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Research on the Influence Mechanism of Venture Capital and Enterprise Green Innovation

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Abstract

As Venture Capital (VC) becomes more prevalent in global capital markets, its role in driving green innovation has gained significant attention. Using data from listed companies between 2010 and 2023, this paper empirically examines the impact of VC on corporate green innovation. The findings reveal that VC significantly enhances corporate green innovation levels, and this conclusion remains robust after a series of robustness checks and endogeneity analyses. Heterogeneous analysis indicates that the positive role of VC is more pronounced in companies serviced by the Big Four auditing institutions and in manufacturing groups. The mechanism examination shows that VC drives green innovation by alleviating financing constraints and optimizing governance supervision. Our study suggests that VC not only provides financial support but also aids in the implementation of corporate green innovation strategies. These findings are highly significant for encouraging VC institutions to support corporate green transformation and for achieving sustainable economic and environmental development.

Keywords

Venture Capital; Green Innovation; Financing Constraints; Corporate Governance.

1. Introduction

Green innovation, as a key force in promoting sustainable development, plays a pivotal role in the present era. It is not only a core element for realizing the coordinated progress of the economy, society and the environment, but also has a bearing on China's position and future direction in the global green competition pattern. The report of the 20th Party Congress emphasized that "promoting green development and harmonious coexistence between human beings and nature", and explicitly called for accelerating the innovation and application of green technology to provide strong support for the high-quality development of China's economy and society. However, China's enterprises still face many difficulties in the practice of green innovation, and green technology research and development investment is large and high risk [47]. These problems seriously restrict the development of green innovation, therefore, it is of great practical significance and theoretical value to deeply investigate the influencing factors of enterprise green innovation and its role mechanism.

Numerous literatures have revealed the driving mechanism of corporate green innovation from multiple dimensions.Government regulatory pressure and environmental non-governmental organizations (ENGOs) have a significant effect on corporate green innovation based on the institutional theory[3].The public awareness of environmental protection through the mechanism of public opinion monitoring positively influences the green innovation and investment of corporations[14].At the level of policy tools, environmental regulatory tools such as sewage tax rates and sewage permit prices have an incentive effect on enterprises' green technological innovation[46]; ewage trading pilot policies effectively induce innovative activities

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in polluting industries through the price signaling mechanism[32]; and pilot policies for low-carbon cities stimulate the overall innovation response of enterprises through the regional demonstration effect[45];environmental protection tax reform has a significant role in promoting green innovation activities of enterprises[28]. Recent studies have further deepened into the field of fiscal and taxation policies, based on the existing literature, which mostly focuses on external drivers such as government regulation, public pressure and policy tools, this paper focuses on internal drivers, i.e., the impact of venture capital on corporate green innovation, to provide a new perspective for improving the green innovation driving system.

Theoretically, venture capital (VC) has a significant role in promoting corporate green innovation. From the perspective of certification supervision function, VC optimizes the corporate decision-making process, reduces the agency cost, and improves the corporate governance level of invested enterprises through board supervision[36]. In addition VCs have rich management experience and can help enterprises optimize their governance structure and improve management efficiency[10].Firms with VC participation are more specialized in human resource policies, equity incentive implementation, and the hiring of marketing executives[16]. From the perspective of providing social resources, VCs have rich interpersonal and social network resources, and by virtue of their relational networks they can improve their ability to utilize investment opportunities and assist in the rapid development of invested firms[5]. Through the relationship network, enterprises can also obtain resources from the outside world and make full use of them in order to realize value appreciation [13]. In addition, venture capital participation helps to promote the formation of strategic alliances among enterprises, effectively utilizing their information advantages and other resources to promote enterprise development[26]. Venture capital provides systemic support for green innovation by alleviating corporate financing constraints, supervising corporate governance and providing social resources.

However, venture capital may also have an inhibitory effect on corporate green innovation. The impact of venture capital on corporate innovation in China is not linear, showing a "U-shaped" curve relationship that first decreases and then increases, i.e., venture capital will inhibit the development of corporate innovation to a certain extent during a certain period of time at the early stage of investment[41]. In addition, there is a target conflict between the short-term exit demand of venture capital and the long-cycle characteristics of green innovation.Venture capital usually pursues short-term returns, while green innovation projects require long-term R&D investment and market cultivation, which can lead to instability and unsustainability of venture capital's support for corporate innovation[9]. The high degree of uncertainty of green innovation makes it more dependent on continuous and stable financial support, and the short-termist tendency of venture capital may lead to fluctuations in corporate R&D investment, which in turn inhibits the development of green innovation[37]. At the same time, venture capital organizations may intervene excessively in the decision-making process of enterprises in the process of participating in the management of enterprises, which may lead to the mismatch or loss of green innovation resources and limit the breakthrough of enterprise innovation[42]. In summary, when the short-term goals of venture capital are inconsistent with the long-term needs of enterprise green innovation, its role in promoting enterprise green innovation may be weakened, and may even have a negative effect.

Existing studies have not yet formed a consistent conclusion on the theoretical direction of venture capital's influence on corporate green innovation, and need to clarify its role path through empirical analysis. Taking A-share listed companies from 2010 to 2023 as samples, this paper finds that venture capital has a significant positive facilitating effect on corporate green innovation, and this conclusion still holds after controlling the endogeneity problem and multi-dimensional robustness test. Heterogeneity analysis shows that this facilitating effect is more prominent among firms audited by Big Four accounting firms and manufacturing firms,

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reflecting the strengthening of the effect of information transparency and industry pollution degree. Mechanism tests reveal that venture capital promotes green innovation mainly through two paths: alleviating financing constraints and strengthening supervision and management, with the former breaking through resource bottlenecks and the latter optimizing the efficiency of strategy implementation. The findings are in line with the theoretical expectation that venture capital promotes green innovation in enterprises, and provide policy insights for enterprises to achieve green development goals.

The contributions of this paper may include: first, expanding the research dimension of the economic consequences of venture capital. Existing research on the direction of venture capital mostly focuses on its impact on firm performance[2], IPO timing[21], corporate governance [36], and traditional innovation activities [15,10], and insufficient attention has been paid to it in the field of green innovation. On this basis, this paper deeply explores the influence mechanism of venture capital on enterprise green innovation, a specific type of innovation, to further enrich the theoretical connotation of the relationship between venture capital and enterprise green innovation. Second, it deepens the understanding of the factors influencing corporate green innovation. Previous studies have mainly explored the influencing factors of corporate green innovation from the external macro-environmental factors such as government policy[7] and market competition[19], as well as from the internal micro-subjective characteristics such as R&D investment[51] and profitability[22] of enterprises. And this paper cuts in from the perspective of venture capital, revealing the driving role of venture capital on enterprise green innovation in terms of financing constraints and supervision and management, providing new ideas and directions for enterprise green innovation management practice. Thirdly, it has important practical significance. At present, the global environmental problems are getting more and more serious, and the concept of sustainable development is deeply rooted in people's hearts, in this context, the green innovation of enterprises has become the key to realize the coordination and co-progress of economic development and environmental protection. The research of this paper helps to clarify the role of venture capital and influence mechanism, so as to grasp the relationship between venture capital and enterprise green innovation more accurately, and to promote the green transformation of enterprises.

The structure of this paper is as follows: the second part is the literature review, the third part is the research hypothesis and empirical design, the fourth part is the empirical analysis, the fifth part is the mechanism test, and the sixth part is the conclusion and recommendation.

2. Literature Review

Relevant studies on venture capital. VentureCapital (VC for short) is a kind of equity investment as the core, focusing on providing financial support to startups or innovative projects with high growth potential and participating in the management of financial activities, which is an important financing channel and risk-sharing carrier for scientific and technological, growth-oriented startups. Its core features are manifested in three aspects: First, high risk and high return coexist, VC institutions bear high risk of failure, but successful projects can bring high returns; second, phased investment, VC institutions according to the life cycle of the enterprise to dynamically adjust the injection of funds and valuation strategy; third, active participation in the enterprise's operation, VC institutions not only provide capital, but also through strategic guidance, resource docking and management optimization of the depth of intervention in the development of the enterprise, forming a "capital + risk-sharing carrier". VC is an important promoter of scientific and technological innovation for enterprises and helps to form the ecology of emerging industries, but at the same time, the excessive profit-seeking nature of VC may force enterprises to deviate from their long-term innovation goals for short-term returns.

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With the rapid development of the venture capital industry, academic research on VC has been deepening. Domestic and international research on VC mainly focuses on two aspects. A part of the literature focuses on the impact of VC on the aspects of corporate business activities, and VC has a significant impact on corporate governance, corporate performance and innovation activities through expertise output, resource integration and governance optimization. From the perspective of corporate governance, firms with VC involvement are more specialized in human resource policies, implementation of equity incentives, and hiring of marketing executives, etc[16]. VCs can optimize firms' strategic decisions and promote operational efficiency by leveraging their information advantages and industry resources[26]. The pay performance sensitivity of listed companies with VC participation is higher, suggesting that VCs improve governance by strengthening incentive and constraint mechanisms[36]. In terms of corporate performance, due to VC participation, positive signals of corporate health will be released and the contractual efficiency between the company and its customers will be improved[12]. Firms with VC ownership have better customer stability. In addition[48], VC involvement significantly increases the sales and productivity of portfolio companies[8]. And Wu, Chaopeng et al. reveal the positive role of VC in curbing the abuse of corporate free cash flow and alleviating the problem of underinvestment[42]. In terms of firms' innovation activities, VC entry promotes portfolio firms' innovations and increases firms' innovation investment[15, 10].The impact of VC on innovation shows a "U-shaped" curve relationship that first decreases and then increases[41].

Another part of the literature focuses on the impact of VC on the IPO aspect of firms. As an important point in the firm's life cycle, IPO is both a major exit channel for VCs and a key test of their value creation ability.VC-backed firms exhibit better financial performance and investor returns after IPO[2].VC-backed IPO firms have significantly better market performance than non-VC-backed firms.VC-backed IPO firms significantly outperform non-VC-backed firms, which is closely related to the brand endorsement and resource empowerment of VCs, and the more experienced the VC is, the higher the probability of successful IPO for the portfolio firm[33]. From the perspective of listing timing, here is a "timing effect" in VCs, i.e., to promote the listing of a company at a high market valuation in order to maximize financing returns[21]. This strategy not only reflects the market acumen of VCs, but also their demand for profit maximization. However, VCs participate in IPOs of firms with higher discount rates, suggesting that VCs may build up their industry reputation through a discounted exit strategy, thus attracting subsequent capital inflows[9]. In addition, the performance of foreign VCs is unique: foreign VCs tend to adopt a prudent investment strategy and improve corporate profitability by optimizing corporate governance structure, which ultimately reduces the IPO discount rate and improves long-term returns[49]. The above studies collectively show that VCs play the dual roles of market guides and interest coordinators in the IPO process, and their behavioral patterns profoundly affect the resource allocation efficiency of the capital market.

Research related to green innovation. Green innovation is a systematic innovation activity carried out by enterprises to meet environmental challenges and realize sustainable development, covering the innovation of technology, products, processes and management modes, which can not only realize value-added for customers and enterprises, but also significantly reduce the negative impact on the environment. Different from traditional innovation, green innovation emphasizes the adoption of new technologies and concepts to achieve efficient use of resources and effective reduction of pollution, and at the same time obtain the corresponding economic performance. Its core objective is to balance economic and environmental benefits by reducing resource consumption, lowering pollution emissions and improving eco-efficiency. In terms of consequences, green innovation can not only alleviate environmental pressure and enhance resource utilization efficiency, but also enhance market position through differentiated competition, shape corporate green brand image, and even

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promote the overall transformation of the industry to low-carbonization. Therefore, green innovation is increasingly recognized as an important strategy for enterprises to gain sustainable competitive advantages in the new arena.

In recent years, research on green innovation at home and abroad mainly focuses on two aspects, on the one hand, the internal driving factors of green innovation, and on the other hand, the external driving factors of green innovation. The internal driving mechanism focuses on the enterprise's own resource input, technology accumulation and strategic choice, and enhances the enterprise's innovation effectiveness through optimizing resource allocation and capacity building. Firstly, in terms of optimizing resource allocation, the input of corporate environmental governance costs is significantly positively correlated with the number of green patents[4]. Through in-depth research that the intensity of R&D investment has a more obvious role in promoting green innovation efficiency in high-tech industries[37]. The promotion effect of R&D investment on green technological innovation is enhanced over time, indicating that continuous investment can form the advantage of technology iteration[51]. Secondly, it is the optimization of innovation capacity, the positive impact of internal innovation capacity on green innovation strategy far exceeds that of innovation resources, highlighting the importance of technology accumulation and management experience[7]. In addition, financial capability and strategic orientation should not be ignored.High profitability firms are more likely to take the risk of green product innovation and gain long-term benefits through brand premiums[22];while executive environmental awareness plays a key role in regulating the relationship between policy pressure and innovation resources[7]. Together, these studies suggest that firms need to transform their green goals into substantial innovations by optimizing resource allocation and enhancing innovation capabilities.

The external environment shapes corporate green innovation behavior through institutional constraints and social constraints together. Policy regulation is the core driving force. Environmental regulatory tools such as emissions tax rates and emissions permit prices significantly incentivize enterprises to innovate in green technology[46], and emissions trading pilot policies induce innovative activities in polluting industries through market-based mechanisms[32]. Pilot policies for low-carbon cities stimulate the overall innovation response of enterprises through regional demonstration effects[45]. However, there is heterogeneity in the effects of the policies: while sewage charges stimulate innovation through a "push" mechanism, environmental protection subsidies may have a "crowding-out effect" due to rent-seeking behavior [23]. In terms of social constraints, green credit policy leads to increased innovation activity in restricted industries through financing constraints[38], while consumers' willingness to pay for high-value-added green products creates a market push[19], and that the green market and demand for low-cost energy directly drive technological transformation [11]. Public awareness of environmental protection influences corporate reputation through public opinion monitoring and promotes corporate green innovation[14]. In addition,both government regulatory pressure and pressure from ENGO organizations are effective in promoting firms' green innovation[3]. In addition, government R&D subsidies have a positive effect on strategic innovation performance, but have an inverted U-shaped relationship with substantive innovation, and over-reliance on short-term subsidies needs to be avoided [39]. These studies suggest that enterprises build sustainable innovation ecosystems through the synergy of external factors such as precise policies, market response and social participation.

Literature review. Existing literature has systematically sorted out the core role of venture capital (VC) in optimizing enterprise operations and promoting the IPO process, revealing its intrinsic mechanism of empowering enterprise innovation and development through both capital and services. Meanwhile, research in the field of green innovation focuses on the driving path of internal resource capacity integration and external market synergy, and clarifies the strategic choice for enterprises to realize a balance between economic and environmental

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benefits. However, existing studies have not yet explored in depth the key topic of how venture capital affects corporate green innovation, especially lacking empirical tests of the dynamic role mechanisms of VC financing constraints and supervision and management on innovative behaviors such as corporate green technology development. This paper empirically analyzes the effect of venture capital on corporate green innovation, and reveals the unique value of VC in promoting sustainable development under the goal of "dual carbon". This study not only expands the theoretical dimension of the economic consequences of venture capital, but also provides a new perspective for the integration and analysis of the driving factors of green innovation, which is an important revelation for the improvement of the green financial policy system and the optimization of the VC empowerment path.

3. Research Hypotheses and Empirical Design

Research hypotheses. The traditional certification hypothesis holds that VCs have the functions of certification and monitoring. From the certification perspective, VC's participation through rigorous ex-ante screening can not only bring financing to firms, but also signal superior firm quality to the market, significantly alleviate the information asymmetry between firms and external stakeholders, and reduce the financing friction of firms' green technology R&D [30]. From a monitoring perspective, VCs bind their own interests through equity exit proceeds, and thus have sufficient incentives to monitor and supervise the management of invested projects while providing capital to firms [6,20].Firms with more patents in the IPOs are able to obtain higher market valuations, so VCs will ensure that firms' long-term strategic resources are skewed toward green innovation through regulation[17]. This dual-function attribute of "certification-supervision" enables VCs not only to attract external capital injection, but also to enhance the scientific nature of corporate innovation decision-making through institutionalized governance, thus providing dual support for green innovation in terms of both resource guarantee and institutional guarantee.

1) Venture capital can ease financing constraints. VC significantly alleviates the financing constraints of enterprises' green innovation through the financing injection mechanism and signaling mechanism. On the one hand, VC can directly provide financing for enterprises and significantly alleviate their financing constraints through equity investment and joint investment.[42]On the other hand, due to the participation of venture capital, enterprise stakeholders will take the participation of venture capital as a positive signal for the healthy development of the enterprise, and this positive signal alleviates the stakeholders' concerns about enterprise risks, reduces the unnecessary costs between them due to information asymmetry, and enhances the contractual efficiency between the company and its customers[12], and also attracts external follow-on investments to alleviate corporate financing constraints [26].

2) Venture capital can supervise and manage enterprises. VCs supervise and manage enterprises by improving corporate governance and effectively supervising management. First, as professional investors, VCs usually have rich experience in corporate management and have accumulated certain industry experience and resources in the fields they invest in, and can help investee companies improve their value-added capabilities in a variety of ways.VCs enhance the level of corporate governance of investee companies through a series of measures such as resident directors to reduce the agency problem in the process of their operation, and then realize the value-added [29]. In addition, VC participation in enterprises can effectively supervise management and inhibit managers' opportunistic behaviors such as surplus management [1,31], and the supervisory role of VC on investee firms makes this risk greatly reduced and effectively saves the agency cost of the firm.

3) Financing constraints and supervisory and regulatory impacts on green innovation. The high risk and positive externalities of green innovation require the dual support of financing

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guarantees and regulatory guarantees. In terms of financing constraints, technological innovation by enterprises usually requires high inputs, and the results are highly uncertain, which makes enterprises engaging in innovation face greater risks and more volatile short-term financial performance[40]. Green innovation is also characterized by a long R&D cycle, high technological risk, and large upfront investment, so its process is vulnerable to being hindered by a broken capital chain or insufficient liquidity [37].VC reduces the information asymmetry between enterprises and stakeholders by providing a stable flow of capital, bridges the long-term capital gap required for green innovation, and reduces the likelihood that enterprises will cut back on R&D investment due to a lack of capital. thereby promoting corporate green innovation[10]. In terms of supervision and management, due to the existence of positive externalities of green innovation, but its lagging economic returns are prone to triggering the management's pursuit of short-term performance, which leads to the problem of under-allocation of innovation resources within the enterprise.By supervising the management, VCs can create a good business environment, inhibit opportunistic behaviors, and ensure that resources are tilted towards green innovation projects [16]. Then VCs use their own management experience and industry resources to optimize the level of corporate governance, which can improve internal efficiency, reduce agency costs, and ensure that more resources flow to green innovation projects[48]. In summary, VCs can effectively promote corporate green innovation through financing constraints and supervision and management, so the following hypotheses are proposed.

Hypothesis H1: Venture capital can positively promote corporate green innovation.

Modeling. In order to verify the impact of venture capital on corporate green innovation, this paper sets up model (1) to test it with reference to the practices of Chen Si et al. and Zhang Guangdong and Shao Yan[10,48]:

$$Green_{i,t+1} = \alpha + \beta VC_{i,t} + \gamma Control_{i,t} + \sum Year + \sum Industry + \varepsilon_{i,t}$$

Where *Green* is the explanatory variable of the paper, *VC* is the core explanatory variable of the paper, Control is the set of control variables and ε is the random error term.

4. Definition of Variables

1) Explained variable: corporate green innovation. *Green* for corporate green innovation. When exploring the aspect of Green to measure corporate green innovation, three common measurement methods in existing studies can be drawn upon. First, the ratio of R&D investment to waste emissions is used to construct an assessment index for green technological innovation [24]. Second, it is based on the green patent-related data published by listed companies as the basis of measurement [27]. Third, it is measured from two different dimensions of products and processes [35]. In this paper, the total number of green patents applied independently or jointly by listed companies in the observation year is selected as a measurement indicator. The number of green patents applied by enterprises in the same year can reflect to a certain extent the active degree of green technological innovation of enterprises, and can also map the stimulating effect of external stakeholders, especially venture capital institutions, on the green technological innovation behavior of enterprises.

2) Explanatory variables: venture capital. *VC* is venture capital. Referring to the existing literature [43,48], *VC* is set as a dummy variable, and the judgment is made according to whether there are venture capital institutions in the top ten shareholders of the listed company in the current period of the observation year; in the disclosure of the listed company, if the names of the institutions belonging to the top ten shareholders include the words of "high-tech

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investment", "high-tech investment" and "innovative investment", it is unanimously considered that the listed company is a company with the background of venture capital. In the disclosure of the listed company, if the names of the organizations to which its top ten shareholders belong include the words "high-tech investment", "high-tech investment" and "innovation investment", it is unanimously considered that they belong to venture capital organizations, and it is considered that this kind of listed company is a company with the background of venture capital. If there is, the value is assigned to 1, if not, the value is assigned to 0. This paper focuses on the estimation of regression coefficient β. If the estimation value is significantly positive, it indicates that venture capital promotes green innovation of enterprises, and the hypothesis of this paper is proved.

3) Control variables. Control is a series of control variables, including gearing ratio (*Lev*), net profit margin on total assets (*ROA*), firm size (*Size*), years of listing (*ListAge*), cashflow ratio (*Cashflow*), Tobin's Q (*TobinQ*), shareholding ratio of top ten shareholders' holdings (*Top10*), growth rate of operating income (*Growth*) , Fixed Asset Share (*Fixed*), Management Shareholding (*Mshare*), Executive Compensation Incentive (*Pay*), and Independent Director Share (*Indep*).*Year* and Industry indicate that the paper controls for year and industry fixed effects, respectively. Specific variables are defined below.

Table 1. Description of variable names and definitions

	variable name	variable symbol	Variable Definition
explanatory variable	Total green patent applications	*Green*	ln (number of green patents filed by the enterprise in the year + 1)
explanatory variable	venture capital	*VC*	If the firm receives venture capital, take 1, otherwise take 0
control variable	gearing	*Lev*	Total liabilities/total assets
	Net profit margin on total assets	*ROA*	Net profit/average of total assets at the beginning and end of the period
	Company size	*Size*	ln (total assets at the end of the period)
	Number of years listed	*ListAge*	ln (current year year - year of listing + 1)
	Cash flow ratio	*Cashflow*	Net cash flows from operating activities/total assets
	Tobin's Q	*TobinQ*	(Market value of equity + book value of liabilities)/total assets
	Top Ten Shareholders' Shareholding Shareholding Ratio	*Top10*	Total shareholding of top ten shareholders
	Revenue growth rate	*Growth*	(Current year's operating income - prior year's operating income)/prior year's operating income
	Fixed assets as a percentage	*Fixed*	Net fixed assets/total assets
	Management shareholding	*Mshare*	Management shareholding/total share capital
	Executive compensation incentives	*Pay*	ln (total annual remuneration of management)
	Percentage of independent directors	*Indep*	Number of independent directors/directors

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4) Data sources. This paper empirically examines the impact of venture capital intervention on green innovation of China's A-share listed companies. In terms of sample selection, this paper selects a sample of all listed companies in China's A-share market from 2010 to 2023, in which the financial data involved in the study come from the database of Cathay Pacific (CSMAR), the details of the top ten shareholders of listed companies come from the database of CSMAR, and a list of names of VC institutions is exported from the database of CVsource for cross-checking. The number of green patent applications and acquisitions of listed companies are from China Research Data Service Platform (CNRDS). In addition, this paper carries out the following cleaning steps on the raw data: firstly, excluding enterprises with abnormal business status, such as ST, *ST, PT and enterprises delisted during the period; secondly, excluding listed companies in the sample whose industry is financial according to the industry classification standard of the Securities and Exchange Commission (SEC) in 2012; thirdly, excluding listed companies with missing numbers of green patents filed and obtained; fourthly, retaining those companies which samples that do not have missing data for at least five consecutive years; and fifth, to eliminate the effect of data extremes by shrinking the upper and lower 1% of all continuous variables. A total of 29,018 panel data observations are obtained after screening, of which 7,431 observations are with venture capital involvement and 21,587 observations are without venture capital involvement. The following table shows the descriptive statistics of the key variables.

Table 2. Descriptive statistics of variables

variant	(1)	(2)	(3)	(4)	(5)
	sample size	average value	variance (statistics)	minimum value	maximum values
Green	28997	0.326	0.733	0.000	3.611
VC	28997	0.256	0.436	0.000	1.000
Lev	28997	0.420	0.203	0.056	0.887
ROA	28997	0.040	0.062	-0.212	0.220
Size	28997	22.250	1.292	19.980	26.310
ListAge	28997	2.175	0.787	0.693	3.367
Cashflow	28997	0.048	0.067	-0.146	0.239
TobinQ	28997	2.040	1.300	0.841	8.406
Top10	28997	0.580	0.152	0.230	0.904
Growth	28997	0.156	0.351	-0.523	1.964
Fixed	28997	0.213	0.158	0.002	0.693
Mshare	28997	13.200	19.270	0.000	67.510
Pay	28997	15.350	0.728	13.570	17.340
Indep	28997	37.610	5.366	33.330	57.140

The results of descriptive statistics show that the mean value of enterprise green innovation level (*Green*) is 0.326, indicating that the overall level of enterprise green innovation activities is low, but there are some enterprises with active green innovation, whose maximum value reaches 3.611; the mean value of venture capital participation (*VC*) is 0.256, which means that about 25.6% of the enterprises are supported by venture capital, and the standard deviation is 0.436, showing that significant differences in the distribution of VC among enterprises. The average of enterprise financial leverage (*Lev*) is 0.420, the average of return on assets (*ROA*) is 0.040, and the average of enterprise size (Size) is 22.250, and the gap between the maximum and minimum values of these variables is large, reflecting the heterogeneity among enterprises.The standard deviation of both *Green* and *VC* is large, 0.733 and 0.436, respectively, which indicates that the level of enterprise green innovation and the level of VC participation

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level are significantly different among different enterprises, which provides a suitable basis for studying the impact of VC on corporate green innovation and makes the regression analysis effective in capturing the potential relationship between variables.

5. Empirical Findings

Table 3. Benchmark regression

variant	(1)	(2)	(3)	(4)
	Green	*Green*	*Green*	*Green*
VC	0.238***	0.198***	0.182***	0.148***
	(11.428)	(10.300)	(9.721)	(8.419)
Lev			0.153***	0.168***
			(3.052)	(3.481)
ROA			0.229**	0.415***
			(1.968)	(3.717)
Size			0.121***	0.121***
			(7.692)	(8.214)
ListAge			-0.141***	-0.060***
			(-9.978)	(-4.231)
Cashflow			-0.061	0.053
			(-0.679)	(0.639)
TobinQ			0.022***	0.014**
			(3.981)	(2.442)
Top10			-0.328***	-0.149**
			(-4.438)	(-2.257)
Growth			-0.012	-0.035***
			(-0.917)	(-2.851)
Fixed			-0.094	-0.069
			(-1.536)	(-0.991)
Mshare			0.001*	-0.000
			(1.905)	(-0.328)
Pay			0.080***	0.082***
			(5.180)	(5.079)
Indep			0.001	0.001
			(0.677)	(0.353)
Constant	0.265***	-0.003	-3.291***	-3.679***
	(29.063)	(-0.086)	(-9.486)	(-10.587)
Observations	28997	28997	28997	28997
R^2	0.020	0.141	0.077	0.196
industry effect	NO	YES	NO	YES
vintage effect	NO	YES	NO	YES

Note: ***, ***, and * indicate that the statistical tests are significant at the 1%, 5%, and 10% levels, respectively. The t-values are in parentheses, where the standard errors are adjusted for firm-level clustering, and the rest of the table is the same.

Baseline regression. This paper utilizes model (1) to conduct the initial test of hypothesis 1, and the regression results are shown in Table 3. In columns (1) and (2) of Table 3, the coefficients of venture capital are significantly positive, which are 0.238 and 0.198, respectively, suggesting

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that venture capital promotes enterprises' green innovation. In columns (3) and (4) of Table 3, the regression results after adding control variables are still significantly positive, indicating that venture capital has a positive effect on corporate green innovation. Columns (2) and (4) of Table 3 are fixed for industry and year, indicating that the hypothesis H1 proposed in this paper is valid under the double fixed effects model of industry and year. In addition, firm size (*Size*), profitability of total assets (*ROA*), and executive compensation incentives (*Pay*) are significantly positive, suggesting that firms with large size, strong profitability, and higher executive compensation are more likely to promote green innovation; while ListAge (age at listing) is significantly negative, implying that emerging firms are more innovative.

Robustness tests. In order to ensure the robustness of the regression results and to avoid bias in conclusions due to chance in model setting or variable selection, this paper validates the results in the following aspects:

1) Replacement of explanatory variable measures. In the benchmark regression, this paper uses the total number of green patents filed by listed companies in the observation year (*Green*) as a measure as the dependent variable. Since the variable measure may be biased, in order to test the robustness of the results, this paper uses the total number of green patents obtained (Green_1) as an alternative explanatory variable in the regression. Column (1) of Table 4 shows the regression results for the sum of green patents obtained (Green_1). From the results in the table, it can be seen that the coefficient of the core explanatory variable *VC* is significantly positive, which supports the baseline regression results of this paper and verifies the robustness of the results.

2) Replacement of explanatory variable measures. In addition to the explanatory variable *VC* in the baseline model, this paper also introduces venture capital shareholding (*vcshare*) to replace the explanatory variable in the regression. The *vcshare* is calculated by querying the number of shares held by VC organizations among the top ten shareholders of listed companies in the observation year as a percentage of the total share capital of the firms. the resulting regression results are shown in Column (2) of Table 4, where the coefficients of the core variables maintain a significant positive relationship after replacing the explanatory variables, which further confirms the robustness of the impact of the core variables and indicates that the research conclusions do not rely on the specific choice of explanatory variables, proving that the that the original core findings still hold.

3) Propensity score matching method (PSM). To reduce the impact of sample selection bias on the results, the sample is processed using propensity score matching method. Specifically, a Logit model is used to estimate the propensity score of firms to obtain venture capital (*VC*), and 1:1 nearest-neighbor matching is performed based on industry, financial indicators and corporate governance variables, with a 5% caliper value set to ensure the quality of matching. The results of the balance test indicate that there is no significant difference in key covariates between the matched treatment group and the control group, satisfying the common support hypothesis. Further re-regression analysis of the matched samples reveals that the promotion effect of venture capital (*VC*) on the number of green patent applications (*Green*) of enterprises is still significant, and the direction and magnitude of the coefficients are highly consistent with the baseline regression results. This finding holds under different model settings controlling for industry and year fixed effects or not. In summary, the PSM test confirms the robustness of the benchmark results, suggesting that the positive impact of VC on firms' green innovation is not driven by sample selectivity bias, which further strengthens the credibility of the study's findings.

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Table 4. Robustness test

variant	(1)	(2)	(3)
	Green_1	*Green*	*Green*
	Replacement of the dependent variable	Replacement of independent variables	PSM
VC	0.111***		0.144***
	(6.904)		(7.607)
vcshare		0.002***	
		(8.243)	
Lev	0.111**	0.166***	0.176**
	(2.466)	(3.444)	(2.390)
ROA	0.249**	0.413***	0.547***
	(2.366)	(3.696)	(3.186)
Size	0.105***	0.121***	0.155***
	(7.812)	(8.231)	(7.145)
ListAge	-0.056***	-0.061***	-0.072***
	(-4.284)	(-4.309)	(-3.470)
Cashflow	0.104	0.057	-0.005
	(1.385)	(0.678)	(-0.037)
TobinQ	0.013**	0.014**	0.013
	(2.558)	(2.476)	(1.568)
Top10	-0.143**	-0.206***	-0.118
	(-2.350)	(-3.136)	(-1.135)
Growth	-0.031***	-0.035***	-0.087***
	(-2.866)	(-2.838)	(-3.847)
Fixed	-0.052	-0.068	-0.105
	(-0.821)	(-0.982)	(-0.982)
Mshare	0.000	-0.000	-0.000
	(0.176)	(-0.325)	(-0.026)
Pay	0.074***	0.082***	0.088***
	(5.179)	(5.125)	(3.769)
Indep	-0.000	0.001	-0.001
	(-0.087)	(0.353)	(-0.253)
Constant	-3.246***	-3.665***	-4.493***
	(-10.089)	(-10.550)	(-9.249)
Observations	25193	28997	13050
R^2	0.198	0.196	0.224
industry effect	YES	YES	YES
vintage effect	YES	YES	YES

6. Endogeneity Test

1) Heckman two-step method. To mitigate the endogeneity problem caused by sample selection bias, this study draws on the research methodology of Dong Jing et al. (2017) to use a Heckman two-stage model for testing[13]. The first stage estimates the decision equation for firms' access to venture capital through the Probit model, controlling for financial indicators, corporate governance variables, and industry and year fixed effects. The results show that firm size (*Size*), profitability (*ROA*) and governance structure have a significant effect on the probability of obtaining venture capital. After further calculating the Inverse Mills Ratio (*IMR*) and adding the second stage regression, the regression coefficient of Venture Capital (*VC*) is still significantly negative, indicating a robust regression result. Secondly the IMR is also significant indicating that endogeneity is present and controlled for. The method further supports the positive effect of VC on corporate green innovation.

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Table 5. Heckman two-step method

variant	(1)	(2)
	VC	*Green*
VC		0.143***
		(8.141)
IMR		1.605***
		(5.056)
Lev	-0.546***	-0.506***
	(-9.268)	(-3.369)
ROA	-0.450**	-0.114
	(-2.462)	(-0.690)
Size	0.191***	0.352***
	(16.648)	(6.536)
ListAge	-0.275***	-0.392***
	(-17.467)	(-5.589)
Cashflow	-0.348**	-0.392***
	(-2.285)	(-3.337)
TobinQ	0.002	0.016***
	(0.297)	(2.709)
Top10	-0.021	-0.174***
	(-0.316)	(-2.633)
Growth	-0.079***	-0.131***
	(-2.996)	(-5.552)
Fixed	0.141*	0.106
	(1.887)	(1.341)
Mshare	-0.005***	-0.006***
	(-8.500)	(-4.681)
Pay	0.088***	0.189***
	(5.680)	(6.781)
Indep	-0.003*	-0.003*
	(-1.743)	(-1.768)
Constant	-5.794***	-11.971***
	(-21.117)	(-6.570)
Observations	28997	28997
R^2	0.105	0.198
industry effect	YES	YES
vintage effect	YES	YES

2) Instrumental variables approach. Based on the relevant study by Xueyong Zhang and Yeqing Zhang (2016)[50], in order to solve the endogeneity problem caused by potential omitted variables, this study selects the industry annual average value of venture capital investment (*iv*) as an instrumental variable for two-stage least squares estimation. The rationality of the instrumental variable is based on the following two points: first, industry-level VC activity affects the probability of firms obtaining investment; second, the industry annual mean reflects macro-environmental characteristics and is not directly related to individual firm performance. The regression results are shown in Table 6 below. The first-stage regression results show that the instrumental variable (*iv*) has a significant positive effect on venture capital (*VC*) and the F-statistic is well above the empirical threshold of 10, indicating that there is no weak instrumental variable problem. The coefficient of venture capital (*VC*) remains significantly positive in the second stage regression, which is highly consistent with the results of the benchmark regression. The test of instrumental variable approach further excludes endogenous interference and confirms the positive facilitating relationship between VC and corporate green innovation.

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Table 6. Instrumental variables based on provincial averages

variant	(1)	(2)
	VC	*Green*
iv	0.995***	
	(25.535)	
VC		0.128**
		(2.456)
Lev	-0.137***	0.165***
	(-4.761)	(3.378)
ROA	-0.124*	0.413***
	(-1.827)	(3.667)
Size	0.054***	0.122***
	(9.029)	(8.113)
ListAge	-0.078***	-0.061***
	(-9.463)	(-4.161)
Cashflow	-0.063	0.052
	(-1.295)	(0.615)
TobinQ	0.004	0.014**
	(1.243)	(2.432)
Top10	-0.014	-0.149**
	(-0.385)	(-2.252)
Growth	-0.020***	-0.036***
	(-2.692)	(-2.857)
Fixed	0.036	-0.068
	(1.046)	(-0.972)
Mshare	-0.001***	-0.000
	(-5.141)	(-0.378)
Pay	0.029***	0.082***
	(3.691)	(5.088)
Indep	-0.001	0.001
	(-0.729)	(0.340)
Constant	-1.311***	-3.702***
	(-9.865)	(-10.509)
Observations	28997	28997
R^2	0.137	0.189
industry effect	YES	YES
vintage effect	YES	YES

7. Heterogeneity Analysis

1) Whether the four major. Venture capital organizations often face the challenge of information asymmetry when participating in corporate governance, making it difficult to gain direct access to the true green innovation potential of enterprises. In this context, high-quality external auditing becomes a key mechanism to alleviate information barriers and enhance the reliability of investment decisions. The Big 4 accounting firms (*Big4*) can significantly enhance the quality of corporate disclosure due to their strict auditing procedures and independence requirements[18].The supervisory role of Big 4 auditing can reduce corporate environmental risk concealment behavior and provide a more credible assessment basis for risk capital[25]. In summary, the Big Four audits may amplify the role of venture capital in promoting corporate green innovation through information certification and supervision functions.

In this study, we refer to the measure of Huang Chao et al. [18], and use "whether it is audited by a Big 4 accounting firm" (*big4*) as a proxy variable for audit quality. In order to test the moderating effect of audit quality, the cross-multiplier term (*big4_VC*) between venture capital

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(*VC*) and Big 4 auditing (*big4*) is first constructed and regressed in groups based on the full sample. The regression results are shown in Column (1) of Table 7 below, and the coefficient of the cross-multiplier term (*big4_VC*) in Column (1) is significantly positive, indicating that Big 4 auditing significantly enhances the positive impact of venture capital on green innovation. This result is consistent with theoretical expectations and verifies the positive moderating role of high-quality auditing in the relationship between venture capital and corporate green innovation.

Table 7. Heterogeneity analysis

variant	(1)	(2)
	Green	*Green*
VC	0.126***	0.055**
	(7.232)	(2.136)
big4	0.036	
	(0.807)	
big4× VC	0.271***	
	(3.266)	
MFG		-0.328***
		(-6.387)
MFG× VC		0.137***
		(3.990)
Lev	0.179***	0.164***
	(3.736)	(3.402)
ROA	0.441***	0.408***
	(4.043)	(3.646)
Size	0.111***	0.122***
	(8.037)	(8.293)
ListAge	-0.061***	-0.060***
	(-4.353)	(-4.247)
Cashflow	0.042	0.046
	(0.513)	(0.546)
TobinQ	0.013**	0.014**
	(2.189)	(2.445)
Top10	-0.177***	-0.143**
	(-2.721)	(-2.169)
Growth	-0.033***	-0.036***
	(-2.649)	(-2.906)
Fixed	-0.068	-0.071
	(-1.003)	(-1.031)
Mshare	-0.000	-0.000
	(-0.214)	(-0.303)
Pay	0.078***	0.080***
	(4.914)	(5.007)
Indep	0.000	0.001
	(0.096)	(0.354)
Constant	-3.392***	-3.673***
	(-10.486)	(-10.623)
Observations	28997	28992
R^2	0.199	0.197
industry effect	YES	YES
vintage effect	YES	YES

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2) Whether manufacturing. As a typical high-pollution and high-energy-consumption industry, the green innovation behavior of the manufacturing industry is subject to the dual influence of environmental regulations and resource constraints. On the one hand, strict environmental protection policies force manufacturing enterprises to increase green technology R&D investment to reduce environmental compliance costs [34]; on the other hand, the inherent asset-heavy attributes of the manufacturing industry and short-term profitability pressures may crowd out innovation resources, leading to insufficient incentives for green transformation[44]. Therefore, firms in the manufacturing sector are subject to stronger financing constraints, which may reinforce the role of venture capital in promoting green innovation.

In this study, we refer to the industry classification standard of Tao Feng et al. [34], and use whether it belongs to the manufacturing industry (*MFG*) as a proxy variable for industry pollution attributes. In order to test the moderating effect of manufacturing industry, the cross-multiplier term (*MFG_VC*) between venture capital (*VC*) and manufacturing industry attributes (*MFG*) is firstly constructed and regressed in groups based on the full sample. The regression results are shown in column (2) of Table 7 below, and the coefficient of the cross-multiplier term (*MFG_VC*) is significantly positive, indicating that manufacturing attributes significantly enhance the positive impact of venture capital on green innovation. This result is consistent with the theoretical expectation and verifies that resource path dependence and environmental regulatory pressure in pollution-intensive industries promote the incentives for green innovation in venture capital.

8. Mechanism Testing

The previous paper confirms the promotion effect of venture capital (*VC*) on enterprise green innovation (*Green*), but its specific mechanism of action still needs to be further revealed. In this paper, the mechanism is tested from the two paths of financing constraints, supervision and management, and the regression results are shown in Table 8.

Strengthening of supervisory and management mechanisms. Based on the positive role of venture capital in corporate governance, this paper further explores its impact on corporate supervision and management. By sending directors to enterprises and participating in major decision-making, VCs are able to effectively supervise the management of enterprises, optimize the corporate governance structure, and reduce the agency cost, thus improving the operational efficiency and rationality of resource allocation [15,16]. In the field of green innovation, the supervisory and management role of venture capital helps to ensure that enterprises tilt their resources towards green innovation projects and avoid management neglecting long-term green development strategies in pursuit of short-term performance.

In order to accurately measure the intensity of supervision and management that enterprises are subjected to, this paper draws on the research method of Zhang Guangdong et al.[48] and constructs the corresponding agency cost (*AgC1_3*). The larger the index is, the stronger and more effective supervision and management the enterprise is subject to. In the empirical analysis, the regression coefficient of venture capital is significantly positive, which fully indicates that venture capital can significantly enhance the intensity of supervision and management that enterprises are subject to. By strengthening supervision and management, venture capital helps to standardize the management behavior of enterprises, optimize the strategic layout of green innovation, promote the implementation of green innovation projects, and then promote the improvement of the level of green innovation of enterprises.

Mechanisms for alleviating financing constraints. This paper proposes the hypothesis that venture capital can promote green innovation by alleviating corporate financing constraints. Given that green innovation is characterized by a long research and development cycle, high

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technological risk, and large upfront investment, enterprises often face significant financing difficulties when carrying out green innovation activities[7]. The intervention of venture capital can not only directly inject funds into enterprises to alleviate their financial constraints, but also transmit positive signals to the outside by virtue of its professional ability and market reputation,[26]thus effectively reducing the degree of information asymmetry between enterprises and external stakeholders, further alleviating the financing constraints of enterprises, and providing strong financial support for green innovation.

In measuring the degree of corporate financing constraints, this paper refers to the research method of Wu Chaopeng et al. [42]and adopts the calculated financing constraint index (*KZIndex*) as a metric. The larger the value of this index, the stronger the financing constraints faced by the enterprise. Analyzed by constructing a regression model, the results are shown in column (2) of Table 8 below, and the regression coefficient of venture capital is significantly negative. This indicates that venture capital can effectively inhibit the degree of enterprise financing constraints, which in turn provides a favorable financial environment for the smooth development of green innovation activities and promotes enterprises to increase green innovation investment.

Table 8. Mechanism tests

variant	(1)	(2)
	AgC1_3	*KZIndex*
VC	0.023***	-0.285***
	(2.950)	(-17.787)
Lev	0.557***	5.922***
	(18.802)	(105.907)
ROA	1.225***	-5.325***
	(20.158)	(-33.563)
Size	-0.050***	-0.052***
	(-8.377)	(-4.762)
ListAge	0.030***	0.152***
	(3.799)	(10.526)
Cashflow	0.545***	-14.204***
	(11.842)	(-114.157)
TobinQ	-0.012***	0.447***
	(-3.941)	(45.799)
Top10	0.174***	-0.663***
	(4.969)	(-10.541)
Growth	0.123***	-0.142***
	(15.750)	(-6.760)
F	-0.122***	1.611***
	(-3.339)	(25.377)
Mshare	-0.001***	-0.002***
	(-3.489)	(-4.192)
Pay	0.071***	-0.072***
	(9.525)	(-5.039)
Indep	-0.000	0.001
	(-0.491)	(0.557)
Constant	0.190	1.574***
	(1.499)	(5.702)
Observations	28972	29011
R^2	0.362	0.832
industry effect	YES	YES
vintage effect	YES	YES

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9. Conclusion and Recommendations

Conclusions of the study. This paper delves into the impact of venture capital on corporate green innovation and its mechanism of action through empirical research. The study shows that venture capital has a significant positive promotion effect on corporate green innovation, and this conclusion remains robust after robustness test, endogeneity treatment and heterogeneity analysis. Specifically, venture capital mainly promotes corporate green innovation through the following two paths: first, easing corporate financing constraints, venture capital can not only directly provide financial support for enterprises, but also reduce the degree of information asymmetry between enterprises and external stakeholders by virtue of its professional ability and market reputation, alleviating the financial bottleneck faced by enterprises' green innovation; second, strengthening the supervision and management, venture capital, by sending directors and participating in major decision-making, has a positive effect on corporate green innovation. Second, strengthening supervision and management, venture capital optimizes the corporate governance structure by assigning directors to enterprises and participating in major decision-making, so as to effectively supervise the management of enterprises and ensure that resources are tilted to green innovation projects, thus enhancing the level of green innovation of enterprises. In addition, the heterogeneity analysis finds that the promotion effect of venture capital on corporate green innovation is significantly different among enterprises with different audit quality and industry types. The promotion effect of venture capital on corporate green innovation is more significant in enterprises audited by Big 4 accounting firms and in the manufacturing group. This suggests that external monitoring mechanisms and enterprise types have an important moderating effect on the value effect of venture capital.

Policy recommendations. From the perspective of enterprises, enterprises with potential and demand for green innovation should take the initiative to dock with venture capital organizations, show their green innovation projects and development prospects, and attract financial support from venture capital; strengthen the independence and professionalism of the board of directors, establish an effective supervision mechanism, prevent insider control and waste of resources, and improve the efficiency of enterprise operation and innovation ability; enterprises should pay attention to the research and development of green technology and the cultivation of innovation teams. enterprises should focus on green technology R&D and innovation team cultivation, establish green innovation culture, carry out industry-university-research cooperation projects, and improve the level and efficiency of green innovation; enterprises should disclose financial and non-financial information timely, accurately and completely in accordance with the relevant laws, regulations and regulatory requirements, select high-quality auditing institutions to conduct financial audits and green innovation audits, enhance the credibility of information disclosure, and reduce the degree of information asymmetry between them and venture capital institutions.

From the perspective of VCs, VCs should continuously strengthen their research and understanding of green technology and environmental protection industry, cultivate professional investment teams, and improve the analytical ability and decision-making level of investment personnel in the field of green innovation; VCs should actively integrate their own social network resources, provide value-added services other than financial support for enterprises, assist enterprises in establishing strategic partnerships, and promote resource sharing and technology exchanges among enterprises. Venture capital institutions should actively integrate their social network resources to provide enterprises with value-added services in addition to financial support, assist enterprises in establishing strategic partnerships, promote resource sharing and technology exchanges among enterprises, and promote the implementation of green innovation projects. After investing in enterprises,

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venture capital institutions should actively intervene in corporate governance by sending directors and participating in major decision-making, supervise the operation and management of enterprises, prevent short-sightedness and waste of resources on the part of management, and guide enterprises to tilt their resources towards green innovation projects to realize sustainable development of the enterprises.

From the government's point of view, the government should introduce tax incentives, financial subsidies, etc., to encourage venture capital institutions to increase investment in green innovation, set up a green innovation guidance fund to attract the participation of social capital, and expand the supply of green innovation funds; strengthen the supervision of the venture capital market, standardize the market order, prevent market manipulation, transfer of benefits and other illegal and irregular behaviors, and protect the legitimate rights and interests of investors. At the same time, the government should provide efficient government services, simplify the approval process, and create a favorable policy environment for the cooperation between venture capital institutions and enterprises; the government should set up an information platform for green innovation projects, provide information exchange and project docking services for enterprises and venture capital institutions, and promote the cooperation and communication between the two sides.

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