are more inclined to engage in significant innovative activities.

Replacement of the Model Estimation Method

Considering the diversity of values within enterprises' data, Table 6 displays the regression outcomes using the Tobit model. These outcomes align with those obtained from the OLS model, underscoring the robustness of the study's results.

Table 5. Regression results of replacing the explained variables.

Variable	(1)		(2)	(3)	
	GreInvig	Greumig	RD	GreInvig	Greumig
Pubsubs	0.060 *** (8.86)	0.054 *** (11.18)	0.007 *** (18.09)	0.046 *** (9.50)	0.053 *** (7.85)
RD				1.083 *** (7.91)	0.961 *** (7.43)
Year	YES	YES	YES	YES	YES

Note: The statistics are in brackets ***, **, and *, representing significance at 1%, 5%, and 10%, respectively.

Table 6. Tobit model regression results.

Variable	(1)		(2)	(3)	
	GreInvig	Greumig	RD	GreInvig	Greumig
Pubsubs	0.273 *** (16.74)	0.162 *** (10.41)	0.007 *** (18.66)	0.222 *** (13.70)	0.140 *** (8.88)
RD				6.445 *** (19.12)	3.20 *** (9.23)
Year	YES	YES	YES	YES	YES

Note: The statistics are in brackets ***, **, and *, representing significance at 1%, 5%, and 10%, respectively.

Heterogeneous Analysis

Differences in Enterprise Ownership

According to the nature of enterprise ownership, this study divides sample enterprises into two types: state-owned and non-state-owned. It performs regression analysis on the two types of enterprises, respectively. Table 7 shows the regression results. It can be seen from the regression results that government subsidies have a significant positive impact on the number of invention patents and utility model patents of state-owned enterprises and non-state-owned enterprises. The impact on invention patents is greater than that on utility model patents, consistent with the benchmark regression results for the full sample.

However, the regression coefficients of invention and utility model patents of state-owned enterprises are larger than those of non-state-owned enterprises. The test of the coefficient difference between groups reveals significant differences, which shows that government subsidies have a more positive impact on state-owned enterprises. The incentive effect of green innovation is greater than that of non-state-owned enterprises. In addition, whether a state-owned or non-state-owned enterprise, R&D investment is partially an intermediary in government subsidies promoting green innovation. From the perspective of the intermediary effect of government subsidies on the substantive green innovation and strategic innovation of enterprises through R&D investment, for non-state-owned enterprises, the intermediary effect accounts for 18.1% and 15.7%, respectively. For state-owned enterprises, the intermediary effect accounts for 16.8% and 10.7%, respectively. The effect on non-state-owned enterprises is greater than that on state-owned enterprises. Furthermore, R&D investment plays a more important role in promoting the invention patents and substantial innovation capabilities of these enterprises.

Differences in Enterprise Scale

The regression analysis is further refined by categorizing enterprises based on their size into large, small, and medium-sized enterprises. Table 8 details the regression results for these categories. It reveals that the influence of government subsidies on green innovation activities varies significantly across enterprises of different sizes. For model (1), whether it is large or small enterprises, an increase in government subsidies will significantly increase the number of applications for green invention patents and utility model patents. The impact of government subsidies on enterprises' Still, large enterprises' government subsidy coefficients are greater than those of small and medium-sized enterprises. The effect of government subsidies on the green innovation of large enterprises is more significant.

From the perspective of intermediary effects, for large enterprises, the coefficient of government subsidies in the model (2) is 0.005, which is positively significant at the 1% level. The government subsidies and R&D investment coefficients for invention and non-

Table 7. Government subsidies and green innovation in enterprises: by nature of enterprise ownership.
Sub-Table A: Sample of non-state-owned enterprises.

Variable	(1)		RD	(2)	
	GreInvig	Greumig		GreInvig	Greumig
Pubsubs	0.149*** (12.20)	0.089*** (7.45)	0.005*** (0.74)	0.121*** (10.03)	0.074*** (6.22)
RD				5.427*** (14.57)	2.776*** (7.50)
Year	YES	YES	YES	YES	YES
R2	0.286	0.305	0.140	0.318	0.314

Sub-Table B: Sample of state-owned enterprises.

Variable	(1)		RD	(2)	
	GreInvig	Greumig		GreInvig	Greumig
Pubsubs	0.119*** (13.59)	0.075*** (8.48)	0.009*** (16.12)	0.099*** (11.23)	0.067*** (7.47)
RD				2.252*** (13.95)	0.901*** (5.46)
Year	YES	YES	YES	YES	YES
R2	0.156	0.143	0.170	0.173	0.146

Note: The statistics are in brackets, ***, **, and *, and represent significance at 1%, 5%, and 10%, respectively.

Table 8. Government subsidies and enterprise green innovation: By Enterprise scale.
Sub-table A: Large enterprises.

Variable	(1)		RD	(2)	
	GreInvig	Greumig		GreInvig	Greumig
Pubsubs	0.160*** (13.79)	0.110*** (9.82)	0.005*** (12.48)	0.131*** (11.27)	0.096*** (8.35)
RD				5.326*** (6.92)	2.887*** (5.19)
Year	YES	YES	YES	YES	YES
R2	0.214	0.203	0.200	0.242	0.211

Sub-table B: SMEs.

Variable	(1)		RD	(2)	
	GreInvig	Greumig		GreInvig	Greumig
Pubsubs	0.085*** (9.37)	0.039*** (4.43)	0.012*** (13.97)	0.064*** (6.92)	0.031*** (3.45)
RD				1.855*** (6.60)	0.706*** (4.39)
Year	YES	YES	YES	YES	YES
R2	0.053	0.039	0.160	0.076	0.043

Note: The statistics in brackets ***, **, and * represent significance at 1%, 5%, and 10%, respectively.

invention patents in model (3) are significant, indicating that R&D investment partially mediates the impact of government subsidies on the substantive innovation and strategic innovation of large, small, and medium-sized enterprises. On the whole, R&D investment has a more significant mediating effect on the impact of government subsidies on the green innovation activities of large enterprises. It may be because R&D activities require a large amount of fund support. Large-scale enterprises have stronger financial strength than small and medium-sized enterprises and are more able to bear R&D risks. Therefore, with the government's support, they are more willing to invest in innovation activities.

Differences in the Carbon Emission Trading Pilot Area

To analyze government subsidies' impact on enterprises' green innovation in different regions, this paper classifies the sample enterprises according to whether they are located in the pilot regions of carbon emission trading. At present, six provinces in China have launched carbon emission trading pilot projects. Therefore, this paper divides the sample enterprises into two categories: the enterprises located in the carbon emission trading pilot areas and the other group found in the non-carbon emission trading pilot areas. This paper conducts regression analysis on these two groups of enterprises, respectively, and the regression results are shown in Table 9.

It can be seen from Table 9 that the impact of government subsidies on the invention patents and utility model patents of the two groups of enterprises is significantly positive, and the impact on invention patents is greater, which is consistent with the regression results of the full sample. However, the coefficients of invention and utility model patents of enterprises in carbon emission trading pilot areas are significantly higher than those of enterprises in non-carbon emission trading pilot areas. After the coefficient difference test between groups, it was found that there were significant differences between the two. This indicates that enterprises in the carbon emissions trading pilot areas are under stronger carbon constraint pressure. Consequently, they are more active in using government subsidies to pursue green innovations, aiming to reduce carbon emission costs and improve carbon efficiency. At the same time, enterprises in carbon emission trading pilot areas can also obtain additional income and funds by participating in the carbon market, thereby increasing their ability and willingness to invest in green innovation. In addition, enterprises in the carbon emissions trading pilot areas can also learn from the experience and technology of enterprises in other pilot areas and enjoy the information, training, consulting, and other support services the government provides, thereby improving the efficiency and quality of green innovation. Therefore, enterprises in carbon emission trading pilot areas use more government subsidies for enterprise green innovation.

Secondly, for both groups, there is an impact of government subsidies to promote green innovation, and R&D investment has an intermediary effect. From the perspective of the intermediary effect of government

Table 9. Government subsidies and enterprise green innovation: impact of carbon emissions trading pilots.
Sub-Table A: Carbon emission trading pilot areas.

Variable	(1)		RD	(2)	
	GreInvig	Greumig		GreInvig	Greumig
Pubsubs	0.179*** (15.27)	0.107*** (9.14)	0.010*** (14.09)	0.155*** (13.12)	0.104*** (8.75)
RD				2.331*** (11.00)	0.268 (1.25)
Year	YES	YES	YES	YES	YES
R2	0.295	0.281	0.219	0.310	0.281

Sub-table B: Non-carbon emission trading pilot areas.

Variable	(1)		RD	(2)	
	GreInvig	Greumig		GreInvig	Greumig
Pubsubs	0.092*** (9.86)	0.059*** (6.27)	0.006*** (12.51)	0.074*** (7.92)	0.044*** (4.70)
RD				3.285*** (13.58)	2.647*** (10.81)
Year	YES	YES	YES	YES	YES
R2	0.162	0.174	0.160	0.183	0.187

Note: The statistics are in brackets ***, **, and *, representing significance at 1%, 5%, and 10%, respectively.

subsidies on the substantive green innovation and strategic innovation of enterprises through R&D investment, for non-carbon emission trading pilot regions, the intermediary effect accounts for 21.7% and 27.1%, respectively. For carbon emission trading pilot regions, government subsidies only impact the substantial green innovation of enterprises through R&D investment, and the intermediary effect accounts for 12.8%.

The reason why R&D investment has less impact on substantive green innovation in pilot regions than in non-pilot regions can be explained as follows: The carbon emission trading system has been introduced in pilot regions. Due to the uncertainty of the carbon emission trading market, policymakers may pay more attention to achieving carbon emission reduction goals than promoting innovation. Companies may focus more on cost reduction than green innovation, resulting in less investment in research and development. Therefore, the pilot areas should provide more favorable incentive mechanisms and policy support to provide more green innovation subsidies and financial support to encourage enterprises to increase R&D investment and promote green innovation in these areas.

Differences in Industry Structure

According to the "Regulations on the Management of the List of Key Pollutant Discharge and Environmental Risk Control Units", enterprises with codes B06, B07, B08, B09, C17, C19, C22, C25, C26, C27, C28, C30, C31, C32, C33, and D44 are classified as polluting industries, and the rest are non-polluting industries. This paper divides the samples into two categories: polluting and non-polluting industries and regression analysis is performed on the two groups of samples, respectively. Table 9 shows the regression results. From the regression results, it can be seen that the impact of government subsidies on invention patents and utility model patents in both polluting and non-polluting industries is positive at a significant level of 1%. The impact on enterprise invention patents is greater, consistent with the benchmark regression results. However, the coefficients of invention and utility model patents in non-polluting industries are larger than those in polluting industries. Through the test of the difference in coefficients between groups, there are significant differences between the two coefficients, indicating that although government subsidies impact green innovation in polluting industries, green innovation faces various difficulties and constraints.

First, it is difficult for technological innovations to be widely disseminated and applied to traditional polluting industries. Second, affected by economic pressure and production arrangements, enterprises are unwilling or unable to invest sufficient resources in green innovation. Furthermore, the core technologies polluting industries mostly rely on foreign countries, and intellectual property rights restrict enterprises in the research and development process. To promote green innovation in polluting industries, it requires the synergy of policies, markets, and enterprises. Therefore, compared with

Table 10. Government subsidies and enterprise green innovation: impact of polluting industries.
Sub-table A: Polluting industries.

Variable	(1)		RD	(2)	
	GreInvig	Greumig		GreInvig	Greumig
Pubsubs	0.043*** (4.14)	0.007 (0.69)	0.002*** (5.64)	0.043*** (4.08)	0.007 (0.70)
RD				0.248*** (0.52)	-0.048 (-0.12)
Year	YES	YES	YES	YES	YES
R2	0.174	0.252	0.203	0.175	0.255

Sub-table B: Non-polluting industries.

Variable	(1)		RD	(2)	
	GreInvig	Greumig		GreInvig	Greumig
Pubsubs	0.158*** (17.60)	0.102*** (11.24)	0.009*** (16.51)	0.133*** (14.85)	0.093*** (10.07)
RD				2.824*** (16.47)	1.085*** (6.17)
Year	YES	YES	YES	YES	YES
R2	0.255	0.230	0.185	0.277	0.234

Note: The statistics are in brackets, and ***, **, and * and represent significance at 1%, 5%, and 10%, respectively.

polluting industries, non-polluting industries can more effectively use government subsidies for enterprise innovation.

Moreover, in non-polluting industries, R&D investment is a partial intermediary in government subsidies promoting enterprises' green innovation. From the perspective of the intermediary effect of government subsidies on enterprises' substantive green innovation and strategic innovation for non-polluting industries, the intermediary effects accounted for 16% and 10%, respectively. For polluting industries, government subsidies only impact the substantial green innovation of enterprises through R&D investment, and the intermediary effect accounts for 2%.

Discussion

This paper explores the impact of government subsidies on enterprise green innovation and the heterogeneous responses of different types of enterprises. Fritsch (2017) [71] believes that traditional innovation integrates production functions and conditions into the production system. Green innovation, also known as environmental innovation, is a product that combines conventional technological innovation with the concept of an ecological environment. Research and development in innovation can significantly reduce environmental pollution and create economic benefits. Since the Chinese economy entered a new normal, upgrading the industrial structure has led to increasingly fierce competition among enterprises. Consequently, green innovation has become a key means to enhance the core competitiveness of enterprises [72]. Accelerating the drive for green innovation in enterprises with high investment and risk in green innovation activities is also the key to achieving green transformation in the Chinese economy.

The main contribution of this paper is as follows: First, it theoretically analyzes how government subsidies motivate enterprises to implement substantive and strategic green innovation. The main viewpoint of existing literature is that when the government provides ex-post support to fund or protect specific enterprises, the market function will be disrupted, and there will be rent-seeking behavior in the economy. Sovacool (2017) [73] proposed that government subsidies will have a series of negative impacts on society and the environment, including significant government fiscal deficits, artificially increased pollution, and worsening poverty. Whether government subsidies can effectively play a driving role in enterprise innovation activities depends on whether the innovation output of enterprises can meet the value demands of local governments, which depends on the heterogeneity of value creation in innovation activities [74]. Enterprises obtain more government funding through simple innovation or by pursuing some patents. This kind of innovative behavior of enterprises emphasizes "fast" over "good" and "quantity" over "quality", which reflects a kind of strategic innovation. Even though government subsidies promote enterprise innovation, companies may only

perform strategic innovation due to rent-seeking and other factors [64].

Unlike the existing literature, this paper argues that enterprises are more inclined to use government subsidies for meaningful green innovation than for strategic green innovation. This indicates that enterprises prioritize innovation quality in pursuit of long-term sustainable development. The government's reasonable and effective use of subsidy funds to stimulate substantial innovation in enterprises, thereby promoting high-quality economic growth, is an important measure to achieve innovation-driven development and an important means to compensate for the failure of the R&D market. Second, existing research mainly explores the impact of factors such as social responsibility fulfillment, executive gender, academic experience, media attention, environmental interviews, and environmental regulations on corporate green innovation. These studies approach from perspectives of corporate governance, executive characteristics, public opinion supervision, and environmental governance [75, 76]. This paper empirically verifies the difference in government subsidies' impact on the green innovation of different types of enterprises.

According to the different characteristics of enterprises, this paper conducts a multi-dimensional heterogeneity analysis and finds the influencing factors of government subsidies on enterprises' green innovation. Government subsidies for green innovation in enterprises significantly reduce the mismatch rate of green innovation and promote the rational allocation of innovation resources. It brings a series of changes to enterprises, including resource release, financing convenience, industrial upgrading, and efficiency optimization, providing more ideas and opportunities to break through the bottleneck of green development and achieve high-quality green growth.

This paper finds that enterprises in carbon emission trading pilots, non-polluting industries, and large enterprises are more likely to use government subsidies to carry out green innovation. As a link between government environmental regulatory measures and the sustainable green development of enterprises, green innovation is an important means to break through ecological resource constraints and drive the green development of heavily polluting industries [77]. It shows that government subsidies should formulate more reasonable and effective incentive mechanisms based on the needs and characteristics of different types of enterprises and focus more on polluting industries, private enterprises, and small and medium-sized enterprises. YE (2021) [8] believed that increasing government subsidies positively alleviates private enterprises' financing difficulties in green innovation. However, it has a negative regulatory effect on state-owned enterprises. Wu et al. (2018) [78] attributed differences in the funding effects of government subsidies for state-owned and non-state-owned enterprises to 'political' advantages. Cheng and Lin (2018) [79] argued that the highly concentrated equity and rigid organizational structure of state-owned enterprises could easily lead to low innovation enthusiasm and efficiency, which is not conducive to transforming innovation achievements. On this basis, Jin et al. (2018) [80] pointed out that government subsidies have a more significant positive effect on the innovation investment of private enterprises.

Most of the existing literature believes that government subsidies will have a greater impact on the green innovation capabilities of private enterprises. However, this paper finds that state-owned enterprises make more use of government subsidies for green innovation, which further shows that state-owned enterprises, as an important subject of ecological civilization construction, are important promoters of green development and contributors to green development. The development concept is integrated into the whole enterprise construction and development process, and green innovation is carried out to provide impetus for high-quality economic development. This paper supports the signaling effect in theory and believes that enterprises should seize the opportunity to innovate and use it to enhance their value and shape the company's image. Therefore, this study argues that adopting such strategies can significantly alleviate market failures, promote green innovation, and support sustainable development.

This paper provides more evidence to support the next step in implementing the carbon emission trading market. Empirical research shows that the European Union's carbon trading system (EU ETS) and China's carbon emission trading market are conducive to promoting enterprises' green innovation activities [81, 82]. Facts have proven that the carbon emission trading mechanism can stimulate enterprises to use government subsidies to carry out green innovation, which is an application of the theory of externalities. The pilot carbon emission trading market has enabled enterprises to convert market externalities into internal costs and established a market-oriented mechanism for assuming external responsibilities. The practice of China's carbon market has shown that optimizing energy consumption structure through carbon trading can reduce carbon emission intensity and benefit the environment [83]. Carbon trading is constrained by enterprises' emission reduction potential and the carbon quota mechanism.

On the one hand, large enterprises have high emission reduction potential and have the drive for technological improvement. Enterprises in heavy industries such as steel and electricity are more concerned about carbon emissions [84]. On the other hand, carbon quotas determine carbon trading prices. When carbon quotas are less than carbon demand, this raises emission reduction costs, forces technological upgrades, and promotes emission reduction effects [85].

The pilot carbon emission trading market enables enterprises to transform market externalities into

internal costs and establishes a market-oriented external responsibility-taking mechanism. The carbon emission trading mechanism is an effective means of internalizing externalities. It can encourage enterprises to improve production efficiency, reduce carbon emission intensity, and increase R&D investment, thereby realizing green innovation. As a policy tool, government subsidies can further strengthen the incentive effect of the carbon emission trading mechanism on enterprises' green innovation and improve innovation motivation and ability. The research results of this paper provide useful references and inspiration for improving China's carbon emission trading market and formulating government subsidy policies. The stronger the internal incentive effect obtained by enterprises in regions with strict carbon quota management and high carbon emission market activity, the greater the possibility of enterprises in pilot areas of carbon emission trading participating in green innovation through government subsidies. Therefore, while fully considering the environmental capacity of each region, China should increase the intensity of carbon regulation, further improve the cross-regional carbon emission trading mechanism, and enhance the enthusiasm of enterprises to participate in carbon emission trading [86].

This paper also has some deficiencies that need improvement in future research. For example, the green innovation indicators selected in this paper may not be sufficiently accurate. Future research could utilize additional data sources and methods to more accurately measure enterprises' green innovation levels. This article does not discuss the impact of different forms and intensities of government subsidies on enterprises' green innovation. The classification and measurement of government subsidies can be further refined, and their optimal incentive effect on enterprises' green innovation can be analyzed. In addition, this paper only discusses the intermediary effect of R&D investment on government subsidies and enterprises' green innovation. Future research could identify other potential intermediary variables to deepen the analysis of government subsidies' effectiveness on enterprises' green innovation. Finally, when conducting the robustness test, this paper refers to the instrumental variable method [7]. This issue still needs further exploration to see if more appropriate instrumental variables exist to obtain more robust estimates.

Many aspects can be further studied in future research on government subsidies and enterprise green innovation. First, compare the effects of different government subsidies on enterprise green innovation and analyze which subsidy method is more conducive to promoting enterprise green innovation. Second, find more variable indicators and data sources that reflect the green innovation level. Third, start from the internal factors of the enterprise to examine whether the degree of green awareness of top managers will affect the use of government subsidies for green innovation by enterprises, as well as explore other possible intermediary variables such as the policy environment and low-carbon city pilots.

Conclusions

Green innovation is significant for realizing enterprises' green transformation and high-quality economic development. This study examines the micro-effects of government subsidies on enterprise green innovation. By analyzing the green patent and financial data of China's Shanghai and Shenzhen A-share listed companies from 2009 to 2019, we empirically study the impact of government subsidies on enterprises' green innovation and the intermediary effect of R&D investment. This analysis of the impact mechanism of innovation provides a theoretical basis for the government to enhance green innovation in enterprises more effectively.

(1) Government subsidies can directly promote enterprises' substantive and strategic innovation, especially since the effect on substantive innovation is more significant.

(2) Government subsidies can encourage enterprises to increase R&D investment, thereby promoting enterprises to carry out green innovation. R&D investment significantly mediates between government subsidies and enterprise substantive innovation and strategic innovation.

(3) The impact of government subsidies on enterprise green innovation is heterogeneous among different types of companies. The mediating effects of R&D investment on the green innovation of state-owned enterprises, large enterprises, non-polluting industries, and enterprises in non-carbon emission trading pilot areas are more significant.

Therefore, government subsidies are important in promoting green innovation in enterprises, especially for substantive innovation. In addition, R&D investment plays an important role between government subsidies and enterprise green innovation, and the significance of the intermediary effect is affected by enterprise attributes. These research results provide a useful reference for the government to formulate more effective policy measures and promote enterprises to strengthen green innovation.

(1) Government subsidies have a significant positive impact on enterprise green innovation, but different types of companies are affected differently. Polluting industries, private enterprises, and SMEs depend more on government subsidies for green innovation. Therefore, the government should formulate differentiated subsidy policies based on enterprises' internal conditions and external environment and focus on supporting those enterprises with weak green innovation capabilities and greater environmental pressure.

(2) Carbon emission trading significantly incentivizes green innovation in enterprises, though the extent of these incentives varies among different

types of enterprises. Polluting industries, state-owned enterprises, and large enterprises are more constrained and promoted by carbon emission trading because their carbon emissions are larger and carbon trading costs are lower. Therefore, the government should expand the pilot areas of carbon emission trading, improve the system, use market mechanisms to mobilize enterprises to upgrade their industrial structure and technological innovation and improve their efficiency in green innovation.

(3) Government subsidies and carbon emission trading have complementary effects on enterprise green innovation. When the two exist together, the promotion effect on enterprise green innovation is greater than when the two exist separately. It shows that government subsidies can compensate for the possible negative effects of carbon emission trading, such as increasing enterprise costs and reducing competitiveness. In contrast, carbon emission trading can compensate for the possible negative effects of government subsidies, such as moral hazard and crowding-out effects. Therefore, the government should coordinate using these two policy tools to achieve policy synergy.

(4) The government should intensify the publicity of green innovation and development and improve private enterprises' awareness of green innovation. Organize relevant lectures and training sessions to foster green innovation cooperation among enterprises. At the same time, establish a robust green innovation platform, increase R&D investment for enterprises, and enhance the financing environment.

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Conflict of interest

The authors declare no conflict of interest.

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