

Carbon Neutrality Management and Firm Risk

Junyao Gong

Sunwah international business school, Liaoning University, Liaoning 110000, China

Junyaogong86@163.com

Abstract. Under the backdrop of the 'dual carbon' goals, carbon neutrality has become a critical strategy for firms to address climate change and achieve sustainable development, with its impact on corporate risk attracting increasing attention. Using data from Chinese A-share listed companies on the Shanghai and Shenzhen stock exchanges from 2018 to 2022, this paper empirically examines the impact of corporate carbon neutrality management on firm risk and its underlying mechanisms through multiple regression models. The findings reveal that corporate carbon neutrality management significantly reduces firm risk, and this conclusion remains robust across a series of robustness checks, including alternative risk measurement indicators, replacement of the core explanatory variable, and controlling for endogeneity issues. Heterogeneity analysis demonstrates that the risk-reducing effect of carbon neutrality management is more pronounced in firms with lower audit quality and lower institutional investor ownership, suggesting that carbon neutrality management plays a more critical role in signaling and governance in firms characterized by higher information asymmetry and relatively weaker external monitoring. Mechanism analysis indicates that corporate carbon neutrality management reduces firm risk by alleviating financing constraints. Specifically, the positive signals conveyed by carbon neutrality management reduce the degree of information asymmetry, enabling firms to obtain external funding support at lower costs, thereby enhancing resource allocation capabilities, improving operational efficiency, and ultimately reducing firm risk. These results are consistent with the theoretical expectation that carbon neutrality management reduces corporate information asymmetry, mitigates financing constraints, and consequently lowers firm risk. The findings of this paper not only enrich the literature on the economic consequences of carbon neutrality management but also provide important theoretical foundations and practical implications for firms implementing carbon neutrality strategies, enhancing risk management capabilities, and for governments refining green finance policies.

Keywords: Carbon neutrality management, firm risk, financing constraints, information asymmetry.

1. Introduction

The challenges posed by global climate change are becoming increasingly severe, and global climate governance has become a shared responsibility of the international community. Carbon neutrality (Net-zero) has emerged as a global strategy to address the societal and environmental issues posed by climate change (Wang & Zhang, 2020). As macro-level strategies are translated into micro-level practices, firms—as the key executive subjects for achieving carbon neutrality goals—are receiving unprecedented attention regarding their roles and responsibilities. By embracing the concept of carbon neutrality management and implementing effective management measures, firms could not only benefit themselves but also expand their value chains to benefit the public. How enterprises can mitigate risks through carbon neutrality management represents a pressing question demanding immediate attention.

Existing literature has examined the impact of corporate ESG performance and carbon neutrality management from multiple perspectives. Component of the environmental dimension within the ESG framework, carbon neutrality management shares intrinsic connections with ESG performance while maintaining its distinct characteristics: both emphasize corporate sustainable development capacity and social responsibility fulfillment, yet carbon neutrality management places greater emphasis on specific practices and management mechanisms for addressing climate change and achieving net-zero greenhouse gas emissions. Regarding ESG performance, Li et al. (2021) confirmed that ESG performance significantly enhances corporate performance. Zhang et al. (2022) and Li et al. (2023) demonstrated that sound ESG practices generate positive market reputation effects, thereby elevating

overall corporate value. In carbon neutrality management research, existing studies primarily focus on its impact on corporate performance and value. Song et al. (2019) indicated that while carbon disclosure exerts negative short-term effects on corporate performance, it promotes long-term market value growth through signaling mechanisms. Wu & Song (2024) further revealed a U-shaped relationship between carbon neutrality management and corporate value. Additionally, scholars have identified multiple positive effects of carbon neutrality management. Yao and Zhou (2024) argued that carbon neutrality management provides green innovation incentives, effectively enhancing enterprises' future green innovation capabilities. Chen et al. (2023) found that superior carbon neutrality management performance not only strengthens corporate market reputation but also improves supply chain stability and reinforces collaborative relationships. Yao & Li (2024) confirmed that strong carbon neutrality performance effectively curbs corporate R&D manipulation behavior.

Despite existing research revealing multiple positive effects of carbon neutrality management, its impact on firm risk remains theoretically contested. On one hand, carbon neutrality management may elevate firm risk. Grounded in principal-agent theory, conflicts of interest frequently arise between corporate managers and shareholders. In pursuing personal reputation and self-interest, managers may overinvest in carbon neutrality initiatives to enhance their individual standing. Such behavior can lead to firm misallocation of resources, escalating operational costs and financial burdens, thereby amplifying overall corporate risk exposure (Wang & Zeng, 2013). Furthermore, carbon neutrality management may mitigate greenwashing risks. Certain firms may exaggerate their carbon neutrality achievements or disseminate misleading information to secure policy support or bolster their corporate image (Huang, 2021). Once exposed by the market, these firms face reputational damage and declining investor confidence (Huang & Zhao, 2018), which subsequently impairs their financing capacity and market valuation. Consequently, carbon neutrality management may, under certain circumstances, exacerbate corporate financing constraints and increase firm risk exposure through multiple channels, including agency problems and greenwashing risks.

On the other hand, corporate carbon neutrality management may effectively mitigate risk. The non-financial information and positive signals conveyed through carbon neutrality management can reduce managerial adverse selection behavior (Fang & Lin, 2023), thereby diminishing the degree of information asymmetry within firms. Information asymmetry generates disparities in external financing costs, with such costs reflecting the severity of financing constraints (Qu et al., 2011). When information asymmetry is alleviated, the risk premium demanded by investors and creditors declines accordingly, enabling firms to secure external funding at lower costs and thus easing financing constraints. This constraint-alleviating effect endows firms with sufficient capital and resources while simultaneously enhancing their capabilities in resource integration and efficient allocation (Zhang et al., 2017). Abundant capital and resources not only ensure the sustainability of organizational transactions and reduce risks stemming from funding shortfalls, but the improved resource integration and allocation capabilities also enhance operational efficiency (Wang et al., 2022), thereby reducing overall corporate risk and strengthening resilience against adverse conditions. In summary, theoretical perspectives regarding the directional impact of carbon neutrality management on firm risk have yet to converge toward a unified conclusion.

Based on the above analysis, this study employs a sample of listed firms from China's Shanghai and Shenzhen A-share markets spanning 2018-2022 to empirically examine the effect of carbon neutrality management on firm risk. The findings reveal that carbon neutrality management exerts a significant mitigating effect on firm risk, a conclusion that remains robust across alternative variable measurements, with endogeneity concerns effectively addressed through instrumental variable estimation. Heterogeneity analysis demonstrates that the risk-reduction effect of carbon neutrality management is more pronounced in firms characterized by lower institutional investors shareholding ratio and inferior audit quality. Mechanism analysis further reveals that carbon neutrality management reduces firm risk through the channel of alleviating information asymmetry and financing constraints.

This study makes three primary contributions. Firstly, it provides novel evidence on the effectiveness of corporate carbon neutrality management from a firm risk perspective. Existing

research predominantly focuses on the theoretical dimensions of carbon neutrality, such as macroeconomic growth (Lin, 2022) and development models (Yu et al., 2021), with limited micro-level empirical examination. By utilizing carbon neutrality rating data from third-party agencies, this study empirically investigates whether carbon neutrality performance could influence firm's risk-taking behavior. This extends research on the economic consequences of carbon neutrality management and provides empirical evidence for improving China's carbon neutrality information disclosure system.

Furthermore, it expands the literature on corporate risk governance from the perspective of market-based soft regulation through carbon neutrality ratings. Existing studies primarily examine corporate risk from traditional perspectives such as corporate governance (Yu et al., 2008; Xie, 2013; Lai et al., 2019) and economic policy (Zhang & Huang, 2009; Rao & Xu, 2017). This study reveals whether firm's carbon neutrality performance could reduce firm risk, thus offering a new theoretical perspective on firm risk.

Thirdly, this study also advances empirical research in the carbon neutrality domain. Existing carbon-related studies remain in their nascent stage, primarily concentrating on traditional perspectives such as carbon information disclosure (Chen et al., 2013; Li et al., 2019; Sun et al., 2023). Leveraging the unique dataset of Huazheng Carbon Neutrality Ratings, this study empirically tests the risk-mitigating effects of carbon neutrality management. This not only distinguishes itself from the broad ESG perspective (Wang et al., 2022; Tan et al., 2022; Jiang & Yao, 2024) but also focuses specifically on the value of corporate carbon neutrality management under the "dual carbon" goals, providing valuable insights for deepening research on the micro-level mechanisms of carbon neutrality.

The rest of this report is structured as follows. Section 2 outlines the literature review and development of hypotheses. Section 3 details the methodology, covering data cleaning, variable definition, and descriptive statistics. Section 4 presents the baseline regression results. Section 5 presents further discussion and heterogeneity analysis. Section 6 concludes with some policy recommendations.

2. Literature Review and Hypothesis Development

2.1. Literature Review

2.1.1. Carbon Neutrality Management

Carbon neutrality management, also served as carbon neutrality performance, encompasses the practical strategies and governance frameworks through which firms reduce or offset greenhouse gas (GHG) emissions to achieve "net-zero" GHG output (Yao & Zhou, 2024; He et al., 2013). Typical initiatives under this approach include enhancing energy efficiency, adopting clean energy sources, optimizing production processes, and implementing carbon capture technologies (Fu et al., 2008).

In recent years, scholars have conducted extensive research on the impact of carbon neutrality management within firms, primarily focusing on corporate value, innovation capacity, and operational performance. Regarding corporate value, Zhang et al. (2022) and Li et al. (2023) find that carbon neutrality initiatives generate substantial reputational effects in the market, positively influencing overall firm value. Wu and Song (2024) further document a U-shaped relationship between carbon neutrality performance and firm value. Song et al. (2019) demonstrate that while carbon disclosure exerts adverse short-term performance effects, it enhances long-term market value through signaling mechanisms. Concerning innovation capacity, Yao & Zhou (2024) identify a synergistic green innovation effect of carbon neutrality management that effectively promotes firms' future green innovation performance. Yao & Li (2024) reveal that superior carbon neutrality performance significantly curtails R&D manipulation. With respect to operational performance, Li et al. (2021) establish that ESG performance enhances enterprise performance. Chen et al. (2023) find

that exemplary carbon neutrality management not only elevates corporate market reputation but also strengthens customer stability and enhances supply chain resilience.

Regarding the mechanisms through which carbon neutrality management influences firms, existing research primarily explores financing costs, capital market stability, and managerial behavior. Concerning financing costs, Lu et al. (2022) find that the carbon benefits of green bonds significantly reduce financing costs. Reber et al. (2022) demonstrate that superior ESG performance substantially lowers corporate cost of capital and reduces idiosyncratic risk in the first year post-IPO. Eliwa et al. (2021) document positive effects of ESG performance on reducing both cost of equity and cost of debt. With respect to capital market stability, Zhou et al. (2022) find that firms with strong ESG performance exhibit lower stock price volatility, enhancing corporate resilience and stabilizing stock prices. Bae et al. (2021) establish that ESG ratings mitigate stock price crash risk, with the marginal effect of ESG performance being particularly pronounced for firms facing severe financing constraints. However, carbon neutrality management may also generate adverse consequences. Sun et al. (2023) reveal that carbon neutrality information disclosure may induce corporate catering behavior, resulting in premium loss through diminished investor confidence and reduced debt financing levels.

2.1.2. Firm Risk

Based on whether risk can be diversified, risk can be classified into systematic risk and nonsystematic risk. Systematic risk refers to risk that affects the entire market and cannot be eliminated through portfolio diversification. Nonsystematic risk is firm idiosyncratic risk, which can be reduced or eliminated through portfolio diversification (Tan et al., 2022). Existing research has explored the determinants of firm risk from both external and internal perspectives. Demirgüç-Kunt and Detragiache (1998) and Pesaran et al. (2006) point out that external macroeconomic factors such as politics, economy, law, and culture profoundly influence the market risk faced by firms. These factors are typically difficult to control but can alter the firm's operating environment, thereby increasing uncertainty and risk. Regarding internal factors, Zhen and Wang (2021), as well as Feng et al. (2016), find that microeconomic factors such as equity nature, managerial characteristics, firm size, and firm behavior also exert significant impacts on firm risk.

Based on differential effects, factors influencing firm risk can be further categorized into those that mitigate risk and those that amplify it. Existing research identifies that risk-mitigating factors primarily encompass government and stakeholder relations, corporate governance structure, corporate non-financial behavior, and ESG performance. Regarding government and stakeholder relations, Zhang & Huang (2009) find that firms with stronger government connections more readily access diversified resources, thereby reducing future firm risk. Wang et al. (2022) demonstrate that maintaining favorable collaborative relationships with suppliers and other stakeholders provides resource support for corporate risk-taking, significantly lowering overall risk exposure. Concerning corporate governance structure, Daily & Dalton (1994) and Kesner (1987) document that improvements in ownership structure reduce firm risk through channels including alleviating financing constraints and enhancing investment efficiency. Daily & Dalton (1994) further reveal significant differences between bankrupt and viable firms in board composition and CEO duality, with broader board social capital contributing to risk mitigation. Yu et al. (2008) establishes that optimization of corporate governance reduces corporate financing risk. Zhang et al. (2019) find that high-quality internal control effectively suppresses the elevated potential firm risk associated with tax avoidance. With respect to corporate non-financial behavior, Zeng et al. (2018) and Wang et al. (2019) demonstrate that non-financial activities such as corporate social responsibility, water information disclosure, and targeted poverty alleviation reduce firm risk through positive signaling, favorable reputation building, and enhanced information transparency. Feng et al. (2016) find that, within China's economic context, superior corporate social responsibility performance more effectively mitigates firm risk. Regarding ESG performance, Sassen et al. (2016) establish that environmental, social, and governance (CSP) factors enhance firm value by reducing corporate risk. Chen (2018) documents a negative correlation between corporate ESG levels and bond default

probability, with firms exhibiting strong ESG performance facing lower risks of bond default or downgrade. Jiang & Yao (2024) reveal that ESG disclosure reduces firm risk by promoting accountability system and diminishing information asymmetry.

Some studies have identified factors that amplify firm risk, primarily encompassing monetary policy, financial frictions, corporate governance structure, and ESG assessment. Lin et al. (2014) finds that accommodative monetary policy exacerbates corporate risk-taking while diminishing risk management efficiency. Chugh (2016) demonstrates that financial frictions generate heterogeneous risk exposure across firms of varying sizes, with such heterogeneity fluctuating in response to GDP volatility. Daily & Dalton (1994) reveal that greater depth of board social capital may paradoxically elevate corporate risk. Notably, the impact of ESG assessment on firm risk may exhibit dual effects. Landi et al. (2022) find that comprehensive ESG assessment may increase systematic risk, particularly when firms demonstrate unstable performance or face substantial pressures in environmental, social, and governance dimensions, rendering such risk more pronounced. Therefore, while ESG assessment is generally perceived as a risk-mitigating factor, under certain circumstances it may also amplify the systematic risk confronting firms.

Based on the foregoing literature review, existing research on the economic consequences of carbon neutrality management predominantly concentrates on firm value, innovation capacity, and enterprise performance. Within the domain of firm risk, extant literature has examined the influence of factors including government and stakeholder relations, corporate governance structure, non-financial behavior, and ESG assessment on corporate risk. However, existing studies rarely establish empirical linkages between micro-level corporate carbon neutrality management and firm risk. Against this backdrop, this study investigates whether carbon neutrality management influences firm risk, endeavoring to enrich the existing literature in both the carbon neutrality management and firm risk domains.

2.2. Hypothesis Development

Carbon neutrality management serves as a mechanism which can signal firms' non-financial information to stakeholders regarding their operational performance, financial strength, and sustainable development capabilities (Tan et al., 2022). Proactive engagement in carbon neutral practices reveals that firms possess comparative advantages in low-carbon policy implementation and green governance, thereby effectively mitigating potential risks arising from climate-related factors and conveying a positive commitment to carbon neutrality management (Yao & Li, 2024).

Based on Asymmetric Information Theory, carbon neutrality management conveys non-financial information and positive signals that mitigate managerial adverse selection (Fang & Lin, 2023), thus reducing the degree of asymmetry information faced by firms. Asymmetry information creates disparities in external financing costs, which reflect the degree of financing constraints (Qu et al., 2011). By alleviating information asymmetry, firms can reduce the risk premium demanded by investors and creditors, acquire external funding at lower costs, and thus ease their financing constraints.

Financing constraint slow-release effect provides firms with greater access to capital and resources, while enhancing their capacity for resource integration and efficient allocation as well (Zhang et al., 2017). And abundant financial resources enable firms to maintain transactional sustainability and mitigate risks associated with capital shortages. Moreover, improved resource integration and allocation capabilities strengthen firm's operational efficiency (Wang et al., 2022), thus reducing corporate risk exposure and bolstering firms' resilience.

Hypothesis 1. Carbon neutrality management could decrease firm risk.

Carbon neutrality management may also elevate firm risk. Based on agency theory, conflicts of interest frequently arise between corporate managers and shareholders. When firms engage in carbon neutrality management, certain managers may overinvest in carbon neutrality projects to enhance personal reputation and secure private benefits (Feng et al., 2016). Such investment decisions deviate from the objective of shareholder value maximization, leading to declining firm resource allocation

efficiency, escalating operating costs (Wang & Zeng, 2013), intensifying financial burdens, and ultimately elevating overall corporate risk levels.

Furthermore, carbon neutrality management may precipitate greenwashing risks. Some firms, seeking to obtain preferential policies or enhance market image, may exaggerate carbon reduction effectiveness or even disseminate false information (Huang, 2022). Once such behavior is exposed, it damages corporate reputation and erodes investor confidence (Huang & Zhao, 2018), subsequently impairing firms' financing capacity and adversely affecting firm market valuation. Consequently, carbon neutrality management may increase firm risk through two channels: first, agency problems stemming from managerial overinvestment, and second, greenwashing risks arising from information distortion. Both channels intensify corporate financial burdens and exacerbate financing constraints.

Hypothesis 2. Carbon neutrality management could increase firm risk.

3. Study Design

3.1. Data

This research draws from a variety of databases to construct its research sample. The data of the independent variable, carbon neutrality management, is obtained from Shanghai HuaZheng Index Information Services Co., Ltd. The financial data of listed firms is sourced from CSMAR Database. This study examines the impact of carbon neutrality management on firm risk, using listed firms from China's Shanghai and Shenzhen A-share markets over the period 2018-2022. While the initial data collection spans from 2018 to 2024, the final regression analysis utilizes data from 2018 to 2022 for all variables, as the measurement of firm risk requires forward-looking data from periods $t+1$ and $t+2$.

To ensure the accuracy of the research, data cleaning procedures are applied as follows: (1) Excluding ST, *ST, and delisted firms, which have consecutive losses for more than two years, as their financial data may be abnormal and influence research accuracy; (2) Excluding financial and insurance firms due to their special capital structure and financial principles; (3) Excluding observations with missing data. Consequently, a panel dataset comprising 4768 listed firms and 18,868 observations is constructed; (4) Winsorizing all continuous variables at the 1st and 99th percentiles.

3.2. Model Setting and Variable Definitions

3.2.1. Model Setting

Following (Yao & Li, 2024; Yu et al., 2013), this research constructs the basic model (1) to examine the impact of carbon neutrality management on firm risk.

$$\widehat{Risk}_{i,t} = \beta_0 + \beta_1 Carbon_{i,t} + \beta_m Controls_{i,t} + Year + Industry + \varepsilon_{i,t} \quad (1)$$

$Risk_{i,t}$ measures the risk of firm i in year t . $Carbon_{i,t}$ represents the carbon neutrality management of firm i in year t . $Controls_{i,t}$ denotes a set of control variables. This research also controls industry-fixed effects ($Industry$) and year-fixed effects ($Year$), with $\varepsilon_{i,t}$ representing the random disturbance term. This research focuses on the regression coefficient of $Carbon_{i,t}$. If carbon neutrality management positively affect firm risk, β_1 would be significantly lower than 0.

3.2.2. Variable Definitions

The independent variable carbon neutrality management ($Carbon$) can be represented by The Huazheng Carbon Neutrality Rating. The Huazheng Carbon Neutrality Rating categorizes the carbon neutrality performance of listed companies into nine tiers, ranked from lowest to highest as follows: C, CC, CCC, B, BB, BBB, A, AA, and AAA. This research assigns scores ranging from 1 to 9 to these nine rating tiers in ascending order. Given that each firm receives two ratings per year, this research takes the average of the two rating scores, adds 1, and then applies the natural logarithm to

represent the independent variable. A higher value of this variable indicates a superior corporate carbon neutrality rating, signifying better carbon neutrality management performance.

$Risk_{i,t}$ represents the level of firm risk, where i denotes the firm, t denotes the time period. Following Yu et al. (2013), this study employs firm earnings volatility to measure firm risk, expressed as $\sigma(ROA_i)$. $\sigma(ROA_i)$ represents the ratio of a firm's earnings before interest, taxes, depreciation and amortization ($EBITDA$) in the corresponding year to its total assets at year-end. In calculating volatility, we first adjust each firm's annual ROA by the industry average, then compute the standard deviation of the industry-adjusted within each observation period. Specifically:

$$RiskT_i = \sqrt{\frac{1}{N-1} \sum_{n=1}^N (ADJ_ROA_{in} - \frac{1}{N} \sum_{n=1}^N ADJ_ROA_{in})^2} \quad | \quad N = 3^1, \text{ 其中:}$$

$$ADJ_ROA_{in} = \frac{EBITDA_{in}}{ASSETS_{in}} - \frac{1}{X_n} \sum_{k=1}^X \frac{EBITDA_{kn}}{ASSETS_{kn}}$$

The research also controls other factors affecting firm risk. These factors include firm size ($Size$), the firm's listing period (Age); ownership nature ($State$), firm growth ($Growth$), firm's boardsize ($Boardsize$), proportion of independent directors (Ind), the shareholding ratio of the largest shareholder at the end of the year ($Top1$); the proportion of dual executives ($Dual$); leverage ratio (Lev), profitability (ROA), industry-fixed effects ($Industry$) and year-fixed effects ($Year$). *Table 1* shows the detailed definition of each variable.

Table 1. Definitions of variables.

Variables	Definitions
Risk	The standard deviation of ROA
Carbon	Measured by Huazheng Carbon Neutrality Rating. Ratings (C to AAA, high to low) are assigned 1–9 points and take the natural logarithm of (annual average of two ratings and plus 1)
Age	Natural logarithm of the sum of years listed plus 1
Size	The total assets of the firm at the end of the period (taking natural logarithm)
State	Whether the firm is state-owned (1 for yes, 0 for otherwise)
Growth	Year-end revenue growth rate of the firm
Boardsize	Natural logarithm of the number of board members
Ind	The proportion of independent directors in the board members
Top1	Shareholding of the largest shareholder at the end of the year as a proportion of the total shares of the firm
Dual	Dummy variable that equals to 1 if the chairman of the board and the general manager are the same individual and 0 otherwise
Lev	The ratio of total assets to total liabilities at the end of the period
ROA	Net profit margin of total assets at the end of the period

¹ In the international literature, when using the volatility of ROA to measure risk-taking, an observation window typically spans 5 years. As the direct decision-makers for investment decisions, corporate managers generally focus on the firm's development during their tenure when making decisions. The tenure of senior executives in Chinese listed companies is typically 3 years; therefore, this paper adopts a 3-year observation window.

² where i represents the firm, n represents the year within the observation window, taking values from 1 to 3. X represents the total number of firms in a given industry, and k represents the k -th firm in that industry.

3.3. Descriptive Statistics

Table 2 presents the descriptive statistics for the variables described above. The mean value of firm risk is 0.037, with a standard deviation of 0.050. And the considerable high variation between the maximum and minimum values provides a good opportunity for this research.

In terms of independent variable, the average of carbon neutrality management for listed firms is 1.100, with a standard deviation of 0.152. The minimum and maximum values are 0.693 and 1.609, respectively, indicating the discrepancy in carbon neutrality management between firms.

Table 2. Descriptive statistics of the main variables

	(1)	(2)	(3)	(4)	(5)
VARIABLES	<i>N</i>	<i>mean</i>	<i>sd</i>	<i>min</i>	<i>max</i>
<i>Risk</i>	18868	0.037	0.050	0.000	0.309
<i>Carbon</i>	18868	1.100	0.152	0.693	1.609
<i>Age</i>	18868	3.023	0.287	2.197	3.584
<i>Size</i>	18868	22.320	1.303	20.060	26.410
<i>State</i>	18868	0.280	0.449	0.000	1.000
<i>Growth</i>	18868	0.136	0.337	-0.568	1.812
<i>Boardsize</i>	18868	2.098	0.195	1.609	2.639
<i>Ind</i>	18868	0.379	0.054	0.333	0.571
<i>Top1</i>	18868	0.330	0.146	0.084	0.736
<i>Dual</i>	18868	0.324	0.468	0.000	1.000
<i>Lev</i>	18868	0.409	0.198	0.058	0.883
<i>ROA</i>	18868	0.034	0.074	-0.321	0.212

4. Results

4.1. Baseline Regression Results

Table 3 presents the baseline results. Column (1) shows the baseline regression, which includes neither controls nor fixed effects. Column (2) incorporates only fixed effects, column (3) incorporates only controls, and column (4) simultaneously incorporates both controls and fixed effects. The regression results reveal that the regression coefficient of carbon neutrality management is significantly negative at the 1% statistical level across all specifications. This indicates that the higher the level of corporate carbon neutrality management, the lower the firm risk. Consequently, these results indicate that higher levels of carbon neutrality management could lead to lower risk of the firm, verifying Hypothesis 1 in our research.

Table 3. Regression results of carbon neutrality management and firm risk

	(1)	(2)	(3)	(4)
VARIABLES	<i>Risk</i>	<i>Risk</i>	<i>Risk</i>	<i>Risk</i>
<i>Carbon</i>	-0.047***	-0.043***	-0.019***	-0.018***
	(-18.911)	(-16.825)	(-7.733)	(-7.280)
<i>Age</i>			-0.002	0.002
			(-1.115)	(1.308)
<i>Size</i>			-0.004***	-0.004***
			(-7.742)	(-8.680)
<i>State</i>			-0.010***	-0.011***
			(-8.870)	(-10.295)
<i>Growth</i>			0.013***	0.013***
			(8.227)	(8.234)
<i>Boardsize</i>			-0.008**	-0.009***
			(-2.438)	(-2.924)
<i>Ind</i>			0.005	-0.006
			(0.472)	(-0.596)
<i>Top1</i>			-0.020***	-0.018***
			(-6.427)	(-6.114)
<i>Dual</i>			-0.002*	-0.001
			(-1.693)	(-1.381)
<i>Lev</i>			-0.010***	-0.009**
			(-2.885)	(-2.554)
<i>ROA</i>			-0.281***	-0.267***
			(-25.512)	(-25.183)
<i>Constant</i>	0.089***	0.089***	0.181***	0.182***
	(30.084)	(13.145)	(16.004)	(15.316)
Observations	18,868	18,868	18,868	18,868
R-squared	0.020	0.125	0.207	0.285
Industry FE	NO	YES	NO	YES
Year FE	NO	YES	NO	YES

Notes: *, **, and *** denote statistical significance at the 10 %, 5 %, and 1 % levels, respectively. T-statistics are in parentheses.

4.2. Robustness Tests

We conduct robustness tests to strengthen the baseline results, including substituting independent and dependent variables, employing instrumental variables in regression, and examining the impact of Carbon Neutrality Management on firm risk.

4.2.1. Replacing Independent Variable

Measurement bias can lead to biased or inconsistent regression coefficients. To address the impact of measurement error on our results, we employ different measures for both dependent and independent variables.

This study replaces the independent variable with another carbon score (*CarbonScore*). The Huazheng carbon neutrality management system encompasses not only the rating indicator employed in the primary analysis but also the carbon neutrality score data corresponding to these ratings, with scores ranging from 0 to 100 on a standardized scale. This study conducts robustness tests using the natural logarithm of carbon neutrality score plus one (*CarbonScore*). The corresponding results are presented in Column (1) in *Table 4*, where the regression coefficient of *CarbonScore* is significantly negative, consistent with the baseline results and further validating the main findings of this study.

4.2.2. Replacing Dependent Variable

This study then replaces the dependent variable. To further verify the robustness of the baseline regression findings, this section adjusts the calculation window for the risk-taking measure. The measurement approach in the baseline regression, which is based on the standard errors across three periods (t-1, t, t+1), is extended to a five-period window spanning from t-2 to t+2. The longer time span better captures the intertemporal persistence characteristics of risk-taking behavior and can effectively mitigate the interference of short-term fluctuations on the measurement of this indicator, thereby testing whether the core conclusions depend on specific window specifications. The result after making this substitution is shown in column (2) of *Table 4*. It reinforces a significant positive impact of carbon neutrality management on firm risk, affirming the robustness of our findings.

Table 4. Robustness test: Replace key variables

VARIABLES	(1) <i>Risk</i>	(2) <i>Risk</i>
<i>CarbonScore</i>	-0.064***	
<i>Carbon</i>	(-5.765)	-0.027*** (-8.511)
<i>Age</i>	0.002 (1.255)	-0.004* (-1.927)
<i>Size</i>	-0.004*** (-7.799)	-0.002*** (-3.591)
<i>State</i>	-0.011*** (-10.263)	-0.011*** (-8.206)
<i>Growth</i>	0.013*** (8.220)	0.008*** (4.502)
<i>Boardsize</i>	-0.009*** (-2.925)	-0.010*** (-2.723)
<i>Ind</i>	-0.006 (-0.620)	0.006 (0.478)
<i>Top1</i>	-0.018*** (-6.097)	-0.021*** (-5.512)
<i>Dual</i>	-0.001 (-1.386)	-0.001 (-0.438)
<i>Lev</i>	-0.009*** (-2.589)	-0.014*** (-3.182)
<i>ROA</i>	-0.267*** (-25.194)	-0.255*** (-22.174)
Constant	0.425*** (10.019)	0.179*** (11.098)
Observations	18,868	18,856
R-squared	0.284	0.371
Industry FE	YES	YES
Year FE	YES	YES

4.2.3. Employing Instrument Variable

There may be a causal relationship between carbon neutrality management and corporate risk. To address the potential endogenous problem, this study, drawing on previous literature (Yao & Li, 2024), selects the mean carbon neutrality performance of other firms (excluding the firm itself) (*Carbon_ave*) in the same year and region (province) as an instrument variable to conduct two-stage

least squares estimation. The selection of this instrument variable is based on the following considerations: the similar external business environment and geographical proximity advantages mean that a firm's own carbon neutrality management is subject to potential influence from other firms in the same region; therefore, this instrument variable satisfies the relevance condition. Meanwhile, the regional mean of carbon neutrality management is an aggregate variable at the regional level, which is unlikely to directly affect individual firm risk, thus satisfying the exogeneity condition of the instrument variable.

As shown in *Table 5*, columns (1) and (2) present the results of the instrumental variable regression. Column (1) reports the first-stage results testing the instrument variable (*Carbon_ave*) against the endogenous explanatory variable, where the regression coefficient is significantly positive, demonstrating that the two variables are significantly correlated. Column (2) of *Table 5* presents the second-stage regression results, where the regression coefficient of *Carbon* is significantly negative. This regression result is consistent with the main regression results, confirming the robustness of the preceding research conclusions.

Table 5. Instrumental Variable Regression Results

VARIABLES	(1)	(2)
<i>Carbon_ave</i>	0.726*** (9.501)	
<i>Carbon</i>		-0.063*** (-2.577)
<i>Age</i>	0.010* (1.786)	0.003 (1.467)
<i>Size</i>	0.046*** (22.815)	-0.002 (-1.638)
<i>State</i>	0.001 (0.304)	-0.011*** (-9.970)
<i>Growth</i>	-0.002 (-0.592)	0.013*** (8.157)
<i>Boardsize</i>	0.022** (2.016)	-0.008** (-2.560)
<i>Ind</i>	0.094*** (2.584)	-0.002 (-0.167)
<i>Top1</i>	0.013 (1.126)	-0.018*** (-5.938)
<i>Dual</i>	-0.001 (-0.340)	-0.001 (-1.434)
<i>Lev</i>	0.012 (1.249)	-0.008** (-2.421)
<i>ROA</i>	0.095*** (5.114)	-0.262*** (-24.285)
<i>Constant</i>	-0.865*** (-8.544)	0.179*** (14.944)
Observations	18,868	18,868
R-squared	0.201	0.283
Industry FE	YES	YES
Year FE	YES	YES

4.3. Channel/Mechanism Analysis

As discussed in the theoretical analysis, carbon neutrality management could influence firm risk through two possible channels.

Corporate carbon neutrality management reduces the degree of information asymmetry by conveying positive non-financial information and signals, thereby alleviating financing constraints and enabling firms to obtain external funding support at lower costs. The mitigation of financial constraints provides firms with sufficient capital and resources. Abundant capital and resources enhance firms' integration and allocation of resource capabilities, which in turn increase operational efficiency. Ultimately, firm risk is reduced and resilience is strengthened.

This study follows the methodologies of Song et al. (2021) and Yu et al. (2012) to measure information asymmetry (*ASY1*、*ASY2*) and adopts the financing constraint index of Whited & Wu (2006) (*WW*) and the financing constraints index of Kaplan & Zingales (1997) (*KZ*) to measure financing constraints. Higher *WW* and *KZ* indicate greater financing constraints faced by firms. According to the regression results shown in *Table 6*, the coefficients of the carbon neutrality variable are significantly negative across all information asymmetry and financing constraints indices (*ASY1*、*ASY2*、*WW*、*KZ*), indicating that firms with higher levels of carbon neutrality management experience lower degrees of financing constraints. These findings validate that corporate carbon neutrality management effectively alleviates financing constraints by reducing information asymmetry and transmitting positive signals, enabling firms to secure external financing support at lower costs and providing sufficient financial resources for subsequent resource allocation and risk management.

Table 6. Carbon neutrality management and firm risk: channel analysis

	(1)	(2)	(3)	(4)
VARIABLES	<i>ASY1</i>	<i>ASY2</i>	<i>WW</i>	<i>KZ</i>
<i>Carbon</i>	-0.144*** (-5.091)	-0.195*** (-5.310)	-0.008*** (-4.492)	-0.911*** (-8.643)
<i>Age</i>	0.025* (1.739)	0.037** (2.018)	0.004*** (3.888)	0.515*** (8.471)
<i>Size</i>	-0.257*** (-46.247)	-0.315*** (-43.012)	-0.048*** (-145.330)	-0.254*** (-15.380)
<i>State</i>	0.019 (1.600)	0.024 (1.589)	-0.001 (-0.763)	0.217*** (5.638)
<i>Growth</i>	-0.100*** (-10.259)	-0.127*** (-10.180)	-0.044*** (-37.550)	-0.116** (-2.404)
<i>Boardsize</i>	-0.008 (-0.264)	-0.016 (-0.442)	-0.002 (-0.971)	-0.122 (-1.194)
<i>Ind</i>	-0.298*** (-3.169)	-0.399*** (-3.288)	0.004 (0.662)	0.193 (0.565)
<i>Top1</i>	0.401*** (13.699)	0.482*** (12.826)	-0.020*** (-9.327)	-1.079*** (-9.486)
<i>Dual</i>	-0.017** (-2.168)	-0.024** (-2.382)	-0.001 (-1.617)	-0.083** (-2.476)
<i>Lev</i>	0.316*** (12.774)	0.399*** (12.695)	0.025*** (11.753)	7.287*** (73.511)
<i>ROA</i>	-0.739*** (-13.012)	-0.943*** (-13.086)	-0.186*** (-36.338)	-9.354*** (-32.673)
<i>Constant</i>	5.357*** (34.219)	6.685*** (32.669)	0.062*** (6.534)	4.178*** (8.857)
Observations	18,865	18,865	14,818	18,863
R-squared	0.544	0.529	0.864	0.589
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

5. Heterogeneity Analysis

We further explore the heterogeneous effects of carbon neutrality management on firm risk from the perspectives of Institutional investors shareholding ratio heterogeneity and audit quality heterogeneity. This analysis would provide a deeper understanding of how carbon neutrality management influence firm risk based on different firm characteristics.

5.1. Institutional Investors Shareholding Ratio

Institutional investors are important participants in the capital market, possessing professional investment analysis capabilities, extensive risk management experience, and strong information acquisition advantages. Existing research demonstrates that institutional investors contribute to improving corporate governance levels, particularly the degree of information disclosure (Yang et al., 2012; Niu et al., 2013). Compared to individual investors, institutional investors place greater emphasis on firms' long-term value and sustainable development, prioritizing corporate performance in environment, social, and governance (ESG) aspects when making investment decisions. Through exercising shareholder rights, participating in corporate governance, and monitoring managerial decisions, institutional investors can effectively constrain managerial myopia (Du, 2010), thereby reducing firms' financing costs and operational uncertainty, and promoting the strengthening of risk management system construction. Based on these characteristics and mechanisms of institutional investors, firms with higher institutional investors' shareholding ratios tend to have already established relatively well-developed risk management systems and governance mechanisms. Under the supervision and guidance of institutional investors, corporate information disclosure becomes more transparent, operational decisions more prudent, and various risks better identified and controlled. Conversely, in firms with lower institutional investor shareholding ratios, existing risk management systems are often inadequately developed. In such cases, carbon neutrality management, as an integral component of risk management, can fill gaps in risk management and generate greater synergy effects with existing systems, thereby more effectively reducing firm risk. Based on the above analysis, this study proposes the following hypothesis: In firms with lower institutional investors' shareholding ratios, carbon neutrality management, as an important component of risk management, will demonstrate more significant implementation effects and generate greater synergy effects with existing risk management systems, thereby more effectively reducing firm risk.

This study conducts grouped tests based on high and low institutional investor shareholding. The regression results are presented in columns (1) and (2) of *Table 7*. The findings reveal that in the group with lower institutional investors' shareholding ratios (column 2), the coefficient of *Carbon* is -0.036 and significant at the 1% level. In contrast, in the group with higher institutional investors' shareholding ratios (column 1), the coefficient of *Carbon* is -0.003 and not significant. These results indicate that carbon neutrality management exerts a more pronounced effect on reducing firm risk in firms with lower institutional investor shareholding ratios, thereby validating the aforementioned hypothesis.

5.2. Audit Quality

The level of audit quality directly influences corporate transparency and information disclosure quality. High-quality audits can detect and correct false information or misleading statements that may exist in corporate financial reports, thereby enhancing the accuracy and reliability of carbon neutrality management information disclosure and effectively reducing the degree of information asymmetry (Lei et al., 2015). In firms with high audit quality, information is more transparent, management faces greater external supervision pressure, and the degree of information asymmetry and financing constraints problems are relatively less severe (Qu et al., 2011). Conversely, firms with lower audit quality have greater room for information manipulation, resulting in more pronounced information asymmetry. Therefore, this study hypothesizes that: In firms with lower audit quality, due to greater room for information manipulation and more pronounced information asymmetry, the

effect of carbon neutrality management on reducing firm risk through mitigating information asymmetry and alleviating financing constraints will be more significant.

This study conducts grouped tests based on high and low audit quality, with regression results presented in columns (3) and (4) of *Table 7*. The regression results show that in the group with lower audit quality (column 4), the coefficient of *Carbon* is -0.036 and significant at the 1% level. In contrast, in the group with higher audit quality (column 3), the coefficient of *Carbon* is -0.003 and not significant. These results indicate that the lower the audit quality, the more significant the effect of carbon neutrality management on reducing firm risk, thereby validating the aforementioned hypothesis.

Table 7. Carbon neutrality management and firm risk: Heterogeneity analysis

	(1)	(2)	(3)	(4)
VARIABLES	<i>Risk</i>	<i>Risk</i>	<i>Risk</i>	<i>Risk</i>
	High Inst.	Low Inst.	Big Four	Non-Big Four
<i>Carbon</i>	-0.003 (-1.313)	-0.036*** (-8.553)	-0.005 (-1.223)	-0.021*** (-7.320)
<i>Age</i>	0.005** (2.140)	0.000 (0.169)	-0.004 (-0.999)	0.002 (1.175)
<i>Size</i>	-0.005*** (-9.488)	-0.003*** (-4.200)	-0.006*** (-6.582)	-0.004*** (-7.264)
<i>State</i>	-0.011*** (-8.349)	-0.010*** (-6.987)	-0.004* (-1.737)	-0.011*** (-9.877)
<i>Growth</i>	0.015*** (6.842)	0.011*** (4.418)	0.009** (2.099)	0.014*** (7.968)
<i>Boardsize</i>	-0.006* (-1.691)	-0.013*** (-2.898)	0.005 (0.862)	-0.010*** (-3.026)
<i>Ind</i>	-0.010 (-0.937)	-0.008 (-0.563)	-0.020 (-1.171)	-0.004 (-0.400)
<i>Top1</i>	-0.019*** (-4.587)	-0.017*** (-4.145)	-0.005 (-0.794)	-0.020*** (-6.142)
<i>Dual</i>	-0.000 (-0.314)	-0.003* (-1.806)	0.003 (1.351)	-0.002 (-1.574)
<i>Lev</i>	-0.018*** (-4.157)	-0.000 (-0.095)	0.000 (0.022)	-0.009** (-2.502)
<i>ROA</i>	-0.224*** (-15.281)	-0.306*** (-21.179)	-0.083** (-2.582)	-0.273*** (-25.210)
<i>Constant</i>	0.186*** (13.240)	0.197*** (10.056)	0.200*** (8.661)	0.182*** (13.745)
Observations	9,434	9,434	1,210	17,658
R-squared	0.272	0.311	0.435	0.284
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

6. Conclusions

In conclusion, against the backdrop of the "dual carbon" goals, carbon neutrality has shifted from an international public discourse to a corporate practice dimension, evolving into a crucial strategy for firms to address climate change issues, enhance competitiveness, and strengthen risk management capabilities. This research empirically investigates whether carbon neutrality management could affect firm risk by using listed firms' data from China's Shanghai and Shenzhen A-share markets over the period 2018-2022. The research findings are as follows: Firstly, the empirical findings of this research demonstrate that carbon neutrality management exerts a significant mitigating effect on firm risk. This conclusion remains robust after a series of robustness tests. Secondly, mechanism tests reveal that corporate carbon neutrality management reduces firm risk by mitigating information

asymmetry and alleviating financing constraints. Specifically, carbon neutrality management conveys positive signals about firms, reducing the degree of information asymmetry. This enables firms to obtain external funding support at lower costs, thereby enhancing resource allocation capacity, improving operational efficiency, and reducing firm risk. Furthermore, heterogeneity analysis indicates that the risk-reducing effect of corporate carbon neutrality management varies across different firm characteristics. In firms with lower audit quality and lower institutional investors' shareholding ratios, the risk-reducing effect of carbon neutrality management is more pronounced, suggesting that carbon neutrality management plays a more important signaling and governance role in firms with higher degrees of information asymmetry and relatively weaker external oversight. This study focuses on that corporate carbon neutrality management alleviates financing constraints by reducing information asymmetry, enabling firms to obtain sufficient funding support and enhance resource allocation capacity, thereby improving operational efficiency and reducing firm risk.

The findings of this study not only enrich the literature on the economic consequences of carbon neutrality management, but also provide a new perspective for research on the relationship between financing constraints and firm risk, while offering important implications for both firms and policymakers: Firms should actively practice carbon neutrality management, integrating it into strategic planning and daily operations to enhance sustainable development capacity and risk resilience; governments should improve carbon information disclosure systems, strengthen green finance policy support, guide financial resources toward low-carbon transition enterprises, and promote the synergistic realization of high-quality economic development and carbon peaking and carbon neutrality goals.

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