Study on the Impact of Venture Capital on Corporate Carbon Performance

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ABSTRACT As global attention to climate change intensifies, venture capital has become an important driver of corporate carbon performance, including in strategic manufacturing sectors related to electromagnetic materials, antennas, electronic textiles, and low-carbon equipment production. Based on data from Shanghai and Shenzhen A-share listed companies from 2010 to 2023, this study employs a two-way fixed-effects model to analyze the influence of venture capital on corporate carbon performance. The results show that venture capital improves corporate carbon performance by alleviating financing constraints and promoting technological innovation. The impact varies with managerial ability and the intensity of financial regulation. Heterogeneity tests indicate that the effect of venture capital is more pronounced in non-state-owned enterprises, firms located in eastern regions, and heavily polluting corporations. These findings deepen the understanding of the internal logical relationship between venture capital and corporate carbon performance. They also provide practical implications for guiding private capital toward low-carbon technological innovation in advanced manufacturing fields, including electromagnetic-device manufacturing and antenna-related industrial chains, where capital support is needed for cleaner production, energy-efficient processes, and green technology upgrading.

INDEX TERMS venture capital, carbon performance, technological innovation, electromagnetic manufacturing, financial regulation

I. INTRODUCTION

As global climate change becomes increasingly severe, achieving carbon neutrality has emerged as a shared goal for the international community. The 2024 Opinions on Accelerating the Comprehensive Green Transformation of Economic and Social Development issued by the Central Committee of the Communist Party of China and the State Council identifies the green transformation and upgrading of traditional industries as the cornerstone of economic and social transformation, emphasizing the need to advance energy conservation and carbon reduction efforts in depth. However, to achieve strong carbon performance, corporations must invest in energy retrofits, green technology innovation, related areas. During this process, they have to face challenges including substantial capital requirements, long implementation timelines, and difficulties in securing support from traditional financial intermediaries like banks. Consequently, they increasingly favor venture capital (VC) investment. VC not only provides financial backing and offers financial and managerial support, but also assists corporations in standardizing governance systems and aligning with government incentive policies. It delivers comprehensive support for corporate green and low-carbon transformation, thereby enhancing carbon performance. Therefore, vigorously introducing and aggregating high-quality VC resources, increasing its investment proportion in the green and low-carbon sector, leveraging the role in green governance, and achieving both energy conservation and emission reduction alongside value growth are among the key breakthroughs for China on the path toward its 2060 carbon neutrality goal.

In order to address funding constraints in corporate R&D, various countries have successively introduced policy measures to accelerate the development of the VC industry. These measures encompass both micro-level impacts—such as corporate technological innovation[1], corporate governance[2], and financing capacity[3], and macro-level influences, including national digital economies[4], new-quality productive forces[5], and environmental regulations[6]. VC plays a critical role in enhancing corporate R&D investment and technological innovation by providing financial support and industry expertise. It can also participate in corporate governance and major decision-making by optimizing equity structures and appointing board members, thereby enhancing corporate carbon performance and market competitiveness. Dong Jing et al. have indicated that different stages of VC involvement yield varying impacts on startup value, and that VC's professional ability and resource advantages can be leveraged to drive corporate value growth[7]. However, other studies indicate that corporation development may

be constrained by excessive interference and self-serving behaviors of VC. Using a spatial perspective, Zhang Chong et al. revealed that VC not only enhances local economic resilience but also generates spatial spillover effects[8], which can in turn affect corporate carbon performance within the region.

Scholars such as Hao Haixia point out that VC can provide funding for emerging industries and innovative corporations representing advanced productive forces, ensuring the capital needs for corporate R&D and promoting innovation activities[9], thereby laying the technological and financial foundation for corporate carbon performance enhancement. From an innovation perspective, Zhang Pengyang and other scholars note that VC can stimulate corporate innovation[10], enhance resource utilization efficiency, and achieve improved carbon performance. Liu Zhihua et al. argue that new-quality productive forces exert a positive influence on carbon neutrality[11]. As a key driver of new-quality productive forces, VC can indirectly improve corporate carbon performance by supporting them.

In summary, although numerous scholars have conducted relatively systematic explorations of VC, carbon performance, and their symbiotic relationship from multiple perspectives, research in this field currently has two main shortcomings:

First, empirical studies remain scarce, with most research confined to theoretical discussions, leaving the specific effects of VC on corporate carbon performance unsupported by data.

Second, research on the underlying mechanisms lacks sufficient depth, and differences across various industries and corporate types remain unclear.

Given these gaps, this paper theoretically analyzes the mechanisms through which VC influences corporate carbon performance and empirically tests its effects. It aims to provide valuable insights for achieving China's carbon peaking and carbon neutrality goals.

II. THEORETICAL ANALYSIS AND RESEARCH HYPOTHESES

A. DIRECT IMPACT OF VC ON CORPORATE CARBON PERFORMANCE

The emission of greenhouse gases such as carbon dioxide represents external costs in corporate economic activities. Due to environmental regulations, corporate carbon emissions face restrictions, necessitating funding to support R&D in low-carbon technologies. On one hand, the involvement of VC brings rigorous oversight and evaluation of corporations. To secure sustained VC investment, corporations must demonstrate strong environmental awareness and responsibility, implementing proactive measures to reduce carbon emissions and thereby enhance carbon performance. On the other hand, as an external financing method, VC tends to invest in corporations with innovation potential, leveraging its superior information and resource advantages to bridge gaps in corporate innovation activities. By participating in corporate governance and establishing robust carbon management systems, VC positively influences corporate carbon performance.

Hypothesis H1: VC has a positive impact on corporate carbon performance.

B. THE MECHANISM OF VC INFLUENCING CORPORATE CARBON PERFORMANCE

As a traditional corporate financing method, bank loans tend to favor corporations with lower risk and stable returns. Consequently, the high risk associated with green and low-carbon technology innovation companies may hinder their access to bank financing. Bond issuance requires rigorous scrutiny of a company's financial condition and credit history, which innovative corporations in the early stage often struggle to meet. For VC, investment in high-risk, high-growth-potential projects, when successful, delivers exceptionally high returns while alleviating corporate financing constraints. On one hand, corporations can leverage VC capital to support R&D and production, expand financing scale in green and low-carbon sectors, reduce financing costs, and exert a positive impact on carbon performance. On the other hand, the exit mechanisms of VC (such as IPOs and mergers/acquisitions) provide investors with avenues for capital appreciation, fostering a virtuous cycle of capital flow and optimal allocation that further eases financing constraints.

Hypothesis H2a: VC can enhance corporate carbon performance by alleviating financing constraints.

Technological innovation serves as a key driver for corporations to enhance their carbon performance, simultaneously boosting productivity and resource utilization, while optimizing production processes to reduce energy consumption and carbon emissions. First, VC supports corporations in low-carbon technology R&D and application by providing financial backing and value-added services. This enhances corporate capacity for coordinating innovation resources and improving utilization efficiency, thereby facilitating the commercialization and industrialization of technological innovations[40], ultimately elevating corporate carbon performance. Second, addressing information asymmetry—a core issue in principal-agent theory—VC strengthens oversight and evaluation of corporations, helping ensure that technological innovation activities proceed as intended. Finally, VC ensures portfolio stability and returns by constructing diversified investment portfolios. Huang Wenli et al. used ChiNext IPO companies as samples and demonstrated that private equity investments enhance the quantity, quality, efficiency, and sustainability of corporate green innovation[12], providing strong evidence that VC improves corporate carbon performance by promoting green innovation.

Hypothesis H2b: VCs can enhance corporate carbon performance by promoting technological innovation.

C. MODERATING EFFECTS OF MANAGERIAL ABILITY AND FINANCIAL REGULATORY DATA ON CORPORATE CARBON PERFORMANCE

Financial regulation plays a crucial role in capital markets, with varying degrees of oversight yielding different outcomes for VC market development. On one hand, regulatory oversight by financial authorities enhances the stability and predictability of the VC market, thereby supporting improvements in corporate carbon performance. On the other hand, stringent Financial regulation increases operational costs for VC, making it challenging to invest in high-risk, high-growth green sectors and consequently impacting the carbon performance goals of such corporations. Simultaneously, stringent financial regulatory data not only mandates information disclosure but also prolongs investment cycles by increasing project approval and filing processes. In an era of rapid technological change and innovation, this inevitably impacts VC investment decisions regarding technological innovation projects. When formulating and implementing regulatory policies, a balanced approach is essential to weigh various factors, as moderate regulation can effectively balance market risks with innovation. Based on this, the following hypotheses are proposed:

Hypothesis H3a: Financial regulation strengthens the positive effect of VC on corporate carbon performance by VC.

Hypothesis H3b: Financial regulatory data weakens VC efforts to enhance corporate carbon performance.

Managerial ability is one of the key factors in corporate operations and development. Excellent managers can formulate and implement scientific carbon management strategies, optimize resource allocation, reduce corporate costs, and alleviate environmental burdens, to achieve higher investment returns and better exit opportunities. Highly capable managers can more accurately evaluate innovative and sustainable low-carbon projects, assist corporations in gaining competitive advantages in the market[13], and ensure that investments yield long-term, stable returns. Simultaneously, managers' sensitivity to environmental policies influences how corporations prioritize carbon performance, thereby affecting VC's effectiveness in enhancing corporate carbon performance. Therefore, at every stage of VC involvement, strong managerial cooperation can more effectively achieve carbon reduction targets and advance sustainable development.

Hypothesis H4: Managerial ability promotes the positive effect of VC on corporate carbon performance.

III. RESEARCH DESIGN

A. DATA DESCRIPTION

To ensure the continuity and availability of sample data, this paper selects Shanghai and Shenzhen A-share companies from 2010 to 2023 as the sample, excluding data from ST and *ST companies during the sample period. The data were primarily sourced from databases including PEDATA MAX, Wind Information, and CSMAR. Partially missing data points were imputed using interpolation and nearest-neighbor matching. To avoid heteroskedasticity, variables with large magnitudes are log-transformed.

B. MODEL CONSTRUCTION

To verify whether venture capital has a positive impact on corporate carbon performance improvement, this study constructs the following two-way fixed-effects model for empirical analysis. The specific model specification is as follows, where: $CP_{i,t}$ represents the corporate carbon performance proxy variable; $VC_{j,t}$ denotes the venture capital background dummy variable; $VCshare_{j,t}$ indicates the venture capital shareholding ratio; $Controls_{i,j,t}$ represent corporation-level and region-level control variables; μ_i represents the corporation individual effect; δ_t signifies the year fixed effect; and $\epsilon_{i,t}$ is the error term.

$$CP_{i,t} = \alpha_0 + \alpha_1 VC_{j,t} + \gamma Controls_{i,j,t} + \mu_i + \delta_t + \epsilon_{i,t} \quad (1)$$

$$CP_{i,t} = \beta_0 + \beta_1 VCshare_{j,t} + \gamma Controls_{i,j,t} + \mu_i + \delta_t + \epsilon_{i,t} \quad (2)$$

To verify whether financial regulation and managerial ability moderate the effect of venture capital on corporate carbon performance, this study constructs the following models for empirical analysis. The specific model specification is as follows, where: $CP_{i,t}$ denotes the proxy variable for corporate carbon performance; $VC_{j,t}$ represents the dummy variable for venture capital background; $VCshare_{j,t}$ indicates the venture capital shareholding ratio; $FRD_{j,t}$ serves as the proxy variable for financial regulation; $MA_{j,t}$ is the proxy variable for managerial ability.

$$\begin{aligned} CP_{i,t} = {} & c_0 + c_1 VC_{j,t} + c_2 FRD_{j,t} + c_3 VC_{j,t} \times FRD_{j,t} \\ & + \gamma Controls_{i,j,t} + \mu_i + \delta_t + \epsilon_{i,t} \end{aligned} \quad (3)$$

$$\begin{aligned} CP_{i,t} = {} & d_0 + d_1 VCshare_{j,t} + d_2 FRD_{j,t} \\ & + d_3 VCshare_{j,t} \times FRD_{j,t} \\ & + \gamma Controls_{i,j,t} + \mu_i + \delta_t + \epsilon_{i,t} \end{aligned} \quad (4)$$

$$\begin{aligned} CP_{i,t} = {} & e_0 + e_1 VC_{j,t} + e_2 MA_{j,t} + e_3 VC_{j,t} \times MA_{j,t} \\ & + \gamma Controls_{i,j,t} + \mu_i + \delta_t + \epsilon_{i,t} \end{aligned} \quad (5)$$

$$\begin{aligned} CP_{i,t} = {} & f_0 + f_1 VCshare_{j,t} + f_2 MA_{j,t} \\ & + f_3 VCshare_{j,t} \times MA_{j,t} \\ & + \gamma Controls_{i,j,t} + \mu_i + \delta_t + \epsilon_{i,t} \end{aligned} \quad (6)$$

C. VARIABLE DEFINITIONS AND DESCRIPTIVE STATISTICS

1) Explanatory Variables

Corporate Carbon Performance (CP). Following the methodology of Ma Xi et al. (2023), revenue per unit of carbon

emissions serves as a proxy variable for carbon performance (CP) [14]. The specific calculation method is presented in Equation (7):

$$CP = \ln\left(\frac{\text{Corporation Operating Income}}{\left(\frac{\text{Industry Carbon Emissions}}{\frac{\text{Industry Cost of Main Business Activities}}{\text{Cost of Main Business Activities}} \times \text{Corporation Operating Income}}\right) \times \text{Corporation Operating cost}} + 1\right) \tag{7}$$

2) Core Explanatory Variables

Following the research by Wu Chaopeng and Zhang Yuan, listed companies are defined as having a venture capital background if any of their top ten shareholders' names contain "Venture capital," "Venture investment," or "Venture capital investment"[15]. Drawing on Cui Lu (2024)[16], we construct the dummy variable for venture capital background (VC) and the venture capital shareholding ratio (VCshare).

3) Control Variables

Following the methodology of Cui Lu (2024)[16] and Hao Haixia & Zhang Xuna (2025)[9], and in line with the research focus of this paper, we select the following corporate-level micro variables: corporate size (Size), Leverage (Lev), Return on Equity (ROE), Growth potential (Growth), Tobin's Q value (TobinQ), Management Shareholding Ratio (Mshare), Dual Role (Dual), and Logarithm of Age (lnAge) as corporation-level micro variables, along with Urbanization Level (urb) and Logarithm of GDP (lnGDP) as macro variables. Variable definitions are presented in Table 1. Table 2 displays descriptive statistics for all variables.

IV. EMPIRICAL ANALYSIS

A. BENCHMARK REGRESSION RESULTS

Based on Models (1) and (2) constructed in this paper, we examine the relationship between VC and the enhancement of corporate carbon performance. As shown in Table 3, Columns (1) and (3) show that both VC and VC share are statistically significant at the 1% level in improving improving corporate carbon performance (CP) without including any control variables, which supports Hypothesis H1. To ensure the validity of these results, columns (2) and (4) of Table 3 present findings with control variables included. In these columns, VC and VCshare remain statistically significant at the 5% level and 1% level, respectively. This indicates that VC plays a crucial role in enhancing corporate carbon performance.

B. ROBUSTNESS TESTS

First, replacing the explained variable. Both carbon intensity and carbon performance are closely linked to the carbon emissions of corporations or regions. Reducing carbon intensity enhances carbon emission efficiency, and both metrics possess a degree of quantifiability and comparability, aiming to measure the effectiveness of low-carbon transformation. Following Lv Heng, Ma Chunai et al. (2024), we employ the ratio of corporate CO2 emissions to main business revenue to measure carbon intensity[17] for robustness testing. The regression results are presented in columns (1) and (2) of Table 4. The regression coefficients for VC and VCshare on carbon intensity were -0.109 and -0.002, respectively, both passing the 5% significance level test, demonstrating the robustness of the benchmark results.

Second, there may be reverse causality between VC and corporate carbon performance, meaning that the higher the carbon performance level of a corporation, the more VC investment it receives. To avoid the impact of this endogeneity issue on the research conclusions, we conducted a lagged regression analysis will be conducted. The regression results are shown in Table 4, and the conclusions remain robust even after accounting for endogeneity.

Third, excluding samples from certain regions. Considering policy-driven disparities between provincial-level autonomous regions and other provinces, we followed the methodology of Hao Haixia and Zhang Xuna (2025)[9] by removing data from five provincial-level autonomous regions and rerunning the regression. The results presented in Table 4 confirm the robustness of our conclusions.

Fourth, excluding corporations listed for less than three years. The impact of VC on carbon performance faces a series of issues in corporations with less than three years of listing, including conflicts between short-term investment objectives and long-term carbon performance improvement, limitations in technological accumulation and innovation ability, uncertainties in market and policy environments, constraints in capital and resource allocation, as well as issues related to information disclosure and transparency. Therefore, drawing on the relevant research by Xue Qing and Liu Shengnan (2024), we excluded sample data for companies with a listing duration of three years or less and reran the regression. The results, shown in Table 4, demonstrate that the conclusions are robust.

C. MECHANISM TESTING

Venture capital can directly improve the financial condition of a corporation, thereby effectively alleviating its financing constraints[10]. Drawing on the research by Jiao Jijun and Zhu Weidi (2024), this study employs the KZ Index and WW Index to measure the financing constraints faced by corporations[18]. Higher KZ and WW indices indicate greater financing constraints. Additionally, given the study's focus on innovation efficiency and significant gaps in patent application data, this paper adopts the approach from Hong (Lianying, Zhan Huiwen 2024), using technological innovation investment (rdspendsum), that is, the ratio of R&D expenditure to total assets, to measure corporate technological innovation levels[19]. To test whether financing constraints and technological innovation levels mediate the effect of VC on improving corporate carbon performance, we refer to Columns (2) and (4) of Table 5, which report negative coefficients for VC on the mediating variables KZ and WW,

TABLE 1. Variable Definition

Variable	Symbol	Description
Carbon Performance	CP	Revenue per unit of carbon emissions
Venture Capital Background Dummy Variable	VC	1 if held by venture capital institutions, otherwise 0
Venture Capital Shareholding Ratio	VCshare	Total institutional investor holdings / Total share capital
Corporate Size	Size	Natural logarithm of annual total assets
Logarithm of Age	lnAge	Logarithm of company age
Leverage	Lev	Year-end total liabilities / Year-end total assets
Return on Equity	ROE	Net profit divided by net assets
Growth potential	Growth	(Year t revenue - Year $t-1$ revenue) / Year $t-1$ revenue
Tobin's Q value	TobinQ	(Market value of circulating shares + Non-circulating shares $\times$ Net asset value per share + Book value of liabilities) / Total assets
Management Shareholding Ratio	Mshare	Number of shares held by directors, supervisors, and senior management / Total number of shares outstanding
Dual Role	Dual	Chairman concurrently serving as CEO: 1, otherwise 0
Logarithm of GDP	lnGDP	Logarithm of the company's corresponding province GDP
Urbanization Level	urb	Urban population / Total population

TABLE 2. Descriptive Analysis Results

Variable	Obs	Mean	Std.Dev	Min	Max
CP	9997	48.686	199.819	0	3085.861
VC	9997	0.287	0.452	0	1
VCshare	9997	16.504	27.214	0	91.16
Size	9997	22.797	1.387	19.966	27.096
Lev	9997	0.467	0.187	0.054	0.892
ROE	9997	0.082	0.097	-0.533	0.447
Growth	9997	0.148	0.318	-0.502	3.133
TobinQ	9862	1.889	1.179	0.768	9.797
Mshare	9592	0.042	0.107	0	0.66
urb	9997	64.588	13.692	33.81	89.6
lnAge	9997	2.952	0.32	1.386	3.611
lnGDP	9997	10.386	0.777	7.042	11.768
Dual	9997	0.174	0.38	0	1

TABLE 3. Benchmark Regression

	(1) CP	(2) CP	(3) CP	(4) CP
VC	27.7260***	23.3522**		
	(3.76)	(3.25)		
VCshare			0.5305***	0.4659***
			(3.70)	(4.11)
Control Variables		✓		✓
Sample Size	9997	9460	9997	9460
Adjusted R2	0.4571	0.4893	0.4578	0.4899

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are shown in parentheses.

TABLE 4. Robustness Tests

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Replace the explained variable		Lagged 1 period		Lagged 2 periods		Exclude autonomous regions		Exclude corporations listed $\leq$3 years	
	Carbon intensity	Carbon intensity	CP	CP	CP	CP	CP	CP	CP	CP
VC	-0.109**		21.500***		11.276**		23.985***		13.659***	
	(-1.98)		(3.49)		(2.01)		(3.19)		(2.93)	
VCshare		-0.002**		0.408***		0.198**		0.475***		0.278***
		(-2.12)		(3.88)		(2.12)		(3.61)		(3.49)
Control Variables	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ind FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Code FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Samples size	9,328	9,328	8,626	7,902	8,626	7,902	8,915	8,915	8,680	8,680
Adjusted R2	0.175	0.175	0.544	0.556	0.545	0.556	0.541	0.542	0.541	0.541

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are shown in parentheses.

both statistically significant. In columns (3) and (5) of Table 5, the coefficients of KZ and WW on the dependent variable CP are also negative and significant at the 10% significance level. This indicates that VC reduces overall financing constraints, expands financing channels, and improves the financing environment for corporations, thereby leading to

TABLE 5. Mediating Effect Test

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Financing Constraints			Overall Effect		Technological Innovation	
VARIABLES	CP	KZ	CP	WW	CP	rdspendsum	CP
VC	23.407***	-0.004**	20.574***	-0.089**	23.186***	18.515***	1.337e+08**
	(3.24)	(-2.46)	(4.86)	(-2.96)	(4.33)	(2.59)	(2.79)
KZ			-2.444*				
			(-1.68)				
WW					-63.877*		
					(-1.77)		
rdspendsum							3.78e-09*
							(1.82)
Control Variables	✓	✓	✓	✓	✓	✓	✓
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Code FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Samples size	9,448	9,448	9,448	8,727	8,727	7,194	7,194
Adjusted R2	0.532	0.764	0.532	0.788	0.591	0.676	0.544

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are shown in parentheses.

TABLE 6. Results of Bootstrap and Sobel Tests

Mediating Effect	Effect	Z	P> |z|	Confidence Interval	Effect
KZ	Indirect effect	-3.18	0.001	-2.399453, -0.5684638	-1.4839*** (0.37306)
KZ	Direct effect	1.79	0.074	-0.7125409, 15.67881	
WW	Indirect effect	-3.84	0.000	-2.788168, -0.9035773	-1.84583*** (0.4448)
WW	Direct effect	2.34	0.020	1.701175, 19.47557	
rdspendsum	Indirect effect	5.60	0.000	1.09266, 2.27011	1.6813*** (0.40614)
rdspendsum	Direct effect	3.30	0.001	5.27451, 20.75498	

enhanced carbon performance, which supports Hypothesis H2a. The regression results in columns (6) and (7) of Table 5 confirm the mediating effect of technological innovation, indicating that enhancing technological innovation serves as a crucial channel through which VC influences corporate carbon performance.

Table 6 presents the results of Bootstrap tests and Sobel tests, further determining the mediating effects of alleviating financing constraints and technological innovation on VC's impact on enhancing corporate carbon performance. Column (3) of Table 6 indicates that the confidence intervals for VC's indirect effect on enhancing corporate carbon performance all exclude zero. Column (4) of Table 6 indicates that the P-values in the Sobel tests are all less than 0.05, further confirming that financing constraints and technological innovation mediate the relationship between VC and corporate carbon performance improvement. The Bootstrap and Sobel tests mitigate the low statistical power in stepwise regression coefficient tests, providing further evidence supporting the validity of Hypothesis H2.

D. MODERATING EFFECT TEST

Based on the preceding theoretical analysis, this study, drawing upon the research of Zhang Lu et al. (2019), adopts the Tobin model to conduct a firm-level regression on the ratio of corporate current input-output efficiency to the industry optimal level. The residuals from this regression represent Managerial Ability (MA) [20]. Drawing on the research of Wang Ren et al. (2019) [21] and Tang Song et al. (2020) [22], financial regulation is measured using the ratio of financial regulatory expenditures to the local financial sector's value-added. We separately examine whether managerial ability and financial regulation moderate the effect of VC on corporate carbon performance. Interaction terms are constructed between Managerial Ability (MA) and Financial Regulatory Data (FRD) with the explanatory variables, followed by moderation effect regression. In Table 7, columns (1) and (2), the regression coefficients for FRD×VC and FRD×VCshare are -0.001 and -0.269, respectively, statistically significant at the 10% and 5% levels. These results indicate that financial regulatory data weakens the positive effect of VC on corporate carbon performance, supporting Hypothesis H3b. In columns (3) and (4) of Table 7, the regression coefficients for MA×VC and MA×VCshare are 0.016 and 1.419, respectively, and are statistically significant at the 1% and 5% levels. These results indicate that managerial ability enhances the positive effect of VC on corporate carbon performance, supporting Hypothesis H4.

E. HETEROGENEITY TESTS

1) Regional Heterogeneity

Although China's venture capital industry has flourished overall, significant regional disparities exist due to historical factors and influences such as regional economic levels, policy environments, technological innovation, and industry differences. Therefore, this study categorizes the sample based on corporate location into eastern, central, and western regions. As shown in Table 8, VC failed to pass the significance test for carbon performance (CP) in either western or central corporations. Meanwhile, VCshare

TABLE 7. Moderating Effect Test

VARIABLES	(1) CP	(2) CP	(3) CP	(4) CP
VC	0.011*	-0.977**		
	(1.88)	(-2.55)		
FRD_VC	-0.001*			
	(-1.71)			
FRD_VCshare		-0.269**		
		(-2.02)		
FRD	0.950***	6.194*		
	(4.01)	(1.71)		
MA_VC			0.016***	
			(3.17)	
VCshare			-0.983	-0.682
			(-1.60)	(-1.23)
MA_VCshare				1.419**
				(2.06)
MA			-0.756	-63.882
			(-1.59)	(-1.37)
Control Variables	✓	✓	✓	✓
Year FE	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes
Code FE	Yes	Yes	Yes	Yes
Samples size	9,328	9,448	8,988	8,988
Adjusted R2	0.516	0.156	0.532	0.532

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are shown in parentheses.

was only significant at the 10% significance level for the central region sample, and fails the significance test for the western sample. This indicates that VC investment has a more pronounced effect on enhancing carbon performance in eastern enterprises.

TABLE 8. Regional Heterogeneity Test

	Eastern		Western		Central	
VARIABLES	(1) CP	(2) CP	(3) CP	(4) CP	(5) CP	(6) CP
VC	27.684***		8.874		15.004	
	(4.94)		(0.68)		(1.04)	
VCshare		0.525***		0.229		0.364*
		(5.69)		(1.04)		(1.76)
Control Variables	✓	✓	✓	✓	✓	✓
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
Code FE	Yes	Yes	Yes	Yes	Yes	Yes
Samples size	5,860	5,860	1,593	1,593	1,875	1,875
Adjusted R2	0.534	0.535	0.506	0.506	0.588	0.588

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are shown in parentheses.

2) Heterogeneity in Corporate Property Rights

Differences in corporate property rights lead to variations in resource acquisition, governance structures, incentive mechanisms, market competitiveness, and risk tolerance. These differences result in variations in performance between the two corporation types in leveraging the VC market to enhance corporate carbon performance. Therefore, the sample is categorized into state-owned enterprises (SOEs) and non-state-owned enterprises (NSOEs) based on their ownership structure. As shown in Table 9, VC and VCshare are not statistically significant for carbon performance (CP) in SOEs, indicating that VC has a more pronounced effect on improving carbon performance in NSOEs.

TABLE 9. Heterogeneity in Property Rights Nature Test

	SOE		NSOE	
VARIABLES	(1) CP	(2) CP	(3) CP	(4) CP
VC	-1.072		31.697***	
	(-0.29)		(3.28)	
VCshare		0.020		0.620***
		(0.33)		(3.81)
Control Variables	✓	✓	✓	✓
Year FE	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes
Code FE	Yes	Yes	Yes	Yes
Samples size	5,326	5,326	3,988	3,988
Adjusted R2	0.608	0.608	0.545	0.545

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are shown in parentheses.

3) Heterogeneity among Heavy/Non-Heavy Polluters

As environmental policies become increasingly stringent, VC is placing greater emphasis on environmental compliance and potential green technological innovation when selecting investment targets. Consequently, corporations with different pollution levels may attract different levels of venture capital. Differences in pollution levels lead to disparities among corporations in terms of scale and strength, environmental policies and regulations, technological innovation capabilities, market prospects, and growth potential. These differences result in differences in performance among firms with different pollution levels in utilizing venture capital to enhance corporate carbon performance. Therefore, this study adopts the approach of (Pan Ailing, Liu Xin, 2019), classifying corporations with industry codes B06, B07, B08, B09, C17, C19, C22, C25, C26, C28, C29, C30, C31, C32, and D44 as heavy polluters [23], while the remaining samples are classified as non-heavy polluters. As shown in Table 10, VC does not pass the significance test for corporate carbon performance in non-heavy polluters; VC and VCshare are significant for corporate carbon performance in heavy polluters at the 5% and 1% confidence levels, respectively. This indicates that VC has a more pronounced effect on enhancing the carbon performance of heavy polluters.

TABLE 10. Heterogeneity among Heavy/Non-Heavy Polluters

	Heavy Polluters		Non-Heavy Polluters	
	(1)	(2)	(3)	(4)
VARIABLES	CP	CP	CP	CP
VC	9.325**		7.796	
	(2.28)		(1.37)	
VCshare		0.196***		0.223**
		(3.42)		(2.47)
Control Variables	✓	✓	✓	✓
Year FE	Yes	Yes	Yes	Yes
Ind FE	Yes	Yes	Yes	Yes
Code FE	Yes	Yes	Yes	Yes
Samples size	3,146	3,146	6,176	6,176
Adjusted R2	0.540	0.540	0.518	0.519

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are shown in parentheses.

V. CONCLUSIONS AND POLICY RECOMMENDATIONS

A. RESEARCH FINDINGS

Amidst the wave of environmental policies, VC serves as a vital funding source and strategic partner for corporations, acting as a lifeblood for their green development. This study, based on data from Shanghai and Shenzhen A-share listed companies from 2010 to 2023, employs a two-way fixed-effects model to analyze the impact of venture capital (VC) on corporate carbon performance. The findings reveal that VC exerts a significant positive influence on corporate carbon performance, indicating its pivotal role in enhancing such performance. However, the effectiveness of VC in improving carbon performance varies across different regions, ownership structures, and pollution levels among corporations. Specifically, VC demonstrates a more pronounced effect on improving carbon performance for enterprises in the eastern region, non-state-owned enterprises, and heavy polluters. Furthermore, VC enhances corporate carbon performance through two pathways: alleviating financing constraints and fostering technological innovation. Managerial ability also amplifies the positive impact of VC on corporate carbon performance, while financial regulation weakens this positive effect.

B. POLICY RECOMMENDATIONS

First, implement regionally differentiated guidance. The government should adopt regionally differentiated guidance policies. For eastern regions, it should encourage VC to increase investment in green and low-carbon industries, foster green industrial clusters, and play a leading role in demonstration. For central and western regions, the government may establish special guidance funds to provide policy support (such as tax incentives and risk compensation) to VC investing in local green projects. This will attract more VC attention to corporations in central and western regions, thereby promoting balanced green development across regions.

Second, optimize support policies. For non-state-owned enterprises, it should further improve the venture capital market environment, streamline approval procedures, strengthen intellectual property protection, and lower the threshold for non-state-owned enterprises to access VC investment, thus supporting their innovative development in low-carbon sectors. For heavy polluters, it should guide them to allocate VC funds toward green technology upgrades and energy-saving emission-reduction projects, offering incentives such as fiscal subsidies and preferential credit terms to facilitate their low-carbon transformation.

Third, enhance corporate financing and innovation capabilities. To strengthen the role of VC in improving corporate carbon performance by alleviating financing constraints and promoting technological innovation, the government should further develop the financial market system. On one hand, financial institutions should be encouraged to develop financial products tailored to green and low-carbon projects, fostering collaboration among VC, banks, securities firms, and other financial institutions to build a diversified green finance support system. On the other hand, industry-academia-research collaboration platforms should be established to facilitate technological exchange and cooperation among universities, research institutions, and enterprises, accelerating the transformation and industrialization of green technology achievements.

Fourth, balance the intensity of financial regulation. Given the regulatory role of financial oversight in shaping the relationship between VC and corporate carbon performance, regulatory authorities should strike a balance in the intensity of financial regulation. They should appropriately relax regulatory restrictions on VC investments in green and low-carbon sectors while ensuring financial market stability, so as to enhance VC's investment flexibility and innovation. They should also optimize information disclosure systems. On the basis of protecting corporate trade secrets, they should require VC and corporations to reasonably disclose information on green investment projects, thereby improving market transparency and promoting the healthy development of the green finance market.

Fifth, strengthen managerial ability building. To fully leverage the role of managerial ability in enhancing corporate carbon performance through VC, governments and industry associations should intensify training for corporate managers. Training courses and seminars focused on green development should be organized, green performance evaluation mechanisms for managers should be established, and coordination with VCs should be enhanced achieve carbon reduction targets and advance corporate sustainable development.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research was funded by Jilin Provincial Science and Technology Development Program (20250801099FG).

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