Financial Pricing Mechanisms for Corporate Carbon Risks: Methodological Critique and Integration in Empirical Research Under Dual Carbon Goals

Ranran Zhang*

School of Economics & Man, Nanjing Tech University, Nanjing, China

*Corresponding author: zranran23@gmail.com

Abstract. Against the backdrop of China's "dual carbon" goals—peaking carbon emissions by 2030 and achieving carbon neutrality by 2060—corporate carbon risk has become a systemic factor influencing financial asset pricing. This review systematically examines the methodological challenges in empirically pricing carbon risk within this context, focusing on three core issues: poor data reliability, oversimplified policy assumptions, and the limitations of linear pricing models. Specifically, corporate selective disclosure—such as omitting Scope 3 emissions and exploiting ESG rating discrepancies—severely distorts emission data. Moreover, regional carbon market fragmentation and supply-chain spillover effects complicate policy impact assessments, while behavioral biases among investors lead to anomalous pricing outcomes such as the U-shaped premium paradox. To address these challenges, this paper proposes an integrated framework incorporating data, modeling, and policy dimensions. It recommends employing emerging technologies like blockchain to improve data transparency, developing non-linear models that capture policy shocks and investor behaviors, and establishing a cross-regional risk monitoring mechanism. The study concludes that carbon risk pricing embodies dynamic interactions among policy, technology, and behavioral factors, and provides methodological insights tailored to transition economies like China. Future research should focus on data ethics, model adaptability, and quantifying cognitive biases in green investing.

Keywords: Carbon risk; pricing; dual carbon goals; carbon finance.

1. Introduction

In 2021, China issued the "Opinions on Fully, Accurately, and Comprehensively Implementing the New Development Philosophy to Advance Carbon Peaking and Carbon Neutrality," establishing a "1+N" policy framework for its dual carbon goals [1]. This accelerated the emergence of carbon risk as a critical factor in corporate financial pricing. Global climate governance actions further confirm that carbon risk—the risk of value loss for enterprises due to carbon emissions or climate policies—is a systemic factor in asset pricing. This landscape underscores the urgency of exploring carbon risk pricing mechanisms.

However, empirical research within China's "dual carbon" context faces three core challenges: First, inconsistent quality and verification difficulties of corporate carbon data undermine the reliability of research foundations [2]. Second, policy dynamics—such as regional versus national carbon market differences—are often oversimplified, overlooking how policy uncertainty distorts risk transmission [3]. Finally, traditional linear models struggle to capture the nonlinear relationship where high-emission firms face discounts while low-carbon firms command premiums [4].

Therefore, this paper focuses on critiquing and integrating three major methodological shortcomings: First, it explores methods to enhance data quality using technologies like machine learning; second, it articulates the necessity of introducing flexible models capable of capturing policy discontinuities and nonlinear effects, while emphasizing the urgency of endogenizing policy factors; finally, it strives to systematically optimize the research paradigm for carbon risk pricing by constructing a three-dimensional integrated framework of "data-model-policy."

Through these approaches, this paper identifies methodological obstacles in carbon risk pricing within transition economies; proposes a comprehensive research perspective tailored to China's complex “dual carbon” context; and charts breakthrough directions for future studies in data validation, model adaptability, and policy sensitivity.

2. The Dilemma of Carbon Risk Pricing Under Dual Carbon Goals

Systemic risks stemming from global climate change are increasingly drawing attention in financial markets. Among these, carbon risk—the potential financial losses and valuation fluctuations enterprises may face due to carbon emissions or climate policies (such as carbon pricing and technological substitution)—has become a key factor influencing asset pricing.Against this backdrop, the Chinese government formally announced its “carbon peak and carbon neutrality” (“dual carbon”) goals in 2021 and established a “1+N” policy framework, signaling a comprehensive shift toward green and low-carbon development in China's economy and society. This significant policy shift not only accelerates the pace of domestic carbon constraints but also makes the precise identification, measurement, and pricing of corporate carbon risks more critical than ever.

The core significance of this study lies in providing in-depth methodological insights and a practical integrated framework for corporate carbon risk financial pricing research within transition economies, particularly China. Currently, research in this field faces multiple challenges, including a disconnect between theory and rapidly evolving policy practices, weak data foundations, and insufficient model applicability. By systematically critiquing and synthesizing existing approaches, this paper aims to identify common pitfalls in current research (such as overlooking policy uncertainty or overreliance on flawed data/models). It seeks to break down the silos between “data,” “models,” and “policy” dimensions, proposing a comprehensive analytical framework while offering concrete, actionable improvement strategies for subsequent empirical studies—including enhancing data quality and achieving endogenous policy factors.

3. Core Controversy: The Divide Between Theory and Empirical Evidence

3.1. “Penalty Theory” vs “Premium Theory”: The Nonlinear Paradox of Carbon Risk Pricing

A global empirical study by Bolton and Kacperczyk revealed a critical contradiction [4]. The research indicates that while a 1% increase in corporate carbon intensity significantly raises equity financing costs by 0.15%—a phenomenon particularly pronounced in high-emission sectors like manufacturing—this confirms the existence of the so-called “Carbon Penalty,” demonstrating a systemic valuation discount for high-carbon assets. However, the “Green Premium” theory finds no empirical support in the same study. For instance, companies engaged in low-carbon technologies (such as hydrogen energy firms) do not exhibit sustained valuation premiums. Instead, their earnings volatility exceeds market benchmarks by 30%, while also displaying periodic earnings reversals. This empirical paradox indicates that carbon risk impacts asset prices nonlinearly, with its transmission mechanism shaped by the dynamic interplay of three factors: policy frameworks, technological evolution, and behavioral finance. First, policy divergences between regional carbon markets—such as the 30% carbon price differential between Guangdong and Hubei—provide high-emission enterprises with cross-regional buffers, thereby partially mitigating the effectiveness of carbon penalties. Second, low-carbon technologies must first cross the commercial profitability threshold. For instance, leading photovoltaic companies only trigger market premium mechanisms after achieving profitability [5]. Additionally, investor cognitive biases allow some high-emission enterprises with short-term monopoly advantages to temporarily avoid price discounts due to market recognition lags.Thus, carbon risk pricing fundamentally results from the dynamic interplay of policy, technology, and behavioral finance factors; single-dimensional “penalty” or “premium” theoretical frameworks alone cannot fully explain the complexity of carbon market pricing mechanisms.

3.2. Policy Sensitivity in Supply Chain Transmission: How Carbon Costs Trickle Down

A natural experiment based on China's carbon emissions trading pilot programs revealed that rising carbon prices trigger a domino-effect transmission along industrial chains: when carbon prices in pilot regions increase by 10%, the loan interest costs for local high-emission enterprises like thermal power and steel plants directly rise by 0.5%, equivalent to an additional ¥500,000 in annual interest payments per ¥100 million loan. More significantly, such policy shocks propagate upstream—even suppliers of raw materials not directly covered by carbon policies (e.g., mining firms supplying coal to steel mills) face rising financing costs as their regulated downstream customers are impacted: For every 10% increase in a supplier's carbon emissions, loan interest rates rise an additional 0.8%. If suppliers are also located in carbon pilot regions (e.g., Shanghai auto parts firms supplying Wuhan automakers), financing cost increases could expand by an additional 50%. Financial institutions now view carbon price volatility as a systemic risk signal akin to "weather forecasts": once carbon markets experience sharp fluctuations, banks universally tighten credit to high-carbon industrial chains. This indicates that carbon policy impacts extend beyond directly regulated enterprises (like steel mills in Hubei) to permeate entire industrial chains through supply chains (e.g., iron ore mines in Hebei), ultimately raising financing costs across the entire sector. This also explains cross-regional cost transmission from the financing perspective—for instance, electronics manufacturers in Guangdong may be forced to raise product prices due to increased carbon costs among raw material suppliers in Shandong.

4. Analysis of Controversies and Methodological Critiques

4.1. Data Credibility Concerns and Responses

Existing empirical research reveals a "U-shaped premium" phenomenon that contradicts traditional linear pricing models: heavily polluting enterprises with the highest carbon intensity and purely green enterprises with the highest proportion of clean technology revenue often simultaneously achieve excess returns. This paradox highlights the complexity of market pricing mechanisms. Its origins partly stem from systemic cognitive biases among investors:indicates investors exhibit irrational tolerance in valuing high-carbon enterprises with monopoly advantages; Krueger et al. further confirm significant disparities in institutional investors' subjective perceptions of climate risk, exacerbating pricing distortions [6,7].

Against this backdrop, companies possess strong incentives to engage in "selective beautification" of carbon information, primarily manifested in four ways: First, systematic avoidance of disclosing Scope 3 emissions. For instance, statistics by Cheng et al.show that over 60% of sampled companies evade supply chain emissions disclosure by citing "data gaps" or "unclear boundaries." Second, companies deliberately blur emission boundaries by exploiting accounting complexities [8]. Wiedmann & Lenzen note that global supply chain carbon footprints inherently involve complex accounting and ambiguous boundaries, which firms often use as excuses to reduce disclosure intensity and accuracy overall—for instance, by commonly claiming "data unavailability." Additionally, companies engage in "rating arbitrage" by exploiting discrepancies among Environmental, Social and Governance (ESG) rating agencies [9]. Berg et al. found significant discrepancies between the standards and outcomes of different ESG rating agencies, creating "aggregation confusion" that allows companies to selectively adopt the most lenient rating criteria for disclosure [10,11]. Finally, constrained by high disclosure costs, companies often engage in strategic concealment. Experimental evidence from Farjam et al. provide experimental evidence showing that when facing higher disclosure costs, companies are more inclined to deliberately conceal high-emission information, leading to a noticeable "attitude-behavior gap" between disclosed content and actual emission practices [12,13]. These intertwined factors not only significantly weaken the explanatory power of traditional linear models regarding the relationship between carbon risk and returns but also urgently call for subsequent research in data governance and model refinement.

4.2. Modeling Failures in Policy Dynamics

The core issue behind the current suboptimal performance of carbon policy modeling lies in its failure to account for cross-scale interactions: First, barriers exist between regional pilot programs and the national carbon market regarding quota mutual recognition, coupled with differing access standards. This has led to interprovincial price differentials reaching 30%.. This institutional friction not only fuels cross-provincial arbitrage but also distorts overall risk pricing, underestimating the actual risks faced by high-emission enterprises. Second, Ren et al. found through a natural experiment study of China's pilot emissions trading schemes (ETS) that carbon costs escalate nonlinearly along supply chains—a 10% increase in upstream carbon intensity can raise downstream firms' financing costs by as much as 1.8 times [14,15]. This directly validates Engle et al.'s assertion that "climate risk propagates along industrial chains." Less apparent are international-level impacts [16,17]. Hou et al.calculated that carbon leakage from multinational corporations reduces the effectiveness of domestic carbon policies by approximately 18% [18,19]. Hong et al.'s macro-financial transmission framework further indicates that in open economies, such cross-border carbon leakage significantly amplifies distortions in interest rates and credit spreads through global capital flows and credit tightening channels [20,21].

The combined effects of regional market fragmentation, amplified supply chain costs, and international carbon leakage render traditional pricing models—which focus solely on single markets or assume linear transmission—inadequate for accurately capturing the true, dynamic impacts of carbon policies. This necessitates the urgent adoption of cross-scale, nonlinear systemic analytical frameworks for refinement.

4.3. Cognitive Limitations of Linear Pricing Models

Traditional asset pricing models (such as CAPM and its related linear carbon factor extensions) encounter fundamental contradictions when describing carbon risk, primarily manifested in the simultaneous existence of the "U-shaped premium paradox" and multiple behavioral anomalies. Bolton & Kacperczyk's global study sample clearly demonstrates that both companies in the top 10% for carbon intensity (high-carbon firms) and those in the top 10% for clean technology revenue share (ultra-low-carbon firms) achieve additional returns, forming a U-shaped risk-return curve that is entirely contrary to traditional linear model expectations. Krueger et al. further observed significant divergences in institutional investors' perceptions of climate risk, leading to capital misallocation between "green" and "brown" assets [22]. Consequently, the linear framework's singular "carbon beta" fails to capture the complex coexistence of high-carbon discounts and ultra-low-carbon premiums. Moreover, by neglecting investor behavioral anomalies, it amplifies overall pricing errors. This underscores the urgent necessity of breaking free from linear constraints by adopting nonlinear-behavioral integrated models.

5. Conclusion

This paper comprehensively analyzes the core challenges in financial pricing of corporate carbon risks under the dual carbon goals, identifying three primary obstacles: First, distortions in corporate carbon disclosure—such as concealing Scope 3 emissions and manipulating ESG ratings—render traditional models incapable of explaining the paradox where "high-polluting firms achieve excess returns comparable to purely green enterprises." Second, dynamic policy shifts—such as arbitrage between provinces due to fragmented regional carbon markets and the exponential amplification of supply chain carbon costs—expose fundamental flaws in linear pricing models. Third, behavioral finance factors—including investors' irrational tolerance for high-carbon monopolies and sudden premium shifts triggered by technological profitability thresholds—collectively underpin the behavioral mechanisms behind the "penalty-premium" paradox. These findings demonstrate that carbon risk pricing is fundamentally a dynamic interplay among policy, technology, and behavioral factors.

Accordingly, this paper proposes a three-dimensional integrated framework of "Data - Model - Policy". At the data level, leverage blockchain traceability technology to address emission concealment and dynamically correct ESG biases; at the model level, develop nonlinear pricing tools incorporating policy breakpoints and behavioral factors; At the policy level, establish a nationwide carbon market risk monitoring mechanism to prevent and control arbitrage and carbon leakage. Future research should focus on exploring ethical constraints in blockchain-based carbon traceability—specifically balancing transparency with commercial confidentiality; joint risk prevention and control during national carbon market integration, such as real-time alerts for interprovincial arbitrage; and quantifying the impact of "carbon cognitive biases" on green premiums from a behavioral finance perspective. Only through interdisciplinary research can it effectively resolve the contradictions in data ethics, model complexity, and policy implementation, providing transitioning economies with more rigorous and tailored methodological support.

References

[1] Shen J, Zheng H, Zhu L. Quantifying firm-level carbon risk: a novel emission reduction stress factor. Economic Modelling, 2025.

[2] He Z, Liu Z, Zhang C, Zhao Y. How do carbon pricing spillover effects impact green asset price volatility? An empirical study based on the TVP-VAR-DY model. Economic Analysis and Policy, 2025.

[3] Zhang Y, Da Y. The decomposition of energy-related carbon emission and its decoupling with economic growth in China. Renewable and Sustainable Energy Reviews, 2015.

[4] Gollier C. The cost-efficiency carbon pricing puzzle. Journal of Environmental Economics and Management, 2024.

[5] Pástor Ľ, Stambaugh R F, Taylor L A. Sustainable investing in equilibrium. Journal of Financial Economics, 2021.

[6] Wiedmann T, Lenzen M. Environmental and social footprints of international trade. Nature Geoscience, 2018.

[7] Cheng H W, Feng Y, Dong D R. Can corporate green silence offset carbon risk premiums? Securities Market Herald, 2024, 10(2): 56-67.

[8] Engle R F, Giglio S, Kelly B, Lee H, Stroebel J. Hedging climate change news. The Review of Financial Studies, 2020.

[9] Krueger P, Sautner Z, Starks L T. The importance of climate risks for institutional investors. The Review of Financial Studies, 2020.

[10] Hong H, Karolyi G A, Scheinkman J A. Climate finance. The Review of Financial Studies, 2020.

[11] Ren Y, Derouiche I, Hassan M, Liu P. Do creditors price climate transition risks? A natural experiment based on China's carbon emission trading scheme. International Review of Economics and Finance, 2024.

[12] Farjam M, Nikolaychuk O, Bravo G. Experimental evidence of an environmental attitude-behavior gap in high-cost situations. Ecological Economics, 2019.

[13] Hou J, Yue Y, Wang Q, Ye J, Zhang M. Spillover-feedback effects of employment, energy, economy and environment (4E) between domestic-owned and foreign-invested enterprises: taking China as an example. Journal of Cleaner Production, 2023.

[14] Bolton P, Kacperczyk M. Do investors care about carbon risk? Journal of Financial Economics, 2021.

[15] Berg F, Kölbel J F, Rigobon R. Aggregate confusion: the divergence of ESG ratings. The Review of Financial Studies, 2022.

[16] Zhai D, Zhang T, Liang G, Liu B. Quantum carbon finance: carbon emission rights option pricing and investment decision. Energy Economics, 2024.

[17] Hambel C, van der Ploeg F. Policy transition risk, carbon premiums, and asset prices. Journal of Monetary Economics, 2025.

[18] Sun K, Ye J, Yue Y, Xiao N. Tracing carbon emissions and intensity in relational global value chain activities. Journal of Cleaner Production, 2023.

[19] Bai S, Zhang B, Ning Y. Trade-off between carbon emissions and employment embodied in global value chains: a study based on enterprise heterogeneity in China. Journal of Cleaner Production, 2024.
[20] Tian B, Yu J, Tian Z. The impact of market-based environmental regulation on corporate ESG performance: a quasi-natural experiment based on China's carbon emission trading scheme. Heliyon, 2024.
[21] Pástor Ľ, Stambaugh R F, Taylor L A. Dissecting green returns. Journal of Financial Economics, 2022.
[22] Gao Z, Sockin M, Xiong W. Learning about the neighborhood. The Review of Financial Studies, 2021.