Research on the Impact Mechanism of Government Subsidies on Green Innovation of Enterprises

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Abstract. Under the background of the China's Double-Carbon Policy proposed in the 14th Five-Year Plan, promoting the research and development of green innovation is an important way to solve the contradiction between economic growth and environmental sustainability. Based on the panel data of Chinese A-share listed companies in Shanghai and Shenzhen from 2010 to 2021, we empirically examine the impact of government subsidies on corporate green innovation, as well as the moderating role of financing constraints and market power in this process. The empirical results show that government subsidies can promote enterprise green innovation. However, financing constraints and market power will weaken the positive impact of government subsidies on green innovation. We have great significance to promote the green innovation of listed enterprises and realize the sustainable development of our country's economy.

Keywords: Government subsidy; green innovation; financing constraints; market power.

1. Introduction

According to the Global Environmental Performance Index (EPI) Report released by Yale University, China's Environmental Performance Index ranks among 180 countries, dropping from 120th in 2020 to 160th in 2022, further reflecting that China is facing the dual challenge of balancing the contradiction between economic growth and environmental sustainability. In this context, green innovation is an important way to alleviate the contradiction between economic growth and environmental pollution [1], and is the key to achieving economic transformation and upgrading, and promoting sustainable development. The 14th Five-Year Plan proposes a "China's Double-Carbon Policy" strategy of "striving to reach carbon peak by 2030 and achieve carbon neutrality by 2060", promoting green development has reached a new level; The 20th National Congress of the Communist Party of China emphasized that "promoting green development" is an inherent requirement for the comprehensive construction of socialist modernization. For enterprises, green development can be achieved through technological innovation, industrial upgrading, and other means. At the same time, the government should also strengthen support and guidance, provide better policies and environment for enterprises, and promote the development of green innovation. Therefore, exploring how to motivate enterprises to engage in green innovation and accelerate industrial transformation and upgrading has important theoretical and practical significance.

At present, the academic community has explored the key factors affecting green innovation in enterprises from multiple perspectives such as the background characteristics of executives and the disclosure of corporate environmental information [2-4]. However, due to the uncertainty and dual Externality of green innovation, as well as many risks, such as capital chain rupture, innovation failure, market depression, etc. [5], and the difficulty of innovation achievements to be translated into economic benefits in the short term, this has greatly weakened the internal motivation of green innovation of enterprises, thereby reducing the level of green innovation in the whole society. According to the theory of new Classical economics, the government's fiscal policy is an effective measure to solve the inherent drawbacks of green innovation [6]. The government provides effective funding for enterprise innovation activities, shares costs, stimulates innovation enthusiasm, and also provides guidance for enterprise innovation activities, which is conducive to accelerating the market transformation of innovation achievements [7]. However, there is currently no consistent conclusion in the research on the impact of government subsidy policies on green innovation of enterprises. Some scholars believe that government subsidies will "squeeze out" the original innovation investment of

enterprises, which can easily lead to "rent seeking" and "fraudulent subsidy" behavior of enterprises, resulting in ineffective allocation of public resources and adverse effects on green innovation of enterprises [8,9]; From the perspective of enterprise innovation motivation, Liang et al. [10] divided green innovation into strategic green innovation and substantive green innovation, and used institutional quality as a moderating factor. They found that government subsidies have incentive effects on both types of green innovation. So, can government subsidies promote green innovation behavior of enterprises? From the perspective of resource impact, Ye [11] believes that as an important part of public funds, government subsidies are regarded as one of the important ways to ease financing constraints and overcome the "Externality" problem. So, will different levels of financing constraints affect the acceptance of government subsidies by enterprises? From the perspective of market impact, Shi et al. [12] studied the impact of different levels of market power and government subsidies on enterprise innovation activities, and found that government subsidies have different promoting effects on R&D of enterprises with different combinations of market power. Government subsidies and buyer power have significant promoting effects on enterprise innovation decision-making and investment, while seller power can significantly increase the probability of R&D. So, will different levels of market power affect the effectiveness of government subsidies for green innovation in enterprises.

On the basis of existing research, we conducts a theoretical review and summary to explore the impact of financing constraints and market power on the relationship between government subsidies and green innovation in enterprises, and deeply analyzes the mechanism of driving green innovation in enterprises. Our innovation is mainly reflected in the following aspects: firstly, with green innovation as the core, analyze the effectiveness of policies, and expand relevant research on green innovation. The existing literature on green innovation is mainly based on the driving effects of government regulation, information disclosure, and executive incentives, with less consideration given to the driving effects of relevant subsidy policies. We focuses on the impact of government subsidies on green innovation. Secondly, previous literature has solely studied the impact of government subsidies, financing constraints, and market power on green innovation, or explored financing constraints and market power as intermediary variables. We take financing constraints and market power as regulatory variables, on the basis of studying the impact of government subsidies on green innovation, we also specifically explore the regulatory effects of financing constraints and market power on the relationship between government subsidies and enterprise green innovation, expanding the research boundary and enriching the research content in this field.

Therefore, we focus on government subsidies in enterprise green innovation, using Chinese A-share listed companies in Shanghai and Shenzhen as research samples to empirically test the impact of government subsidies on enterprise green innovation, and analyze the regulatory effects of financing constraints and market power on the relationship between government subsidies and enterprise green innovation, in order to provide reference for relevant research and policy formulation on green innovation driven and government subsidy effects.

2. Theory and literature review

2.1 Green Innovation

Schumpeter explores the role of technological innovation in the process of economic development from the perspective of combining technology and economy. Theory of Innovation reveals that innovation is to "establish a new production function", that is, "the recombination of production factors", and the application of technology will lead to the recombination of production factors and production conditions. Therefore, technological progress plays a significant role in the innovation process. Green innovation, as a part of enterprise technological innovation, is reflected in resource allocation and organizational innovation. It differs from traditional innovation in that it has the characteristics of high investment, high risk, and strong uncertainty, requiring certain external

incentives. On the basis of Schumpeter's Theory of Innovation, many scholars have conducted research on the influencing factors of green innovation.

The existing literature has revealed the antecedents of enterprises' green innovation [2-4] from the perspectives of information disclosure, senior executives' sexual characteristics and background characteristics, market regulation, etc. For example, at the internal level of enterprises, Zhang and Yan [2] tested the moderating effect of executive background characteristics on the impact of government subsidies on green innovation in manufacturing enterprises. They ultimately found that the average age, average tenure, and overseas background of executive teams all have a positive moderating effect on the impact of government subsidies on green innovation in enterprises. Yan and Ta [3] empirically tested the impact of female executive participation on green innovation in enterprises. Research has found that female executives' participation significantly inhibits green innovation in enterprises. Chen et al. [4] studied the impact and mechanism of corporate environmental information disclosure on green innovation, and concluded that corporate environmental information disclosure significantly inhibits green innovation. In terms of external factors of enterprises, Xiao et al. [13] used the system GMM method to test the impact effect and mechanism of market incentive environmental regulations on regional green innovation efficiency. They found that market incentive environmental regulations can significantly promote the improvement of regional green innovation efficiency, while an effective fiscal decentralization environment can positively regulate the relationship between market incentive environmental regulations and regional green innovation efficiency. Wang et al. [14] found through research that the innovation drive of enterprises will be positively influenced by both green insurance subsidies and government subsidies. Hounik et al. [15] found that when promoting green innovation in enterprises, the government can not only use control commands such as formulating environmental regulations, but also use economic incentives such as subsidies to achieve the goal of promoting green innovation in enterprises. In addition, some scholars also explored the factors affecting green innovation of enterprises from different perspectives, such as Digital transformation, the nature of property rights, and corporate social responsibility.

2.2 Government Subsidies

The core of Institutional Theory lies in the tendency of organizational structure and processes to gain meaning and achieve self-stability, rather than based on expected effects and efficiency. Based on institutional theory, government subsidies, as a government push, can act on green innovation in enterprises. In the process of green innovation in enterprises, in order to obtain higher legitimacy, they will respond to government policies. By adhering to relevant norms and codes of conduct, responding to the expectations of government subsidies and other policies for corporate behavior, green innovation "convergence" is carried out in a certain form, thereby obtaining a sustained competitive advantage [16].

Based on the above theoretical analysis, we believe that studying government subsidies has profound significance for green innovation in enterprises. In the relevant research on government subsidies, scholars have explained the role of government subsidies from the perspectives of corporate executives' characteristics, resource utilization and allocation, and systems [17-19]. For example, at the internal level of enterprises, Jin et al. [17] tested the incentive effect of government subsidies on executive R&D investment from the perspective of executive innovation efforts, and found that government subsidies reduced salary performance sensitivity and increased salary R&D investment sensitivity. Meanwhile, while maintaining a certain overall risk, government subsidies can help promote executives to engage in relatively high-risk R&D investment activities. At the level of government guidance, Yu [18] found through propensity score matching method that government subsidies provide multiple financial support for green innovation of enterprises, guide them to introduce green technology, and point out the direction for future innovation of enterprises. Huang [19] pointed out that government subsidies can promote cooperation between enterprises and external resources, thereby enhancing their competitiveness. Wu et al. [20] conducted an empirical study on

the incentive effect of government subsidies on the innovation output of high-tech enterprises, pointing out that government subsidies have significantly increased the R&D innovation output of high-tech enterprises as a whole, and the promotion effect of government subsidies on the R&D innovation output of small-scale enterprises and non-state-owned enterprises is more obvious. Some scholars believe that there are many uncertainties in the role of government subsidies in green innovation, and the relationship between the two cannot be simply defined [21].

In summary, it can be seen from previous studies that (1) although existing studies have partially revealed the role of government subsidies in enterprise innovation, there is still a lack of research on the impact of government subsidies on green innovation in enterprises in the context of the new era; (2) In addition, most of the existing literature has studied the direct effects of financing constraints and market power on green innovation in enterprises, with few studies using them as moderating variables and exploring their role in government subsidy resource allocation. The scenario is still incomplete.

3. Hypothesis

3.1 Government Subsidies and Green Innovation

Based on Institutional Theory, government subsidies, as a government push, can act on green innovation in enterprises. Firstly, the positive signals released by government R&D subsidies can help enterprises access external innovation resources and effectively promote enterprise innovation [22]. If an enterprise can receive government research and development subsidies, it can be considered that its technological innovation ability and potential commercial value of research and development projects have been certified by the government [23,24]. This provides external investors with investment positive signals, helps alleviate financing constraints, and disperses the risks brought by innovation uncertainty, insurance effectively enhances the innovation resources of enterprises, thereby motivating them to engage in green innovation. Secondly, government subsidies have resource attributes, which can compensate for some of the investment in green innovation by enterprises, directly alleviate their financial constraints, and have an incentive effect on R&D investment. At the same time, as an important external resource, government subsidies can directly increase enterprises' cash holdings, ease resource constraints, enhance enterprises' Assumption of risk ability [25], and help enterprises' decision-making levels to make policies conducive to green innovation. Finally, based on the factor endowment theory, government subsidies reduce the Weighted average cost of capital of enterprises, reduce the cost of trial and error of enterprises, and mitigate enterprise risks [26]. At the same time, government subsidies can also increase the tolerance of enterprises to the trial-and-error cost of green innovation by improving the level of enterprises' Assumption of risk, thus promoting enterprises' green innovation investment. In summary, we propose the following hypothesis:

H1: Government subsidies can promote green innovation in enterprises.

3.2 Financing Constraints

When enterprises lack sufficient research and development funds for green innovation activities, they often obtain external financing through channels such as bank loans, equity financing, public finance, and venture capital. Therefore, when enterprises face financing constraints, the more difficult green invention patent innovation activities are more likely to be replaced by other investment activities [27], which will weaken the decision-making power of green innovation for enterprises. On the one hand, when the degree of financing constraints of enterprises is high, the scarcity of resources may lead to the use of government subsidies by enterprises to alleviate excessive financing constraints, without using subsidies for green innovation, thereby weakening the promoting effect of government subsidies on green innovation of enterprises. On the other hand, a higher degree of financing constraints will reduce the ability of enterprises to resist risks, thereby reducing their tolerance for the trial-and-error costs of green innovation and suppressing the effect of government subsidies on green

innovation. Therefore, although government subsidies can promote green innovation in enterprises, the effect of government subsidies may be limited when enterprises face financing constraints. In summary, we propose the following hypothesis:

H2: With the strengthening of financing constraints, the relationship between government subsidies and green innovation is weakened.

3.3 Market Power

Market power refers to the ability of an enterprise to occupy an advantageous position in a certain industry or field and fully utilize its ability to formulate market rules and influence market prices. On the one hand, incumbent enterprises with market power often have a certain market monopoly position and enjoy monopoly profits. In order to consolidate their existing market position, they tend to invest in existing technologies rather than green technologies [28]. On the other hand, in the equity market, monopoly status is one of the important signals for investors to distinguish between good and bad enterprises. Monopolistic enterprises have more stable market prospects and lower investment risks due to their strong market power, which leads to the preference of resources to monopoly enterprises [29]. In other words, incumbent enterprises with market power do not lack financial resources, and their emphasis on government subsidies is weak. Therefore, strong market power will weaken the support effect of government subsidies on green innovation of enterprises. In summary, we propose the following hypothesis:

H3: With the increase of market power, the relationship between government subsidies and green innovation is weakened.

4. Research Design

4.1 Sample Selection and Data Sources

We select Chinese A-share listed companies in Shanghai and Shenzhen from 2010 to 2021 as the research sample, and conducts the following screening on the initial sample: (1) excluding companies treated by ST and * ST during the research period; (2) Excluding companies with industry codes in the financial industry during the research period; (3) Excluding companies with missing key data during the research period; (4) To avoid the impact of extreme values, Winsor tail reduction was performed on all continuous variables at the 1% and 99% levels. Finally, a total of 34551 unbalanced panel data of 4681 companies were obtained. Among them, enterprise green innovation data, government subsidies, and other related data are all sourced from the China Stock Market Accounting Research Database (CSMAR).

4.2 Variable Definition and Measurement

4.2.1 Dependent Variable: Enterprise green innovation level (GI)

We draw on the approach of Zhang and Xu [30] to measure the level of green innovation of enterprises based on the annual number of green patent applications. Patent authorization is unstable due to various factors, and the number of patent applications can more accurately and objectively reflect the level of green innovation at the micro enterprise level, which is more stable and reliable than the number of patent authorizations.

4.2.2 Independent Variable: government subsidies (Gov)

Due to the large amount of government subsidies for listed companies, in order to eliminate errors caused by large order of magnitude differences, we take the government subsidy income of enterprises as a logarithm. In addition, some sample companies have government subsidy income of 0. We draw on the approach of Shen and Yuan [31] and measures the government subsidy income of Chinese listed companies by adding 1 and then taking the logarithm.

4.2.3 Moderator Variables

Financing constraints (Finance). We use the SA index designed by Hadlock and Pierce [32] to measure the financing constraints of sample companies. The specific calculation formula is shown in (1):

$$SA = \left| -0.737 \times Size + 0.043 \times \left(Size^2\right) - 0.04 \times Age \right| \quad (1)$$

Among them, Size (in millions of yuan) is the Natural logarithm of the total assets of the enterprise, and Age is the age of the enterprise. The larger the SA value, the higher the financing constraint level of the enterprise.

Market power (Market). Market power is a state of ability that a company ultimately presents at a certain point in time through market behavior, so market power can be seen as a form of market performance. Market power measurement indicators can be reflected through market performance indicators, such as returns and Lerner's index. We refer to the approach of Zhang et al. [2] and measures the ratio of the total operating revenue to the total operating cost of the sample company for the current year.

4.2.4 Control Variable

In order to avoid the influence of other variables, we, on the basis of consulting relevant literature, takes enterprise age, enterprise growth, capital intensity, asset liability ratio, profit margin of sales, market competition HHI (Herfindahl Index), equity concentration and institutional investors' shareholding ratio as control variables into the regression model. The specific variable definitions are shown in Table 1.

Table 1 Variable Definition

Type	Name	Symbolic	Description
Dependent Variable	Enterprise Green Innovation	GI	Total annual green patent applications of enterprises
Independent Variable	Government Subsidies	Gov	The Natural logarithm is taken after adding 1 to the total amount of current government subsidies
Moderator Variables	Financing Constraints	Finance	Enterprise Annual SA Index
	Market Power	Market	The ratio of total operating revenue to total operating cost of a company
Control Variable	Enterprise Age	Age	Observation year minus enterprise establishment year
	Enterprise Growth	Growth	Year-on-year growth rate of total operating revenue
	Asset Liability Ratio	Lev	Total Liabilities/Total Assets
	Capital Intensity	Cap	Ratio of fixed assets to total assets at the end of the year
	Ratio of Sales	Ros	Operating Profit/Total Operating Income
	Market Competition Level	HHI	The sum of squares of the proportion of enterprise operating revenue to the total assets of the entire industry
	Ownership Concentration	Cr	Shareholding ratio of the largest shareholder
	Shareholding Ratio of Institutional Investors	Lisro	Total shares held by institutional investors divided by circulating capital stock

4.3 Model Building

In order to verify the impact mechanism and specific mechanism of government subsidies on green innovation of environmental protection enterprises in the existing policy environment, two main research steps are first divided to construct an empirical research model of the impact of government subsidies on green innovation.

The first step is to establish a benchmark regression model with government subsidies as the independent variable, first verifying the direct impact of government subsidies on green innovation, and having a macro grasp of the research content.

$$GI = \beta_0 + \beta_1 Gov + \alpha X + Year + Industry + \varepsilon \quad (2)$$

Among them, GI is the dependent variable, representing the green innovation output of the enterprise. Gov refers to the total amount of government subsidies received by listed companies in the current period plus 1, taking the natural logarithm. X refers to a series of control variables, Year and Industry respectively refer to the fixed effect of the year and the fixed effect of the industry, and ε refers to the error term.

The second step mainly tests whether financing constraints have a moderating effect between government subsidies and green innovation, and whether market power have a moderating effect between government subsidies and green innovation. The following testing model is constructed.

$$GI = \beta_0 + \beta_1 Gov + \beta_2 Finance + \beta_3 Gov * Finance + \alpha X + Year + Industry + \varepsilon \quad (3)$$

$$GI = \beta_0 + \beta_1 Gov + \beta_2 Market + \beta_3 Gov * Market + \alpha X + Year + Industry + \varepsilon \quad (4)$$

Among them, Finance represents the financing constraint level of the enterprise, and Market represents the market power of the enterprise.

The above models (3) and (4) respectively represent the regulatory role of financing constraints between government subsidies and green innovation, and the regulatory role of market power between government subsidies and green innovation. The specific testing steps mainly focus on the coefficient of interaction term β_3. If the coefficient of β_3 is significant, it indicates the existence of interaction effects. The coefficient of β_3 is positive, indicating that the moderator variable has a promoting effect on the dependent variable; The coefficient of β_3 is negative, indicating that the moderator variable has an inhibitory effect on the dependent variable.

5. Empirical Analysis

5.1 Descriptive Statistics

Table 2 provides descriptive statistics on the various variables defined earlier. It can be seen that the average annual green patent application volume of the sample enterprises is 4.642, with a maximum value of 1234 and a standard deviation of 30.120. This indicates that the overall level of green innovation achievements of enterprises during the study period is relatively low, and there are significant differences in green innovation levels among different enterprises; The average Natural logarithm of government subsidies is 15.900, and the standard deviation is 3.198, indicating that the subsidy intensity obtained by enterprises is not high, and the gap between government subsidies obtained by different enterprises is small.

Table 2 Descriptive statistical results of variables

Variable	Number of Samples	Mean	Standard Deviation	Minimum	Maximum
GI	34,551	4.642	30.120	0.000	1,234

Gov	34,551	15.900	3.198	0.000	20.460
Lisro	34,551	43.700	24.920	0.267	92.040
Age	34,551	9.700	7.611	0.000	31.000
Lev	34,551	0.419	0.209	0.050	0.899
Cap	34,551	0.206	0.159	0.002	0.693
Cr	34,551	30.770	14.330	3.620	68.090
Growth	34,551	0.157	0.397	-0.439	3.256
Market	34,551	2.767	0.216	2.033	3.531
Ros	34,551	-0.007	0.413	-2.243	0.736
HHID	34,551	0.107	0.114	0.019	0.748
Finance	34,551	3.469	0.315	2.895	4.172

5.2 Correlation Analysis

From the Pearson correlation analysis results in Table 3, it can be seen that there is a significant positive correlation between government subsidies and the level of green innovation of enterprises at the 1% level. Assuming H1 is preliminarily verified. It can also be seen that there is a significant correlation between control variables such as Lisro, Age, Growth, HHID, and the dependent variable GI, indicating that the selected control variable is more reasonable. In addition, the correlation coefficients between variables are mostly less than 0.5, so multicollinearity has little impact on the results.

Table 3 Correlation analysis of main variables

	GI	Gov	Finance	Market	Lisro	Age
GI	1					
Gov	0.103***	1				
Finance	-0.078***	-0.024***	1			
Market	-0.016***	-0.043***	0.080***	1		
Lisro	0.097***	0.077***	0.172***	0.080***	1	
Age	0.013**	-0.036***	0.936***	0.092***	0.229***	1
Lev	0.098***	0.070***	0.326***	0.037***	0.207***	0.375***
Cap	0.013**	0.087***	0.082***	0.016***	0.144***	0.094***
Cr	0.029***	0.00600	0.043***	0.098***	0.109***	0.055***
Growth	0.019***	-0.027***	0.017***	0.121***	0.030***	0.017***
Ros	-0.00100	-0.033***	0.069***	0.626***	0.081***	0.076***
HHID	0.053***	-0.016***	-0.00500	0.00700	0.102***	0.018***
	Lev	Cap	Cr	Growth	Ros	HHID
Lev	1					
Cap	0.097***	1				
Cr	0.080***	0.093***	1			
Growth	0.00700	-0.037***	0.027***	1		
Ros	0.039***	0.050***	0.157***	0.145***	1	
HHID	0.033***	0.058***	0.078***	0.010*	0.021***	1

Note: *** represents p<0.01, ** represents p<0.05, and * represents p<0.1.

5.3 Regression analysis

5.3.1 The impact of government subsidies on green innovation in enterprises

As shown in Model (1) in Table 4, government subsidies have a significant positive impact on green innovation in enterprises (β=0.838, P<0.01), indicating that government subsidies are beneficial for enhancing green innovation in enterprises and have a significant value creation effect. Therefore, H1 has been validated.

5.3.2 The regulatory effect of financing constraints

The model (2) in Table 4 tests the moderating effect of financing constraints on the relationship between government subsidies and green innovation, and the results show that the regression coefficient between financing constraints and the interaction term of government subsidies (Gov * Finance) is significantly negative (β=-1.330, P<0.01), therefore H2 has been validated, indicating that financing constraints negatively regulate the relationship between government subsidies and green innovation, as shown in Figure 1.

5.3.3 The regulatory role of market power

The model (3) in Table 4 tests the moderating effect of market power on the relationship between government subsidies and green innovation, and the results show that the regression coefficient of the interaction term between market power and government subsidies (Gov * Market) is significantly negative (β=-3.487, P<0.01), therefore H3 has been validated, indicating that market power negatively regulate the relationship between government subsidies and green innovation, as shown in Figure 2.

Table 4 Regression analysis results of variables

	Model (1) GI	**Model (2)** GI	**Model (3)** GI
Gov	0.838***	13.307***	4.532***
	(11.28)	(7.83)	(6.08)
Finance	-62.209***	-8.072	
	(-12.53)	(-1.40)	
Gov*Finance		-3.501***	
		(-7.65)	
Market	2.981***		23.470***
	(4.16)		(6.12)
Gov*Market			-1.329***
			(-5.13)
Lisro	0.067***	0.059***	0.093***
	(13.32)	(12.23)	(13.91)
Age	2.425***	2.517***	-0.052**
	(12.66)	(12.83)	(-2.25)
Lev	8.870***	8.343***	9.398***
	(12.35)	(11.88)	(12.61)
Cap	-0.472	-0.052	-0.386
	(-0.41)	(-0.05)	(-0.33)
Cr	0.016	0.017	0.023
	(0.70)	(0.75)	(1.01)
Growth	-0.158	-0.066	-0.192
	(-0.30)	(-0.13)	(-0.35)
Ros	-1.173***	-0.266	-1.192***
	(-3.21)	(-0.73)	(-3.11)
HHID	-1.195	0.258	4.579**
	(-0.57)	(0.12)	(2.15)
Constant	168.703***	-16.657	-82.626***
	(11.96)	(-0.78)	(-7.38)
N	34,551	34,551	34,551
R-squared	0.190	0.202	0.144
r2_a	0.188	0.200	0.141
F test	0	0	0
F	39.88	42.84	36.30

Note: *** represents p<0.01, ** represents p<0.05, and * represents p<0.1.

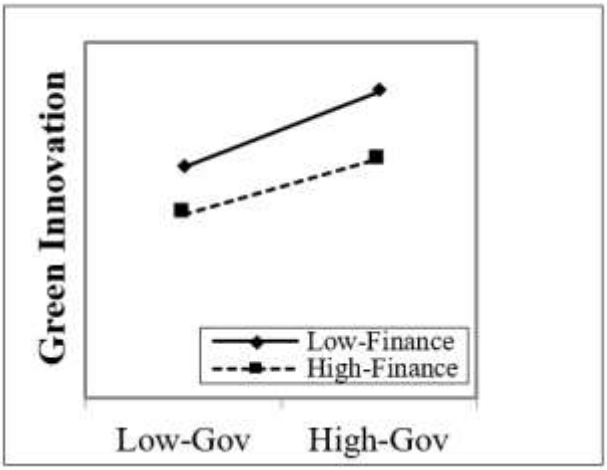

Fig. 1 Financing Constraints

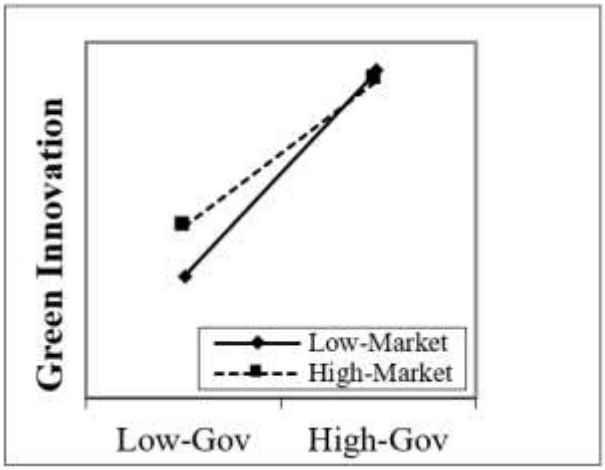

Fig. 2 Market Power

6. Robust Testing

6.1 Addition of regional fixed effects

In conducting regression analysis, in order to more accurately verify the impact of government subsidies on green innovation, financing constraints, and regulatory effects of market power, we introduced regional fixed effects. Regional fixed effects refer to incorporating regional factors into the model to control the impact of regional factors on the results. By introducing regional fixed effects, the interference of inherent regional differences on regression results can be eliminated, thereby enhancing the reliability and accuracy of regression results. Table 5 shows that after adding regional fixed effects, the results of each study remain consistent, indicating that the conclusions are robust and reliable.

Table 5 Regression analysis results of adding fixed effects to regions

	Model (1)	**Model (2)**	**Model (3)**
	GI	GI	GI
Gov	0.805***	12.836***	4.253***
	(11.02)	(7.71)	(5.82)
Finance	-60.376***	-8.317	
	(-12.52)	(-1.46)	
Gov*Finance		-3.377***	
		(-7.53)	
Market	2.998***		22.182***
	(4.18)		(5.90)
Gov*Market			-1.244***
			(-4.89)
Lisro	0.065***	0.057***	0.089***
	(13.35)	(12.29)	(14.02)
Age	2.395***	2.492***	-0.011
	(12.66)	(12.81)	(-0.49)
Lev	9.198***	8.640***	9.871***
	(12.89)	(12.40)	(13.21)
Cap	1.012	1.282	1.631
	(0.85)	(1.07)	(1.32)
Cr	0.017	0.018	0.024
	(0.76)	(0.80)	(1.07)
Growth	-0.163	-0.071	-0.194
	(-0.31)	(-0.14)	(-0.35)

Ros	-1.188***	-0.269	-1.217***
	(-3.26)	(-0.74)	(-3.18)
HHID	-1.096	0.307	4.332**
	(-0.53)	(0.15)	(2.06)
Constant	162.494***	-15.478	-79.135***
	(11.91)	(-0.74)	(-7.23)
N	34,551	34,551	34,551
R-squared	0.200	0.212	0.157
r2_a	0.197	0.209	0.154
F test	0	0	0
F	41.46	44.29	36.93

Note: *** represents p<0.01, ** represents p<0.05, and * represents p<0.1.

6.2 Replacement of sample cycle

The year range of this sample is 2010-2021, and during this period, the COVID-19 has had a significant impact on society. In order to make the regression results more reliable, we divide the sample cycle again, and tests 2020 and 2021 as important samples separately. Table 6 shows that in the stage of COVID-19, the conclusions are still robust and reliable.

Table 6 Regression analysis results of changing sample cycles

	Model (1)	**Model (2)**	**Model (3)**
	GI	GI	GI
Gov	0.386***	3.771***	2.018***
	(7.25)	(4.32)	(4.42)
Finance	-9.981***	5.987**	
	(-4.81)	(2.24)	
Gov*Finance		-0.944***	
		(-4.06)	
Market	-1.135		7.771***
	(-1.09)		(3.00)
Gov*Market			-0.541***
			(-3.77)
Lisro	0.004***	0.002	0.010***
	(3.17)	(1.46)	(5.03)
Age	0.400***	0.393***	0.010
	(4.85)	(4.87)	(1.18)
Lev	0.589***	0.465**	0.742***
	(2.98)	(2.34)	(3.79)
Cap	-0.337	-0.187	-0.385
	(-0.84)	(-0.47)	(-0.93)
Cr	0.067***	0.055***	0.064***
	(2.95)	(3.87)	(2.76)
Growth	-2.576*	-2.829**	-2.613*
	(-1.91)	(-2.23)	(-1.88)
Ros	0.171	-0.028	0.228
	(0.90)	(-0.17)	(1.16)
HHID	3.705	3.915*	3.728
	(1.58)	(1.73)	(1.64)
Constant	25.785***	-34.096***	-32.147***
	(4.20)	(-3.26)	(-3.97)
N	8,198	8,198	8,198
R-squared	0.132	0.144	0.093
r2_a	0.123	0.135	0.0828
F test	0	0	0
F	10.70	11.36	9.940

Note: *** represents p<0.01, ** represents p<0.05, and * represents p<0.1.

6.3 Lag period analysis

In order to avoid endogeneity issues where government subsidies may affect the output of green innovation, we use the number of green patent applications with a lag of one period to replace the current number of green patent applications for testing. Table 7 shows that the research results remain consistent in this test, indicating that the conclusions are robust and reliable.

Table 7 Regression analysis results of lag period

	Model (1) GI	**Model (2)** GI	**Model (3)** GI
Gov	0.829***	13.871***	5.505***
	(9.35)	(6.87)	(5.95)
Finance	-65.876***	-9.300	
	(-11.83)	(-1.28)	
Gov*Finance		-3.667***	
		(-6.74)	
Market	1.091		27.570***
	(1.06)		(5.79)
Gov*Market			-1.676***
			(-5.27)
Lisro	0.069***	0.061***	0.096***
	(11.84)	(10.80)	(12.73)
Age	2.559***	2.648***	-0.089***
	(11.91)	(12.12)	(-3.11)
Lev	10.980***	10.480***	11.357***
	(12.08)	(11.76)	(12.09)
Cap	-0.703	-0.224	-0.550
	(-0.53)	(-0.17)	(-0.40)
Cr	-0.004	-0.001	-0.000
	(-0.14)	(-0.04)	(-0.00)
Growth	1.095	1.121	1.021
	(1.37)	(1.42)	(1.23)
Ros	-1.083*	-0.718	-1.331**
	(-1.80)	(-1.40)	(-2.11)
HHID	-1.145	0.032	5.564**
	(-0.42)	(0.01)	(2.01)
Constant	185.304***	-13.783	-93.797***
	(11.41)	(-0.52)	(-6.76)
N	28,939	28,939	28,939
R-squared	0.192	0.205	0.148
r2_a	0.189	0.202	0.146
F test	0	0	0
F	33.18	35.33	30.60

Note: *** represents p<0.01, ** represents p<0.05, and * represents p<0.1.

6.4 2SLS

The financial subsidies received by enterprises mainly come from local governments, and the government subsidies available to enterprises in the same region are highly overlapping. From the perspective of correlation, there is a correlation between the government R&D subsidies received by a specific enterprise in the province and the average R&D subsidies received by other enterprises in the same province, while the amount of R&D subsidies received by other enterprises in the province is not directly related to the production behavior of that specific enterprise [33]. In order to further eliminate the endogenous problem and estimate its research results again, using the method of Huang

et al. [34] for reference, we select the average subsidy value obtained by other enterprises in the province where the enterprise belongs as the Instrumental variables estimation of government subsidies received by the enterprise. The specific calculation method is shown below:

$$IVE = \frac{\sum_{1}^{n} E_x - E_x}{n-1} \tag{5}$$

Used to represent the subsidy value of enterprises Ex in a specific year or region, and n is used to represent the number of enterprises in a specific year or region. As shown in Table 8, using 2SLS for regression, it was found that the empirical results were consistent with the main regression results.

Table 8 Regression analysis results of 2SLS

	Model (1)
	GI
Gov	5.658***
	(13.32)
Lisro	0.0449***
	(5.20)
Age	0.0446
	(1.47)
Lev	6.580***
	(6.11)
Cap	-10.20***
	(-7.63)
Cr	0.0317**
	(2.47)
Growth	2.211***
	(4.78)
Ros	0.630
	(1.37)
HHID	15.40***
	(9.53)
Constant	-91.35***
	(-14.17)
N	34551

Note: *** represents p<0.01, ** represents p<0.05, and * represents p<0.1.

7. Conclusions and Recommendations

7.1 Research Conclusion

Based on the panel data of Chinese A-share listed companies in Shanghai and Shenzhen from 2010 to 2021, we empirically test the impact of government subsidies on corporate green innovation, and respectively verifies the moderating effect of financing constraints and market power on this impact. The following conclusions are drawn: Firstly, with the increase of government subsidies, the higher the level of green innovation of enterprises. Secondly, with the strengthening of financing constraints, the relationship between government subsidies and green innovation is weakened; Thirdly, with the strengthening of market power, the relationship between government subsidies and green innovation has been weakened.

7.2 Recommendations

First, green innovation of enterprises has significant Externality. The government can use financial subsidy policies to drive enterprises to actively carry out green innovation activities and alleviate the

pressure on enterprises' green innovation resources. At the same time, in the context of strong government support for green innovation under the national concept of green development, enterprises should open up their hands and dare to carry out green innovation activities with high technical difficulties, large competitive advantages and high environmental benefits, so as to achieve green and sustainable development of regional economy.

Secondly, financing constraints negatively regulate the relationship between government subsidies and green innovation. The government should establish a more comprehensive subsidy distribution mechanism, implement differentiated subsidy policies, and appropriately focus on enterprises with low financing constraints, so that government subsidies can maximize the promotion of green innovation. At the same time, under high financing constraints, enterprises should choose appropriate financing paths based on their own development conditions, expand financing channels, reduce financing difficulties, and better play the role of government subsidies in their own green innovation. Secondly, establish and improve the information disclosure mechanism of enterprises, so that external investors can timely obtain information on the development status and performance of enterprise technology innovation, reduce financing constraints caused by information asymmetry, and potentially obtain more financing opportunities to alleviate financing constraints.

Thirdly, market power negatively regulate the relationship between government subsidies and green innovation. The government should establish a subsidy distribution mechanism that implements differentiated subsidies for different types of enterprises, set indicator weights based on the strength of enterprise market dominance, optimize the allocation status of green innovation financial and tax subsidies among enterprises with different market power, and motivate enterprises to implement organizational changes conducive to green innovation [35]. At the same time, market power may strengthen the resource inertia of enterprises towards existing technological innovation, leading to insufficient investment in green innovation. Therefore, enterprises should avoid excessive reliance on existing investment models and reduce the crowding out of green innovation resources. Resource inertia refers to an organization's failure to change its resource investment model when facing significant external changes [36]. In addition, for enterprises with large market power, they can strengthen their investment in green innovation, further maintain their market competitive advantage and leadership position, and improve social development and welfare. For enterprises with relatively small market power, they can increase green innovation investment and expand their competitive advantage through government subsidies and profits obtained in the market.

7.3 Research Shortcomings and Prospects

We have made a preliminary exploration of the effect of government subsidies on green innovation in enterprises, and has included exploration of financing constraints and market power regulation effects. However, there are certain limitations that can be expanded in the following aspects in the future: Firstly, in terms of data sources, we only select the overall government subsidies to measure the impact on the green innovation ability of enterprises, and does not refine them into "Green Government Subsidies" data, May have a certain impact on the results. In the future, we can collect first-hand data on green government subsidies through on-site visits, face-to-face interviews, and other forms, in order to obtain more accurate results. Secondly, we only select the annual number of green patent applications to measure the green innovation capability of enterprises. In the future, indicators such as the proportion of green product sales revenue to total revenue can be selected for more comprehensive testing and analysis [2]. Finally, in terms of research scope, we use companies from the listed company database as samples, and the probability of these companies receiving government subsidies is much higher than that of non-listed companies. However, the majority of non-listed companies receive government subsidies, which may lead to sample selection problems in studies that only select listed companies as samples [12]. Therefore, with the continuous improvement of data in relevant databases, we can further expand its scope and thoroughly test the relevant conclusions.

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