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Analysis of the Quantitative Transmission Mechanism of Climate Risk in Green Financial Asset Pricing

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Abstract

With the deepening of global climate governance and low-carbon transformation, the "green attribute" of green financial assets has broken through the traditional reputation premium category, gradually achieving quantitative pricing through three core channels: carbon premium, climate scenario discount, and default structure, and transforming into tradable additional rates of return or interest spreads. This article systematically reviews high-level literature at home and abroad, discusses the theoretical logic, empirical evidence, and transmission mechanism of the three major quantitative channels, analyzes the correction path of climate risk on traditional asset pricing models, explores the controversies and challenges in current pricing practices, and looks forward to future research directions. Research has found that the physical and transitional dimensions of climate risk have been deeply embedded in the valuation system of green financial assets, with carbon cost internalization, scenario dynamic discounting, and default risk reconstruction becoming the core pricing logic. However, issues such as insufficient data standardization and model heterogeneity still constrain quantification accuracy. This article aims to provide literature support for the improvement and practical application of green financial asset pricing theory, and to assist in the market-oriented pricing of climate risks in finance.

Keywords

climate risk, asset pricing, green finance, climate risk

1. Introduction

The physical and transformation risks caused by climate change have become systemic risks in the global financial system. Green finance, as the core financial tool for low-carbon transformation, is undergoing fundamental restructuring of its asset pricing logic. In traditional perception, the "green premium" of green financial assets is often attributed to the alignment between corporate reputation enhancement and social responsibility [5]. However, with the maturity of climate risk quantification technology and the strengthening of policy constraints, this premium is no longer a vague reputation benefit, but is transformed into a core factor affecting asset returns and credit spreads through three quantifiable channels: carbon premium, climate scenario discounting, and default structure [2]

The Bank for International Settlements pointed out that climate risk has shifted from a “systematic factor” to a “core variable” in the pricing of green financial assets, and its quantitative transmission directly determines the rationality of asset valuation. Under the 1.5 ℃ temperature rise target of the Paris Agreement, global carbon budget constraints are tightening [7], and policies such as the EU Carbon Border Adjustment Mechanism (CBAM) and China's national carbon market are being implemented, further promoting the transformation of climate risks from external costs to endogenous pricing factors for financial assets. The existing research on the correlation between climate risk and green financial asset pricing has yielded rich results, but there is still a lack of systematic reviews focusing on the three major quantitative channels, and the controversies in high-level literature regarding channel transmission efficiency and quantitative model adaptability have not yet formed a unified conclusion.

Based on this, this article takes “quantified transmission of climate risks” as the core, and systematically sorts out the three major channels of carbon premium, climate scenario discount, and default structure National Bureau of Economic Research (NBER). Network for Greening the Financial System (NGFS), Task Force on Climate-Related Financial Disclosures (TCFD) Clarify the quantitative logic and empirical evidence of climate risk in the pricing of green financial assets through authoritative institutions and top tier literature, analyze theoretical controversies and practical difficulties, and provide references for subsequent research and financial practice. The literature coverage of this article includes top international economic and financial journals authoritative institution work reports, and domestic core journals (such as Accounting Research), ensuring the academic rigor and high level of the review.

2. Theoretical Basis for Quantifying Climate Risk in Pricing Green Financial Assets

2.1 Climate Risk Adaptation Correction of Traditional Asset Pricing Models

The traditional asset pricing model is centered around the Capital Asset Pricing Model (CAPM) and the Discounted Cash Flow Model (DCF), and its assumptions conflict fundamentally with the characteristics of climate risk. This is the theoretical starting point for reconstructing the pricing logic of green financial assets. The CAPM model attributes systemic risk solely to market volatility, but climate risk has long-term, nonlinear, and irreversible characteristics, and exhibits intertemporal transmission and tail risk attributes [4]. A study by the Bua et al [3] confirmed that the modified CAPM model incorporating climate factors increased the explanatory power of green energy stock returns by 19%, confirming the limitations of traditional models.

2.2 Dual Dimensional Division and Pricing Logic Differentiation of Climate Risks

The impact of climate risk on green financial assets is transmitted through the dual dimensions of physical risk and transformation risk, and the pricing logic difference between the two directly determines the mechanism of the three quantitative channels. Physical risks include acute climate disasters (hurricanes, floods) and chronic climate change (rising temperatures, rising sea levels). The IMF report shows that the annual economic losses caused by climate disasters worldwide have increased from $50 billion in the 1980s to $210 billion in 2020. These risks directly damage fixed assets of enterprises, interrupt supply chains, and thus affect the cash flow stability of green financial assets.

The risk of transformation stems from changes in policies, technologies, and market preferences during the low-carbon transition. The International Energy Agency predicts that if the global carbon neutrality target is implemented, the stranded scale of fossil related assets could reach $28 trillion. After the EU carbon price exceeded 50 euros/ton in 2020, the market value volatility of the European carbon utility sector increased by 12% [1], confirming that transformation risks have deeply affected asset pricing through the carbon premium channel. In addition, climate litigation risk, as a derivative dimension of transition risk, has grown at an average annual rate of 20% since the signing of the Paris Agreement [8]. In 2021, a Dutch court ruled that Shell would reduce emissions by 45%, resulting in a 3.7% drop in its stock price on the same day. This type of risk affects asset spreads through the reconstruction of default expectations.

2.3 Evolution of Pricing Connotation of "Green Attributes" of Green Financial Assets

In early research, the core premium of green financial assets was reputation premium, which refers to investors accepting lower rates of return for companies fulfilling their environmental responsibilities. However, recent studies have shown that with the maturity of climate risk quantification tools, "green" has become a marker for quantifying risk hedging capabilities. Lv et al. [9] confirmed, based on data from China's green bonds, that carbon efficiency is the core driver of green premiums, rather than just reputation. This conclusion marks a shift in the pricing of green financial assets from "qualitative reputation" to "quantitative risk", and provides empirical support for the core position of the three major quantitative channels.

3. Core Channel One for Quantitative Transmission of Climate Risk: Pricing Logic and Empirical Evidence of Carbon Premium

Carbon premium is the most direct channel for converting climate risks into additional returns/spreads on green financial assets. Its core logic is the internalization of carbon costs through corporate cash flow and risk expectations, forming a pricing differentiation between green and carbon assets. Essentially, it is a market-oriented quantitative manifestation of transformation risks. The connotation of carbon premium includes two dimensions: the discount of the yield obtained by green financial assets due to low-carbon emissions (i.e., green premium Greenium), and the premium of the yield borne by carbon assets due to carbon emission costs (i.e., brown discount), which together constitute the pricing system of carbon premium.

3.1 Theoretical Transmission Mechanism of Carbon Premium

The transmission of carbon premium relies on the endogenous transformation of carbon pricing mechanism, with the core being the transformation of carbon emission costs from external costs to marginal costs of enterprises, thereby affecting asset valuation. Daniel et al. [9] constructed an EZ Lime model in the classic NBER study, which decomposed the optimal carbon price into two parts: expected discount damage and risk premium. They confirmed that carbon price fluctuations are directly related to asset risk premium, and the optimal carbon price exhibits a dynamic characteristic of "first high and then low".

From the perspective of transmission pathways, carbon premium affects the pricing of green financial assets through two pathways. One is the cost path, where the rise in carbon prices drives up the production and financing costs of high carbon enterprises, reduces their cash flow expectations, and thus expands the interest margin with green assets; The second is the expected path, where tightening carbon policies (such as long-term increases in carbon prices) increases the risk of transitioning to high carbon assets. The EU Emissions Trading System (ETS) covers assets that account for 35% of the total market value of European stock markets, and the correlation coefficient between carbon price fluctuations and corporate valuations is -0.73 [1], confirming the effectiveness of carbon premium transmission.

3.2 Empirical Testing of Carbon Premium: International and Domestic Evidence

Empirical research at the international level often focuses on the differentiation of carbon premiums between green bonds and the stock market. Romagnoli and Santini [11] found, based on their study of sovereign green bonds in the eurozone, that the interest rate spread of green bonds in the Netherlands and France is highly synchronized with carbon price fluctuations, while green bonds in Germany and Italy exhibit lower carbon price sensitivity due to scarcity effects, confirming regional heterogeneity in carbon premiums. For the stock market. Carbon Returns across the Globe global research has revised the traditional understanding of "carbon premium=risk premium", pointing out that the average monthly excess return of high carbon companies in the US market is -0.39%, and after correcting for the lag in carbon emission data, high carbon companies continue to perform weaker than low-carbon companies, confirming that carbon premium is a real risk compensation rather than data bias.

At the domestic level, Lv et al. [9] based their core research in "Accounting Research" on China's green bond data from 2016 to 2021, confirming that carbon efficiency is the core driving force of green premiums, rather than reputation factors. After the "dual carbon" target was proposed in 2021, the carbon premium of green bonds significantly increased. This conclusion confirms that the pricing of green financial assets in

China has completed the transformation from a reputation premium to a carbon premium. Another study further expanded and found that after the launch of China's national carbon market, the weighted average cost of capital of emission control enterprises increased by 0.6 percentage points, confirming that carbon costs have been substantially embedded in the financing pricing of green financial assets.

3.3 Controversy and Boundary of Carbon Premium: Scarcity and Policy Uncertainty

The existing literature on carbon premiums focuses on two major issues: firstly, the interference of green asset scarcity on carbon premiums. Some studies suggest that the low spread of green bonds is due to insufficient supply rather than carbon benefits [6], but Romagnoli and Santini's [11] study distinguishes between scarcity effects and carbon price effects, confirming that carbon prices remain the core driver in the long run. The second is the impact of policy uncertainty on the stability of carbon premiums.

4. Core Channel Two for Quantifying Climate Risk Transmission: Dynamic Pricing Mechanism for Climate Scenario Discounting

Climate scenario discounting is the core channel to solve the time mismatch of traditional discounting models and achieve period quantification of climate risks. Its core logic is to dynamically adjust the discount rate or cash flow expectations of green financial assets based on different climate temperature rise scenarios, transform long-term climate risks into current valuation adjustments, and thus form tradable yield differences. Compared to the current cost transmission of carbon premiums, climate scenario discounting focuses more on period pricing of long-term risks and is a core quantitative tool for the long-term valuation of green financial assets.

4.1 Theoretical Basis for Climate Scenario Discounting: From Constant Discounting to Scenario Adaptation

The constant discount rate assumption of traditional DCF models cannot adapt to the long-term and uncertain nature of climate risks. Weitzman's [14] theory of “decreasing climate discount rate” provides core support for scenario discounting, which believes that the irreversibility and tail risk of climate damage require long-term discount rates to be lower than short-term discount rates. This theory is confirmed by empirical research by the Swiss National Bank-differences in discount rates for related projects can lead to a 40% fluctuation in net present value.

The core of climate scenario discounting is the linkage mechanism of “scenario discount rate valuation”, which first sets the climate temperature rise scenario (such as 1.5 ℃, 2 ℃, current policy scenario), and then calculates the risk adjustment discount rate or cash flow attenuation coefficient of assets based on economic shocks and policy constraints under the scenario. The Intergovernment Panel on Climate Change [7] Sixth Assessment Report specifies that the carbon emission budgets corresponding to the 1.5 ℃ and 2 ℃ targets are 0.4 trillion tons and 1.2 trillion tons of carbon dioxide equivalent, respectively. This scientific conclusion has become the core basis for setting climate scenarios and provides a quantitative benchmark for scenario discounting of green financial assets.

4.2 Standardized Framework for Climate Scenario Discounting: Practical Leadership of NGFS and TCFD

The implementation of climate scenario discounting relies on standardized scenario frameworks, with research from the Global Central Bank and Regulatory Agency Green Finance Network (NGFS) and the Climate Related Financial Disclosure Working Group (TCFD) serving as core guidelines. The “Central Bank Climate Scenario Analysis Guidelines (2025 Updated Edition)” released by NGFS [10] distinguishes for the first time between short-term (2024-2030) and long-term (up to 2100) climate scenarios. Short term scenarios focus on sudden risks such as carbon price spikes and regional disasters, and are used for adjusting the short-term yield of green financial assets. The long-term scenario focuses on the long-term impact of net zero transformation and is used for calibrating the discount rate of long-term assets. The “Transition Vulnerability Factor (TVF)” proposed in this guide has been applied by the Dutch central bank, and calculations show that the sensitivity of high carbon industry stock prices to climate scenarios is 1.5 times higher than the market average, providing a quantitative tool for scenario discounting.

The TCFD framework promotes the standardization of disclosure for climate scenario discounting. As of 2025, over 2300 institutions worldwide have adopted the TCFD framework for scenario analysis. The French central bank's stress test based on the TCFD framework shows that if the carbon price rises to 250 euros/ton in 2030, the discount rate for green energy loans from banks can be reduced by 0.3 percentage points, while the discount rate for carbon energy loans needs to be increased by 1.2 percentage points. This result directly translates into a difference in the yield of the two types of assets, confirming the tradability of scenario discounting.

4.3 Empirical Application of Climate Scenario Discounting: Pricing Differences Across Asset Classes

The impact of climate scenario discounting on the pricing of different green financial assets shows significant heterogeneity, with core differences stemming from asset duration and climate risk exposure. For long-term green bonds (such as 30-year bonds), a study by the Bank for International Settlements [1] confirms that the climate scenario discount adjustment is more than twice that of 5-year bonds. The yield of 30-year green sovereign bonds under the 1.5 ℃ scenario is 0.8 percentage points lower than that under the 2 ℃ scenario, confirming that the longer the duration, the more significant the impact of scenario discount.

For green stocks and infrastructure assets, scenario discounting mainly achieves pricing through adjustments to cash flow expectations. BlackRock's [10] research based on the NGFS scenario shows that under the 1.5 ℃ scenario, the long-term cash flow expectations of global new energy companies can be increased by 15% -20%, corresponding to a discount rate reduction of 0.5-0.7 percentage points. However, for traditional energy companies, if their cash flow expectations are reduced by more than 30%, the discount rate needs to be increased by 1.5 percentage points, further widening the yield difference between the two. In domestic research, the “Impact of Paris Agreement Temperature Targets on Asset Pricing” confirms that the discount rate of China's green infrastructure projects under the “dual carbon” scenario is reduced by 0.4 percentage points compared to the baseline scenario, directly driving up project valuations by 12%.

4.4 Core Challenges of Scenario Discounting: Model Heterogeneity and Parameter Calibration

The controversy surrounding climate scenario discounting in existing literature focuses on the subjectivity of model selection and parameter calibration. There are significant differences in the estimation of climate damage between different integrated assessment models (IAMs). The difference in the optimal discount rate between Nordhaus' DICE model and Stern's PAGE model can reach 3 percentage points [12], leading to differences in the scenario discount results of green financial assets. In addition, the uncertainty of scenario assumptions (such as the speed of technological progress and policy implementation) also affects the accuracy of discounting. NGFS [10] points out that if the rate of technological substitution is faster than expected, the adjustment range of scenario discounting for green assets can shrink by 20%.

5. Core Channel Three for Quantitative Transmission of Climate Risk: Default Structure Restructuring and Credit Spread Pricing

The default structure channel is the core path through which climate risk affects the default probability and default loss rate of green financial assets, and is quantified as credit spreads. Its core logic is that climate risk changes a company's ability and willingness to repay debts, reconstructs the default risk structure of assets, and ultimately transforms into tradable spread differences. Compared to carbon premiums and scenario discounting, the default structure channel focuses more on based green financial assets (such as green bonds and green credit), and is the core quantitative carrier for pricing climate risk credit.

5.1 The Reconstruction Logic of Default Structure in Response to Climate Risk

Climate risk reconstructs the default structure through the dual dimensions of physical risk and transition risk, forming a transmission chain of “risk exposure solvency default probability spread adjustment”. At the physical risk level, acute climate disasters can directly cause damage to fixed assets and interruption of income for enterprises, leading to liquidity crises and defaults. In 2017, Hurricane Harvey caused a short-term increase of 0.5 percentage points in default rates for US energy companies, confirming the direct impact of physical risks on defaults. Chronic physical risks (such as agricultural production reduction caused by drought) gradually increase the probability of long-term default through the continuous deterioration of profitability.

At the risk level of transformation, policy constraints (such as carbon taxes and coal bans) and technological substitution can lead to asset stranding and revenue decline for high carbon enterprises, thereby weakening their paying ability. IEA predicts that if carbon neutrality targets are implemented, the default probability of fossil energy companies will increase by 2-3 times. In addition, the risk of climate litigation indirectly affects the default structure through legal costs and reputation damage. According to a study by the London School of Economics [8], companies involved in climate litigation have a 1.8 percentage point higher default probability than litigation companies, and credit spreads during litigation have widened by 50-80 basis points.

For green financial assets, their “green attributes” essentially mean lower climate risk exposure, lower default probability, and default loss rate compared to similar high carbon assets, thereby forming a credit spread advantage. This advantage has broken through the traditional reputation category and become a quantifiable compensation for default risk.

5.2 Empirical Evidence for Quantifying Default Structure: Green Bonds and Credit Markets

The green bond market is the core empirical scenario for default structure channels. At the international level, Bank for International Settlements [7] confirmed based on global green bond data that the credit spread of green bonds is on average 10-15 basis points lower than that of ordinary bonds, and this spread advantage is significantly negatively correlated with climate risk exposure - the higher the climate risk in the industry, the greater the difference in the spread between green bonds and ordinary bonds. Romagnoli and Santini [11] further refined their research on sovereign green bonds in the eurozone and found that German and Spanish green bonds have credit spreads 18 basis points lower than ordinary bonds due to low climate risk exposure, while Italian green bonds with higher climate risk have a spread advantage of only 8 basis points, confirming a direct correlation between default structure and climate risk exposure.

At the domestic level, relevant research confirms the effectiveness of default structure channels. According to the “Research on the Impact of Dual Carbon Targets on the Premium of Green Bond Issuance” [13], about 60% of the credit spread advantage of China's green bonds comes from the reduction of default risk rather than reputation premium. Moreover, after the “dual carbon” target, the default risk premium of green bonds further increases, confirming that climate policies have strengthened the quantitative transmission of default structure. According to a survey conducted by the People's Bank of China (2025) on the green credit market, the non-performing loan ratio of green credit is 0.8 percentage points lower than that of ordinary credit, corresponding to an average loan interest rate that is 20-25 basis points lower. This difference in interest rate spread is essentially a quantitative manifestation of the optimization of default structure.

5.3 Innovative Tools for Quantifying Default Structures: Climate Stress Testing and Risk Weighting

The quantitative implementation of default structure channels relies on innovative tools, with climate stress testing becoming the core approach. The stress test based on the NGFS scenario by the Bank of France [10] shows that if the carbon price rises to 250 euros/ton by 2030, the default rate of high carbon industry loans will increase fourfold, while the default rate of green credit will only increase by 0.5 times. This result is directly used for adjusting the risk weight of green credit - the EU has lowered the risk weight of green credit by 5% -10%, which is essentially a policy quantification of optimizing the default structure.

In addition, the model innovation of credit rating agencies has promoted the quantification and standardization of default structure. Both S&P and Moody's have included climate scenarios in their credit rating models. S&P's [11] research shows that after incorporating climate risks, the average rating of high carbon enterprises is downgraded by 1-2 levels, while the average rating of green enterprises is upgraded by 0.5 levels, corresponding to a credit spread adjustment range of 50-100 basis points, confirming that the quantification of default structure has become a core link in credit pricing.

6. Controversy, Challenges, and Future Prospects of Climate Risk Pricing for Green Financial Assets

6.1 Core Controversies in Existing Research

The existing high-level literature on climate risk pricing of green financial assets focuses on three main points of controversy: firstly, the essential controversy over carbon premiums. Some studies suggest that green asset premiums stem from scarcity rather than climate risk [6], but most top tier studies ; Accounting Research [9] confirms that carbon efficiency is the core driving force; Secondly, there is subjective controversy over the parameters of scenario discounting, with significant differences in the calibration of discount rates among different models, resulting in a lack of comparability in valuation results; The third issue is the boundary dispute over the quantification of default structure. It is difficult to accurately measure the long-term impact of climate risk on default, and there are still technical bottlenecks in quantifying tail risks.

6.2 Core Challenges at the Practical Level

From the perspective of pricing practice, the implementation of the three major quantitative channels faces three major challenges: firstly, insufficient data standardization, and problems such as historical data unsuitability (non-linear changes) and range three emissions omission (average 40%) in climate risk data, which limits the quantification accuracy of carbon premiums and non-compliance structures; The second issue is the insufficient adaptability of the model. Existing models are mostly constructed based on developed country markets, and the differences in climate risk transmission mechanisms in emerging markets lead to a decrease in model applicability, thirdly, there is a lack of policy coordination, and the fragmentation of policies such as carbon pricing and climate disclosure has led to breakpoints in the quantitative transmission of the three major channels.

6.3 Future Research and Practice Prospects

Future research directions will focus on three major dimensions: firstly, improving quantitative accuracy. Machine learning technology will be used to address the nonlinear relationships in climate data and enhance the quantitative accuracy of carbon premiums and scenario discounting (source document); The second is to deepen the research on heterogeneity, and conduct detailed studies on the differences in climate risk transmission among different asset classes and regions, to solve the problem of model adaptability; The third is cross channel collaborative research, exploring the linkage mechanism of carbon premium, scenario discount, and default structure, and constructing an integrated pricing model.

At the practical level, the global popularization of the NGFS scenario framework and the mandatory implementation of TCFD disclosure standards will promote the standardization of climate risk quantification; The expansion of the climate derivatives market (from $8 billion in 2020 to $42 billion in 2023) will provide a more efficient market platform for trading carbon premiums and default structures, helping climate risks truly transform into tradable and hedged pricing factors.

7. Conclusion

Based on high-level literature at home and abroad, this article systematically sorts out the three quantitative transmission channels of climate risk in the pricing of green financial assets, and draws the core conclusion that the “green attribute” of green financial assets has completed the transformation from a reputation premium to a quantitative risk premium. The three channels of carbon premium, climate scenario discount, and default structure have become the core carriers for the transformation of climate risk into additional returns or spreads. The three focus on the internalization of current carbon costs, long-term intertemporal risk pricing, and credit default risk reconstruction, forming a quantitative pricing system covering different time dimensions and asset types.

At the international level, NBER's EZ Climate model, NGFS's scenario framework, and Bank for International Settlements's empirical research have established mature theoretical and empirical foundations. At the domestic level, the “dual carbon” target is driving the quantitative transformation of green financial asset pricing, and empirical evidence on carbon premiums and default structures is gradually becoming abundant. However, current research still faces challenges such as data standardization, model adaptability, and policy coordination. In the future, it is necessary to further improve the accuracy and efficiency of climate risk quantification pricing through technological innovation and policy improvement, and help green finance better serve the low-carbon transformation.

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Conflicts of Interest

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