Pricing and Risk Hedging Strategies for Carbon Financial Derivatives under the Process of Carbon Market Integration

Yifan Ruan

Affiliation: Henan University of Economics and Law 450000 NO.180 Jinshui East Road, Jinshui District, Zhengzhou City, Henan Province, China
Email: 1154413793@qq.com

Abstract

With the expansion of deep international climate governance, carbon market integration has become an important trend in enhancing coordinated carbon emissions governance, opening up brand-new development prospects for the carbon financial derivatives market. This article systematically studies the development history of carbon market integration, describes types, features, and roles of carbon financial derivatives, and studies pricing model applicability and hedging strategy applicability in integrated scenarios. Studies indicate that carbon financial derivatives optimize carbon market liquidity and stability via price exploration and hedging of risks. But their prices must respond to policy-driven and non-linear volatility of carbon prices, whilst hedging strategies of risks must cope with cross-market linkages of prices and uncertainty of policy. Although carbon market integration creates positive conditions for pricing and hedging of derivatives via unified rules and improved disclosure of data, it also expands complexity via poor policy coordination and heterogeneity of markets. This article suggests enhancing policy coordination of global carbon markets, upgrading regulatory and disclosure mechanisms of data, promoting financial innovation to create diversification derivative instruments, and extending tech support to small and medium-sized companies to enhance sustainable development of the carbon financial market.

Keywords: carbon market integration; carbon financial derivatives; pricing model; risk hedging; policy coordination

1. Introduction

As a key policy instrument for dealing with climate change, the carbon market promotes emission reduction for enterprises through emission rights trading and fosters a low-carbon economy. As climate governance continues to deepen globally, carbon market integration has become a prominent tendency in advancing coordinated carbon emissions governance globally. Regional carbon markets, like the EU Emissions Trading System (EU ETS), have revealed a relatively mature operation mechanism, yet interconnectivity of world carbon markets continues to grapple with issues like price volatility, policy divergence and market segmentation [1]. Carbon financial derivatives like carbon options and carbon futures have emerged in this scenario, which give market players instruments of price discovery as well as risk hedging. Particularly during carbon market integration, derivatives can effectively adapt to risks caused by cross-regional carbon price volatility and policy uncertainty [2]. Nonetheless, pricing and risk hedging behaviors of carbon financial derivatives are challenged by the complexity of market mechanisms and uncertainty of external settings, especially when news of intermarket insufficient coordination and limited data openness are present [3]. The research below centers on derivative pricing and risk hedging during carbon market integration, which not only enhances the theoretical framework of carbon financial markets, but also holds important application value for advancing efficient operation of carbon markets globally and financial innovation, and serves as theoretical and practical references for policy makers and market players.

2. Research on Carbon Markets and Carbon Financial Derivatives

2.1 The Development of Carbon Market Integration

Carbon market integration can be traced back to the late 1990s. After the signature of the Kyoto Protocol, international society started to investigate carbon emissions trading mechanisms as an instrument to control climate change. In the early stage, it was primarily based on regional markets, like the European Union Emissions Trading System (EU ETS) introduced in 2005, which enabled carbon markets to evolve from concept to reality. In this stage, carbon market integration was primarily manifested in the international setting up of carbon offset mechanisms, like the Clean Development Mechanism (CDM) and the Joint Implementation Mechanism (JI). These mechanisms facilitated international carbon credits transfer between industrial countries and developing countries and fostered initial global carbon price signal unification [7]. In the 2010s, after Paris Agreement was finally signed, carbon market integration process gained further momentum, and additional countries introduced domestic carbon markets and investigated possible links between markets. For instance, China introduced a national carbon emissions trading market in 2021, and discussion about possible links with EU and California carbon markets increases, demonstrating expansion of integration from regional to international level [8]. But integration process encounters several issues, like policy differences, market segmentation and price volatility. These issues resulted in early failures like that between EU and Australia, but also induced formulation of international standards like Paris Agreement Article 6 aiming to facilitate cross-market cooperation and establish unified rules setting [9].

2.2 Types and characteristics of carbon financial derivatives

Carbon financial derivatives, as an important part of the carbon market, mainly include futures, options, forward contracts and swaps. These products are based on carbon emission quotas or credits and help market participants manage carbon price risks. Futures contracts are standardized products traded on exchanges, such as EUA Futures. They are characterized by high liquidity, leverage, and price discovery, making it easier for investors to hedge against future carbon price fluctuations.[10] Option contracts provide rights rather than obligations, such as carbon call or put options. Their characteristics include asymmetric risk-return and flexibility, making them suitable for market environments with high uncertainty and helping companies lock in emission reduction costs.[11] Forward contracts and swaps are mostly over-the-counter (OTC) transactions, with customized terms to suit specific needs. For example, carbon swaps can exchange quotas from different carbon markets. They are characterized by customization and low transparency, but can effectively transfer cross-market risks.[12] The common characteristics of these derivatives include dependence on the price mechanism of underlying carbon assets, volatility affected by policies, and environmentally oriented value orientation. Compared with traditional financial derivatives, carbon financial derivatives place more emphasis on sustainability and regulatory compliance, while facing the challenges of carbon price uncertainty and market immaturity.

2.3 Research progress at home and abroad

In recent years, research on carbon financial derivative pricing and risk hedging at home and abroad has made significant progress, focusing on model innovation and empirical analysis to adapt to the complexity of carbon market integration. International research mainly emphasizes the construction of dynamic pricing models, such as using jump diffusion models and stochastic volatility models to capture the non-Gaussian characteristics of carbon prices. These models have been verified in the EU carbon market and proved to be accurate in pricing futures and options [13]. In addition, research progress in risk hedging strategies includes the development of dynamic hedging frameworks, such as carbon futures hedging based on the DCC-GARCH model, which empirically shows that it provides diversification benefits in stock portfolios, but its effectiveness decreases during the pandemic [14]. Domestic research focuses on the localization of China's carbon market, such as exploring the pricing mechanism of derivatives under the national carbon emissions trading system, combining policy uncertainty factors, and proposing an improved Monte Carlo simulation method to improve pricing accuracy [15]. At the same time, research on hedging strategies emphasizes the impact of cross-market links, such as the simulation analysis of risk transfer under the integration of the China-EU carbon market, which reveals the key role of policy coordination in the effectiveness of hedging [16]. Overall, the integration of domestic and foreign research from theory to practice has promoted the standardization of carbon financial derivatives, but still needs to further address the challenges of data transparency and model robustness to support the sustainable development of global carbon market integration. 3 Carbon Financial Derivatives Pricing and Risk Management

3. Overview of Carbon Financial Derivatives

3.1 Carbon Financial Derivatives Pricing Models

Carbon financial derivative pricing models are key tools for the financial development of the carbon market, aiming to establish an equitable price standard for instruments such as carbon futures and carbon options. Carbon financial derivative pricing must account for policy-induced volatility and uncertainty about supply and demand in markets such as carbon emission quotas. Standard pricing models comprise altered models from classical finance and dynamic models from classical finance adapted to the carbon market. Modified models from classical finance, such as the Black-Scholes model, hold room for accommodating non-linearity for carbon prices' behavior through strategic volatility and risk-free interest rate modification. However, owing to policy, climate objectives, and level of connectivity, classical models fail to account for their jumpily anapestic volatilities fully. As a result, stochastic volatility models and jump-diffusion models, which capture time-varying volatility better and time-varying effect of shock surprises, are tenable. Moreover, simulation approaches via Monte Carlo simulation can ubiquitously be utilized to simulate paths of carbon prices. Especially for cross-market integration, an overall evaluation of inter-linkages of prices across multiple markets and shock stimulus via policy cohesion must be derived from an integrated perspective. Not only do carbon financial derivative pricing models provide an impetus to transactional decisions of players in markets, but development of carbon financial derivative pricing models is central to carbon markets' liquidity enhancement and price-exploration function, which acts as an anchor for financial innovation within an integration process.

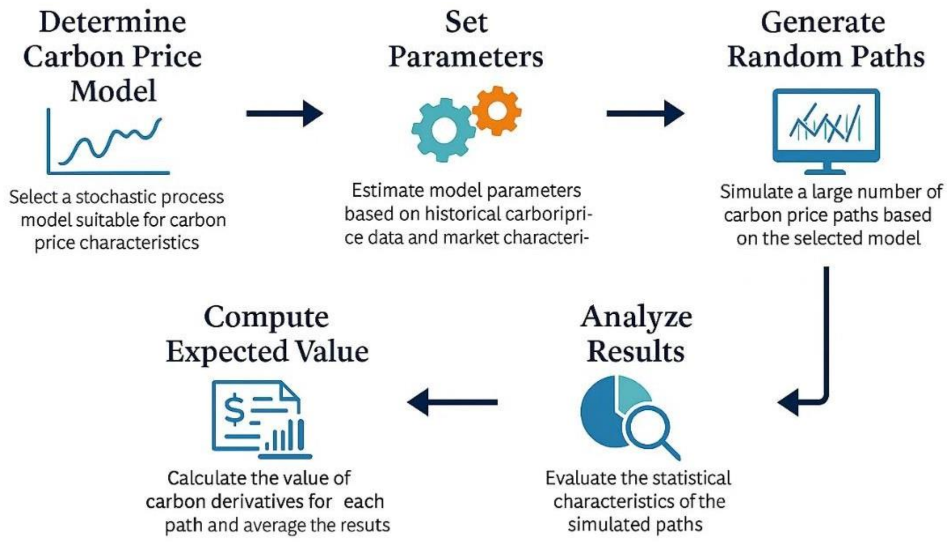

Figure1 Monte Carlo Simulation Method for Carbon Price Paths

Monte Carlo simulation method (Figure 1) can well cope with intricate carbon price dynamics through choosing an optimal stochastic process model, determining model parameters from history, simulating abundant random carbon price paths, computing derivative expected values, and monitoring statistical properties. In carbon market integration, this method can incorporate multi-market price interrelationships and policy disturbances from outside, and enhance pricing precision and risk valuation of carbon financial derivatives to an optimal level.

3.2 Theory and Practice of Risk Hedging Strategies

Risk hedging strategies are one of the fundamental functions of the carbon financial derivatives market, aiming to enable market players to hedge risks from carbon price volatility and uncertainty about policy. From a theoretical point of view, risk hedging strategies rely mostly on hedging theories of financial derivatives, for example, delta hedging and dynamic hedging. Delta hedging offsets volatility risk of prices through building an offsetting position against carbon option price changes, and is appropriate for short-term volatility of markets. Dynamic hedging, plus time series analysis, actively adjusts investment portfolios to counteract long-term uncertainty of carbon prices. In real-world applications, carbon futures and carbon options are popularly utilized for hedging price risk within the carbon market. For instance, companies buy carbon futures to secure future cost of emission, or buy option portfolios to hedge extreme price volatility. In addition, cross-market hedging strategies become popular in carbon market integration, for example, utilizing over-the-counter swaps to spread different carbon markets' price discrepancy risks. Practical issues are, however, insufficient liquidity in markets and complexity in hedging instruments, especially for small and medium-sized companies, who are short of professional knowledge and encounter an inability to conduct efficient hedging. Theory and practice both indicate that risk hedging strategies shall be optimized according to maturity and integration of markets in order to obtain highest cost- effectiveness and lowest risk.

3.3 Impact of Carbon Market Integration on Pricing and Hedging

Carbon market integration, by promoting the interconnection of global carbon markets, has had a profound impact on the pricing and risk hedging of carbon financial derivatives. Regarding pricing, integration has led to more consistent cross-market price signals, reducing the scope for price arbitrage between regional markets, but at the same time, it has increased the complexity of pricing models. Standardized market rules and data transparency help improve carbon price predictability and promote the development of more precise pricing models. However, insufficient policy coordination and divergent market mechanisms can lead to increased price volatility, posing challenges to traditional pricing models. Regarding risk hedging, integration has expanded the range of hedging tools available to market participants, such as through the use of cross-market derivative portfolios to diversify risks in a single market. While the increased liquidity brought about by integration reduces the execution costs of hedging strategies, it also places higher demands on the design of hedging instruments, such as the need to accommodate price correlations and policy risks across multiple markets. Furthermore, regulatory coordination and information sharing mechanisms during the integration process can enhance market stability and provide a reliable environment for hedging strategies. However, in the short term, this may increase risk exposure due to initial market uncertainty. Therefore, carbon market integration provides opportunities for pricing and hedging, but also requires market participants to be more flexible and precise in model design and strategy implementation.

4. Conclusion

Carbon market integration, being one of the important trends towards global climate governance, opens wide avenues for the growth of carbon financial derivatives markets. This article comprehensively compares the development path of carbon market integration, types and features of carbon financial derivatives, pricing models, and hedging strategies, revealing how integration affects the derivatives market. The article reveals that carbon financial derivatives, through their respective price discovery and hedging of risks, have comprehensively improved carbon market liquidity and stability. Nonetheless, their prices must be capable of accommodating policy-oriented and non-linear price volatility of carbon prices, and their hedging of risks must contend with cross-market linkages of prices and market segmentation. Carbon market integration, on one hand, generates pricing and hedging opportunities through unity of rules and openness of data, yet on the other hand, increases complexity through a lack of policy coordination and heterogeneity of markets. In order to facilitate carbon markets' financial development, it is advisable to enhance policy coordination across global carbon markets, establish a unified regulatory and information disclosure mechanism, promote financial innovations in developing varied derivative instruments, and conduct technical assistance to small- and medium-sized entities on enhancing their participation in markets. Future studies can be directed towards optimizing dynamic pricing models, investigating applications of artificial intelligence and big data technologies in carbon price forecasting, and carrying out deep studies on feasibility of cross-market hedging strategies' applicability in growth markets. Simulation methods of multi-scenario scenarios can be adopted, meanwhile, to contend with policy risks, to lay down firmer theories and practices for sustainable development of carbon markets' finances.

References

[1] Daskalakis, G., Psychoyios, D., Markellos, R. N.: Modeling CO2 emission allowance prices and derivatives: Evidence from the European trading scheme. Journal of Banking & Finance, 33(7), 1230-1241 (2009).
[2] Chevallier, J.: Carbon futures and macroeconomic risk factors: A view from the EU ETS. Energy Economics, 31(4), 614-625 (2009).
[3] Benz, E., Trück, S.: Modeling the price dynamics of CO2 emission allowances. Energy Economics, 31(1), 4-15 (2009).
[4] Zhang, Y. J., Wei, Y. M.: An overview of current research on EU ETS: Evidence from its operating mechanism and economic effect. Applied Energy, 87(6), 1804-1814 (2010).
[5] Hintermann, B.: Allowance price drivers in the first phase of the EU ETS. Journal of Environmental Economics and Management, 59(1), 43-56 (2010).
[6] Carmona, R., Hinz, J.: Risk-neutral models for emission allowance prices and option valuation. Management Science, 57(8), 1453-1468 (2011).
[7] Newell, R. G., Pizer, W. A., Raimi, D.: Carbon Markets: Past, Present, and Future. Resources for the Future Discussion Paper 12-51 (2012).
[8] Grubb, M., Drummond, P., Hughes, N.: The Evolution of Carbon Markets and Their Role in Climate Change Mitigation. Oxford Energy Forum 132, 1-20 (2022).
[9] Michaelowa, A., Shishlov, I., Brescia, D.: Evolution of international carbon markets: lessons for the Paris Agreement. Wiley Interdisciplinary Reviews: Climate Change 10(6), e613 (2019).

[10] International Swaps and Derivatives Association: Role of Derivatives in Carbon Markets. ISDA Report (2021).
[11] Swartz, J.: Voluntary carbon market derivatives: Growth, innovation & usage. Energy Research Letters 3(4), 1-10 (2022).
[12] JPMorgan Chase & Co.: Carbon Accounting for Commodity Derivatives. JPMorgan Report (2024).
[13] Li, L., Duan, M., Tang, J., Cai, Y.: Lessons from the development and operational experiences of international carbon markets. Global Energy Interconnection 8(1), 1-10 (2025.
[14] Demiralay, S., Gencer, H. G., Bayraci, S.: Carbon credit futures as an emerging asset: Hedging, diversification and downside risks. Energy Economics 113, 106196 (2022).
[15] Schopp, A., Neuhoff, K.: The Role of Hedging in Carbon Markets. DIW Berlin Discussion Paper 1271 (2013).
[16] Lioui, A., Tarelli, A.: Chasing the ESG factor. Journal of Banking & Finance 139, 106496 (2022).