Proceedings of the 8th International Conference on Computing and Data Science
DOI: 10.54254/2755-2721/2026.37984

Formation Mechanism of Green Credit Default Risk Driven by Carbon Price Shocks in China's National Carbon Market

Ying Zhou

Faculty of Business, Economics and Law (BEL), The University of Queensland, Queensland, Australia
zhouying02549@outlook.com

Abstract. As China's national carbon market expands, fluctuations in carbon prices increasingly affect corporate operating costs, cash flow, and financing conditions, creating more complex transition risks for green credit. Using CEA trading data from July 2021 to December 2025 and quarterly observations of listed firms in regulated industries, ARMA-GARCH is applied to identify abnormal carbon price shocks. The KMV model measures distance to default and expected default frequency. Two-way fixed effects, mediation analysis, and XGBoost-SHAP are then used to examine risk transmission. The results show rapid carbon price increases during 2023 and 2024, followed by high trading activity and a price decline in 2025, indicating clear shifts in market risk states. Sectoral expansion also increased differences in carbon exposure, allowance demand, and cost absorption capacity across firms. Carbon price shocks therefore need to be evaluated together with firm-level carbon exposure and financial vulnerability. Their effects can be transmitted to credit risk through carbon costs, operating cash flow, and financing constraints. These findings provide quantitative support for green credit pricing, carbon stress testing, and early warning of credit risk among carbon-intensive firms.

Keywords: Carbon Price Shock, Green Credit, Default Risk, KMV Model, Interpretable Machine Learning

1. Introduction

Since the launch of China's national carbon emissions trading market in 2021, carbon prices have gradually become an important market signal linking emission reduction constraints, corporate operations, and financial risk. The national carbon market is mainly driven by compliance demand, while changes in allowance prices and market liquidity affect carbon asset management and cost expectations among regulated enterprises [1]. The carbon trading system may also alter corporate risk-taking behavior and generate heterogeneous responses across firms with different financing capacities and ownership structures [2]. Existing studies mainly examine the financial effects of the carbon market from the perspectives of stock returns, bond spreads, bank loan costs, and green innovation, but analyses of how short-term abnormal carbon price shocks affect corporate debt-servicing capacity and further generate green credit default risk remain relatively fragmented. The

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.37984

analysis therefore focuses on carbon price shocks, corporate credit risk, and the associated transmission mechanism.

2. Literature review

2.1. Carbon price shocks

The economic impact of carbon price shocks depends on whether price changes exceed the range of compliance costs that firms can anticipate and absorb. Firms with higher carbon risk generally face larger corporate bond credit spreads, while financing constraints and the degree of green transition further influence the level of risk premiums [3]. Bond markets can reflect investors' pricing of carbon risk, but credit spreads mainly represent financing outcomes and provide only an indirect explanation of how abnormal allowance prices immediately affect corporate operating pressure. Research on bank lending shows that higher corporate carbon risk increases loan financing costs through weaker profitability and greater operating volatility, with stronger effects among firms characterized by poor environmental performance and insufficient green innovation [4]. It is therefore necessary to distinguish ordinary carbon price changes, persistent volatility, and abnormal shocks. Separating predictable components from unexpected innovations in price returns allows the intensity with which carbon market changes enter corporate financial conditions to be identified more accurately.

2.2. Credit risk measurement

Credit risk measurement needs to reflect both corporate accounting-based repayment capacity and capital market assessments of changes in asset value. Carbon trading policies can influence corporate default risk, while financing constraints, transition pressure, and innovation capacity alter firms' ability to absorb carbon costs and consequently generate heterogeneous credit risk responses [5]. Higher corporate carbon emissions may also increase the probability of financial distress, with firms possessing weaker operating capacity and poorer access to credit financing showing greater sensitivity [6]. Traditional financial ratios are subject to clear reporting-period lags, whereas actual default events are low-frequency and discrete outcomes, making them difficult to match directly with high-frequency carbon price shocks. The KMV model can infer corporate asset value from equity market value, stock price volatility, and debt structure and continuously calculate distance to default and expected default frequency, thereby capturing changes in market value and the debt-servicing safety margin before actual default occurs and providing a more suitable measure for dynamic quarterly credit risk analysis.

2.3. Carbon risk transmission

During the transmission of carbon risk into green credit default risk, corporate operating cash flow and financing conditions constitute important links between environmental costs and debt repayment capacity. Higher corporate carbon emissions may reduce new bank lending and shorten loan maturities, while credit ratings can also alter how financial institutions price carbon exposure [7]. Carbon trading constraints may further intensify financing pressure through changes in bank borrowing and debt maturity structures, whereas greater information transparency and stronger governance quality can reduce part of the resulting financing friction [8]. Cost pressure generated by decarbonization policies may also increase default risk among carbon-intensive firms by raising debt

DOI: 10.54254/2755-2721/2026.37984

costs and reducing profitability, while green technological capability influences the strength of this effect [9]. Carbon price shocks can therefore compress profits and cash flow through higher allowance costs, subsequently increase dependence on external financing and refinancing pressure, and ultimately reduce the safety margin between corporate asset value and the default point, while emissions intensity and transition capability determine the extent to which risk is amplified throughout this transmission process.

3. Experimental methods

3.1. Data construction

The study period extends from July 2021 to December 2025. A matched database is constructed at the trading day, quarter, and firm levels. Market data include the daily opening price, highest price, lowest price, closing price, trading volume, and turnover of China Emission Allowances, obtained from the public trading records of the Shanghai Environment and Energy Exchange. Firm level market data include daily closing prices, total shares outstanding, and market capitalization of A share companies, collected from the Shanghai Stock Exchange and Shenzhen Stock Exchange. Balance sheets, income statements, cash flow statements, short term debt, long term debt, operating revenue, and green financing information are obtained from public disclosures on CNINFO. Annual carbon emissions, allowance surrender status, and key emitting entity classifications are compiled from information disclosed by environmental authorities and corporate sustainability reports. Securities codes are used as unified firm identifiers. Daily market variables are aggregated to the quarterly level and matched with corporate financial indicators. Continuous variables are winsorized at the 1st and 99th percentiles. Carbon intensity is constructed using one period lagged data to reduce contemporaneous reverse effects.

3.2. Shock identification

CEA closing prices are first converted into logarithmic returns, while the ARMA order is determined according to the AIC and BIC criteria. Carbon prices exhibit both serial dependence and volatility clustering [10]. The ARMA GARCH model is therefore selected to separate predictable price movements from abnormal conditional volatility and to extract exogenous price shocks, as shown in Equation 1.

$$r_t=\mu+\sum_{i=1}^{p}\phi_i r_{t-i}+\sum_{j=1}^{q}\theta_j\varepsilon_{t-j}+\varepsilon_t$$

$$\varepsilon_t=\sigma_t z_t$$

$$\sigma_t^2=\omega+\alpha\varepsilon_{t-1}^2+\beta\sigma_{t-1}^2 \quad (1)$$

Here, r_t denotes the logarithmic return of CEA prices, σ_t^2 represents conditional variance, and z_t denotes the standardized abnormal shock. The 95th and 5th percentiles are used to identify positive

DOI: 10.54254/2755-2721/2026.37984

and negative tail shocks, respectively. Actual corporate defaults are infrequent and discrete. The KMV model is therefore used because it converts market value and debt structure into a continuous and forward looking default risk measure that can be matched with quarterly carbon price shocks, as shown in Equation 2.

$$E_{it}=V_{A,it}\Phi\left(d_1\right)-D_{it}e^{-rT}\Phi\left(d_2\right)$$

$$DD_{it}=\frac{\ln\left(V_{A,it}/D_{it}\right)+\left(\mu_{A,it}-\frac{1}{2}\sigma_{A,it}^2\right)T}{\sigma_{A,it}\sqrt{T}}$$

$$EDF_{it}=\Phi\left(-DD_{it}\right) \tag{2}$$

Here, V_A and σ_A represent asset value and asset volatility, respectively. D denotes the default point, while DD represents distance to default. A higher EDF indicates stronger credit risk.

3.3. Mechanism testing

Carbon price shocks vary only over time. If they are directly included together with quarter fixed effects, their common time variation will be absorbed. The interaction between quarterly carbon price shocks and lagged firm level carbon exposure is therefore used to construct cross sectional variation [11]. A two way fixed effects model controls for time invariant firm characteristics and common macroeconomic shocks. It is selected to identify heterogeneous credit risk responses to the same carbon price shock across firms with different carbon exposures, as shown in Equation 3.

$$EDF_{it}=\beta_1\left(Shock_t\times Exposure_{i,t-1}\right)+\gamma'X_{i,t-1}+\alpha_i+\lambda_t+\varepsilon_{it} \tag{3}$$

Here, $Shock_t$ denotes the quarterly carbon price shock, while $Exposure_{i,t-1}$ represents lagged carbon emissions intensity. X includes firm size, leverage, ROA, liquidity, and growth. Risk formation involves a continuous financial transmission process. A mediation model is therefore used to decompose the total risk effect into carbon cost pressure, operating cash flow, and financing constraint channels, thereby identifying where default risk is formed, as shown in Equation 4.

$$M_{it}=aZ_{it}+\Gamma'X_{i,t-1}+\alpha_i+\lambda_t+u_{it}$$

$$EDF_{it}=c'Z_{it}+bM_{it}+\Theta'X_{i,t-1}+\alpha_i+\lambda_t+v_{it}$$

DOI: 10.54254/2755-2721/2026.37984

$$Z_{it} = Shock_t \times Exposure_{i,t-1} \quad (4)$$

Here, M is sequentially specified as carbon cost pressure, operating cash flow, and the SA financing constraint index. ab denotes the indirect effect. Its confidence interval is estimated using 5,000 Bootstrap replications. XGBoost is trained on observations from 2021 to 2024, while 2025 is retained as the test set. SHAP is then applied to identify nonlinear thresholds.

4. Results

4.1. Risk effects

CEA trading data show clear shifts in price direction, price range, and liquidity during the sample period. As shown in Figure 1, the year end closing price was CNY 54.22 per ton in 2021 and CNY 55.00 per ton in 2022, corresponding to an annual increase of only 1.44 percent in 2022. Market prices remained relatively stable during this stage. The year end closing price rose to CNY 79.42 per ton in 2023, representing a year on year increase of 44.40 percent. The annual highest and lowest prices reached CNY 82.79 and CNY 50.50 per ton, respectively, indicating a clear expansion in price risk. In 2024, the year end price increased further to CNY 97.49 per ton, while annual turnover reached CNY 18.114 billion. The annual maximum comprehensive price reached CNY 106.02 per ton. In 2025, the year end price declined to CNY 74.63 per ton. Annual trading volume remained high at 235 million tons, with turnover of CNY 14.630 billion. The market therefore shifted into a state characterized by high trading activity and declining prices. As shown in Figure 1, the annual high low range, volume weighted average price, year end closing price, annual return, and turnover jointly capture changes in return direction, volatility, and liquidity risk. These patterns indicate that average carbon prices alone cannot adequately describe transitions between risk states. They also support the separate identification of abnormal returns and conditional volatility in Section 3.2.

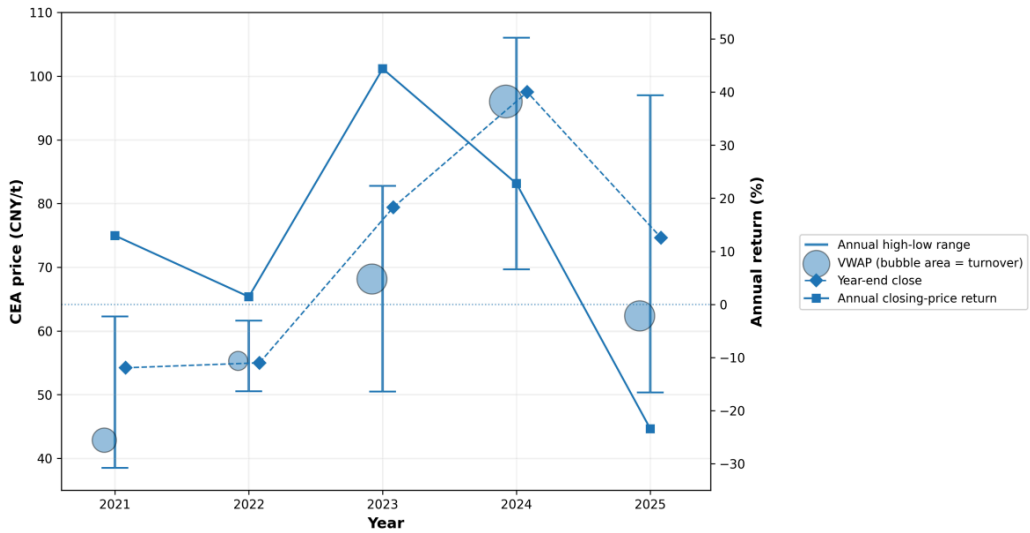

Figure 1. CEA annual price range, VWAP, and liquidity risk profile, 2021 to 2025

DOI: 10.54254/2755-2721/2026.37984

4.2. Transmission effects

The expansion of sectoral coverage increased cross sectional differences in corporate carbon exposure and cost structures. This provides an empirical basis for identifying the shock interaction term and mediation channels. As shown in Table 1, 3,378 key emitting entities were included in allowance management in 2025. The power sector contained 2,087 entities, accounting for 61.78 percent of the total. The cement sector included 962 entities, representing 28.48 percent. The steel sector contained 232 entities, accounting for 6.87 percent, while the aluminum smelting sector included 97 entities, representing 2.87 percent. The newly added cement, steel, and aluminum smelting sectors together contained 1,291 entities, accounting for 38.22 percent of all key emitting entities. Their inclusion increased differences in emissions intensity, allowance demand, and cost absorption capacity across firms. For comparison, the power sector contained 2,096 key emitting entities in 2024 and covered approximately 5.2 billion tons of carbon dioxide emissions. The allowance surrender completion rate for the 2023 compliance year was approximately 99.98 percent. A high overall compliance rate does not imply identical financial exposure across firms. Actual risk differences must be identified by combining firm level carbon intensity with balance sheet conditions.

Table 1. Industry structure of key emitting entities in China's national carbon market in 2025

Industry	Number of Key Emitting Entities	Structural Share	Main Carbon Risk Exposure
Power generation	2,087	61.78%	Fuel and allowance costs
Cement	962	28.48%	Process emissions and clinker costs
Steel	232	6.87%	Energy inputs and process emissions
Aluminum smelting	97	2.87%	Electricity inputs and indirect costs
Total	3,378	100.00%	Cross sector exposure differences

5. Discussion

CEA prices moved through distinct states of low volatility, rapid appreciation, and high-liquidity correction during the sample period. Carbon risk therefore does not change steadily with the price level. In 2025, prices declined while trading activity remained high, showing that price direction and market liquidity may convey different risk signals. Conditional volatility and abnormal shocks are consequently more informative than a single average carbon price. Sectoral expansion also increased differences in emissions intensity, allowance demand, and cost absorption capacity. A high overall compliance rate does not remove firm-level financial vulnerability. When carbon costs interact with high leverage, weak cash flow, or tighter financing constraints, credit risk may become more pronounced. This pattern supports an interpretation based on firm heterogeneity and financial transmission channels.

DOI: 10.54254/2755-2721/2026.37984

6. Conclusion

Using national carbon market and listed-firm data from 2021 to 2025, an empirical framework is established from carbon price shock identification to corporate default risk measurement and transmission analysis. ARMA-GARCH extracts abnormal price innovations, while the KMV model generates continuous measures of distance to default and expected default frequency. Two-way fixed effects, mediation analysis, and XGBoost-SHAP further identify the roles of carbon exposure, carbon costs, operating cash flow, and financing constraints. Carbon prices and liquidity experienced clear regime shifts during the sample period, while market expansion increased cross-firm risk differences. Green credit risk assessment should therefore consider carbon market shocks, firm-level carbon exposure, and financial pressure simultaneously. This framework provides a basis for differentiated credit allocation and dynamic risk management.

References

[1] Bolton, P., & Kacperczyk, M. (2023). Global pricing of carbon-transition risk. *The Journal of Finance, 78*(6), 3677–3754.
[2] Bruno, B., & Lombini, S. (2023). Climate transition risk and bank lending. *Journal of Financial Research, 46*, S59–S106.
[3] Ramos-García, D., López-Martín, C., & Arguedas-Sanz, R. (2023). Climate transition risk in determining credit risk: Evidence from firms listed on the STOXX Europe 600 index: D. Ramos-García et al. *Empirical Economics, 65*(5), 2091–2114.
[4] Dumrose, M., & Höck, A. (2023). Corporate carbon-risk and credit-risk: The impact of carbon-risk exposure and management on credit spreads in different regulatory environments. *Finance Research Letters, 51*, 103414.
[5] Ho, K., & Wong, A. (2023). Effect of climate-related risk on the costs of bank loans: Evidence from syndicated loan markets in emerging economies. *Emerging Markets Review, 55*, 100977.
[6] Delis, M. D., et al. (2024). Being stranded with fossil fuel reserves? Climate policy risk and the pricing of bank loans. *Financial Markets, Institutions & Instruments, 33*(3), 239–265.
[7] Ugolini, A., Reboredo, J. C., & Ojea-Ferreiro, J. (2024). Is climate transition risk priced into corporate credit risk? Evidence from credit default swaps. *Research in International Business and Finance, 70*, 102372.
[8] Dimitras, A. I., Mitsi, C. C., & Zopounidis, C. (2024). Does firm carbon risk matter to banks? Evidence from the US syndicated loan market. *Journal of Environmental Management, 368*, 122249.
[9] Bua, G., et al. (2024). Transition versus physical climate risk pricing in European financial markets: A text-based approach. *The European Journal of Finance, 30*(17), 2076–2110.
[10] Garcia-Villegas, S., & Martorell, E. (2024). Climate transition risk and the role of bank capital requirements. *Economic Modelling, 135*, 106724.
[11] Redondo, H., & Aracil, E. (2024). Climate-related credit risk: Rethinking the credit risk framework. *Global Policy, 15*, 21–33.