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Financing Strategies for Risk-Averse SME Retailers in Low-Carbon Supply Chains: A Dynamic Capabilities Approach to Green Transition

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Abstract

There is a global consensus on the urgent need to reduce carbon emissions. However, integrating carbon emission reduction strategies within supply chains characterized by risk aversion and capital constraints has received limited scholarly attention. This study, considering a risk-neutral manufacturer, investigates financing strategies for risk-averse SME retailers in low-carbon supply chains. Three financing options are analyzed: bank credit financing (BCF), manufacturer credit financing (MCF), and mixed financing (MF). The results indicate that when the retailer's risk aversion level is sufficiently high, the retailer's optimal utility under MF outperforms BCF and MCF. Additionally, an increased MF ratio enhances the manufacturer’s utility but negatively impacts the retailer’s utility, depending on the retailer’s risk aversion level. By applying dynamic capabilities theory as an analytical framework, the study demonstrates how SME retailers’ financing strategies (BCF, MCF, MF) operationalize three core dynamic capabilities: sensing carbon transition risks, seizing hybrid financing opportunities, and transforming resources to balance financial stability with emission reduction. Specifically, MF exemplifies SME retailers' ability to dynamically reconfigure funding sources under risk aversion, turning financial constraints into drivers of green innovation. Through MF, SMEs signal their commitment to low-carbon transition, incentivizing manufacturers to reduce emissions via wholesale price adjustments—a cascading dynamic capability effect across the supply chain. Practically, the findings guide SMEs in selecting financing strategies under risk aversion and financial constraints. Policymakers can leverage these insights to design dynamic risk-sharing mechanisms that integrate financing flexibility with green transition goals.

Keywords: Dynamic Capabilities, Carbon Emission Reduction, Risk-Averse Supply Chain, Mixed Financing Strategy, SME Financing

Introduction

Amidst escalating global warming concerns, the greenhouse effect has emerged as a formidable adversary to sustainable development worldwide, leading to natural calamities and rising sea levels. Excessive carbon emissions are the primary cause of the greenhouse effect, which further promotes the reform of global carbon emission reduction initiatives (Wang et al., 2023) and makes the low-carbon economy the focus of government and academia (Occhipinti, 2023; Thakker et al., 2024). During the global transition to a low-carbon economy, not only is environmental pollution reduced, but there is also an increase in demand for eco-friendly products. For instance, Siemens, as a model of sustainable development, reached product sales of €76 billion in the 2024 fiscal year. The products manufactured by the company in 2024 are expected to avoid approximately 144 million tonnes of CO2 emissions over the life cycle (Siemens, 2024). This achievement highlights the importance of setting ambitious sustainability goals.

Financial constraints for SME retailers in low-carbon supply chains present a dual challenge: balancing the need for affordable financing to maintain operational stability with the imperative to invest in carbon reduction technologies. This tension highlights the crucial role of financing strategy selection in facilitating the green transition. SMEs often encounter higher financing costs, inadequate collateral, and stricter loan conditions than large enterprises. These challenges make SMEs more vulnerable to market fluctuations and uncertainties, affecting the stability of the entire supply chain. To gain deeper insights into these issues, this study will also explore decision-making models to enhance the analysis of SMEs' financing strategies, with implications for their role in advancing green transition through carbon reduction initiatives.

To address these challenges, SME retailers facing capital constraints can turn to banks or manufacturers for financial support (Xie et al., 2023). Retailers often struggle to obtain bank credit due to a lack of collateral and credit history, leading them to favor internal financing options such as trade credit and hybrid financing (Vu et al., 2022). Although supply chain finance brings many benefits to SMEs, it is also accompanied by financial risks such as default and bankruptcy. Consequently, these companies are more risk-averse (He et al., 2024). Additionally, in the existing literature, few studies examine the specific impact of different market conditions and various financing strategies on the decision-making and effectiveness of SMEs. This study fills this gap by introducing a risk aversion coefficient to more accurately depict the decision-making behavior of SMEs in volatile markets, thereby enhancing our understanding of low-carbon supply chain dynamics.

Guided by dynamic capabilities theory (Teece et al., 1997), this study posits that SMEs’ financing strategy selection under risk aversion reflects their ability to dynamically reconfigure financial resources and risk management practices in response to low-carbon transition pressures. This theoretical lens highlights how adaptive financing decisions are critical for SMEs to balance financial stability and environmental goals. In conclusion, our study aimed to answer the following research questions: (i) How does RLRA influence optimal decisions in a low-carbon supply chain across various financing models? (ii) Which financing strategy is more advantageous for the risk-averse retailer? (iii) How does RLRA affect the utilities of low-carbon supply chain members, given varying MF ratios?

In order to answer these issues, a low-carbon supply chain model was constructed in which the capital-constrained and risk-averse retailer could secure funding from either the bank or the manufacturer. The manufacturer sets each product unit's final carbon emission and wholesale price. Subsequently, the retailer decides on the selling price. Numerical analysis reveals that the RLRA significantly influences the optimal decision-making and the associated utilities. A low MF ratio, which Indicates a smaller proportion of the retailer's financing comes from the manufacturer and a higher proportion from the bank, negatively affects the manufacturer's utility but benefits the retailer's utility depending on the RLRA.

This study makes two significant contributions: First, it highlights the substantial influence of risk aversion on wholesale pricing and carbon emissions, filling a research gap in previous studies concerning low-carbon supply chains with financial limitations. It provides practical guidance for SMEs to optimize their financing decisions, helping them identify the financing models best suited to their financial conditions, thereby effectively reducing financing costs and financial risks. Second, the numerical analysis compares MF, BCF, and MCF under various conditions, demonstrating that the mixed financing strategy can significantly enhance retailer utility under specific circumstances. This provides crucial insights for retailers facing financial constraints and carbon reduction pressures and offers data-driven support for policymakers to develop more effective policies that align with low-carbon goals, thus advancing the development of a low-carbon economy.

From a theoretical perspective, this study applies the dynamic capabilities lens (Teece et al., 1997) to reveal how SMEs' financing strategies under risk aversion reflect their capacity to reconfigure financial resources and manage carbon transition pressures. The findings demonstrate that mixed financing strategies are dynamic, enabling retailers to balance risk mitigation and environmental goals while maintaining supply chain adaptability. It explores how these factors interact within low-carbon supply chains, offering insights into their dynamics. Practically, the research provides actionable guidance for SMEs navigating financial constraints while pursuing sustainability and delivers critical insights for policymakers to craft effective regulations that support sustainable business practices.

The organization of this paper is as follows: Section 2 provides a literature review on low-carbon supply chains, risk aversion in supply chains, and operational management under financial constraints. Section 3 articulates the models' framework, assumptions, and nomenclature. Section 4 derives optimal decisions across three distinct models. Section 5 examines retailers' risk aversion impacts wholesale prices and carbon emissions across various financing models. It also includes a comparative analysis of retailer utility between MF and BCF strategies. Section 6 elucidates these findings through numerical analysis and culminates in the conclusions presented in Section 7.

Literature Review

This section establishes the theoretical basis for this study by reviewing previous studies on risk-averse supply chains, low-carbon supply chains, and financial constraints and further clarifies the direction of this research.

Low Carbon Supply Chains

Recently, research on low-carbon supply chains has mainly focused on achieving carbon emission reductions and sustainable supply chain development through various strategies and policies. In terms of carbon policy applications, Ma and Lu (2023) used the Stackelberg game theory to study optimal operational strategies under carbon tax policies, and the results showed that increased carbon taxes affect not only environmental performance but also achieve optimal performance by balancing economic, social, and environmental goals. Zhang et al. (2024) explored the practical application of carbon quota strategies and found that adopting a benchmarking approach can provide fairer and more efficient outcomes and contribute to achieving carbon neutrality goals. Liu et al. (2023) discussed the impact of consumer carbon subsidy policies on enterprises' low-carbon decisions. The results showed that with the increase in carbon prices and adjustment of carbon allowances, enterprises' profits and carbon emission reduction strategies could be significantly affected, highlighting the important role of carbon subsidies in promoting the market's transition to low carbon. Meng (2022) studied the synergic emission reduction effect of enterprises' energy performance contracts under carbon trading and carbon tax policies, and the results showed the effectiveness of mixed carbon policies in promoting cooperative emission reduction within the supply chain. Regarding dynamic analysis and coordination, Song et al. (2024) found that consumer concerns about equity significantly influence the decision-making behavior of participants in a low-carbon supply chain. Huang (2023) studied the dual-market low-carbon supply chain and noted that market demand fluctuations would significantly affect supply chain decision-making. Hamidoğlu and Weber (2024) used Nash game theory to study the implementation of low-carbon strategies within the agricultural supply chain, and the results showed that reasonable low-carbon strategies could effectively reduce carbon emissions and enhance the overall efficiency of the supply chain.

Risk-Averse in Supply Chains

Over the past few years, researchers from different disciplines have investigated the effects of risk aversion on decision-making processes and supply chain performance. In terms of supply chain coordination, Zang et al. (2022) studied external failure cost-sharing and quality improvement investments in manufacturer-led, supplier-led Stackelberg settings, and centralized settings, proposing a new contract to coordinate decentralized systems and demonstrating through numerical examples the impact of key parameters on equilibrium results under different supply chain structures. Chen et al. (2024) examined how shareholding and risk-aversion conditions affect supply chain optimization and coordination within a push-pull strategy. Risk aversion and shareholding ratio significantly influence the optimal order or production quantity. Regarding risk sharing, Zhen et al. (2024) examined how portfolio financing equilibrium evolves in risk-averse supply chains subject to partial trade credit policies. Their research showed that higher degrees of risk aversion result in more conservative ordering practices, whereas higher valuation levels promote increased order quantities. Wu et al. (2024) examined how risk aversion affects supply chain performance and carbon reduction efforts under asymmetric information, finding that risk-averse behavior significantly influences overall supply chain efficiency. Regarding technology application, Qi et al. (2023) investigated joint production and emission reduction strategies under carbon tax policies, revealing that risk-averse firms can sometimes achieve higher optimal profits than risk-neutral firms, suggesting that risk aversion does not permanently harm profitability.

Operational Management with Financial Constraint

Increasing market competition and consumer awareness of environmental protection have prompted companies to seek competitive advantage through low-carbon production; however, financial constraints often hinder these efforts. Regarding supply chain coordination and financing strategies, Chen et al. (2022) developed dynamic game models considering bounded rationality to evaluate the performance of a dyadic supply chain consisting of a single supplier and two competing retailers dealing with capital constraints and environmental concerns. They compared models of full trade credit (FTC) and hybrid trade credit (HTC), discovering that the supplier's adjustment speed significantly influences system stability and anticipated profits. High trade credit ratios increased dynamic green levels, wholesale prices, and supplier profits. Tian et al. (2023) employed the Conditional Value-at-Risk (CVaR) criterion to investigate the best financing strategies for risk-averse suppliers within financially constrained supply chains. They observed that risk-averse suppliers typically offer partial credit guarantees (PCG), although this choice may adversely affect the supplier’s utility and the retailer’s expected profits. Zong and Huang (2023) analyzed the optimal financing decisions for manufacturers facing capital constraints in low-carbon supply chains using the Stackelberg game theory. They examined the options between bank financing (BF) and trade credit financing (TCF), concluding that manufacturers prefer bank financing when trade credit interest rates exceed bank rates and choose trade credit financing when the rates are lower than a specific threshold. Regarding risk management and financial constraints, Xie et al. (2024) studied the impact of various supply chain financing strategies on the profits of participants and the spread and influence of default risk. The results showed that trade credit provided by manufacturers could improve the profits of supply chain participants. However, it also increased the expected losses of creditors, quickly leading to the contagion and diffusion effect of default risk. Regarding technology application and sustainability, Lai et al. (2022) examined internal collaborative GSCF schemes and external investment schemes, finding that despite financial support from suppliers, manufacturers tend to reduce green investments compared to scenarios without capital constraints.

The existing literature underscores the significance of low-carbon supply chains, risk aversion, and financial constraints in supply chain management. However, there is a discernible gap in research that integrates these three aspects, particularly about SMEs. Drawing on dynamic capabilities theory, this study posits that SMEs’ financing strategy selection under such integrated pressures reflects their ability to dynamically reconfigure financial resources (e.g., hybrid financing) while balancing risk mitigation and carbon reduction. Investigating optimal financing strategies for risk-averse retailers within low-carbon supply chains provides a comprehensive analysis of how these factors interact and influence supply chain decisions.

Model Description

The preceding chapter established the theoretical significance of integrating low-carbon supply chains with risk aversion and financial constraints while highlighting unresolved research gaps. Drawing on dynamic capabilities theory, this study explores the interaction of these factors and how they influence supply chain decisions for SMEs. This chapter develops a methodological framework to evaluate financing strategies for risk-averse SME retailers operating under carbon emission constraints.

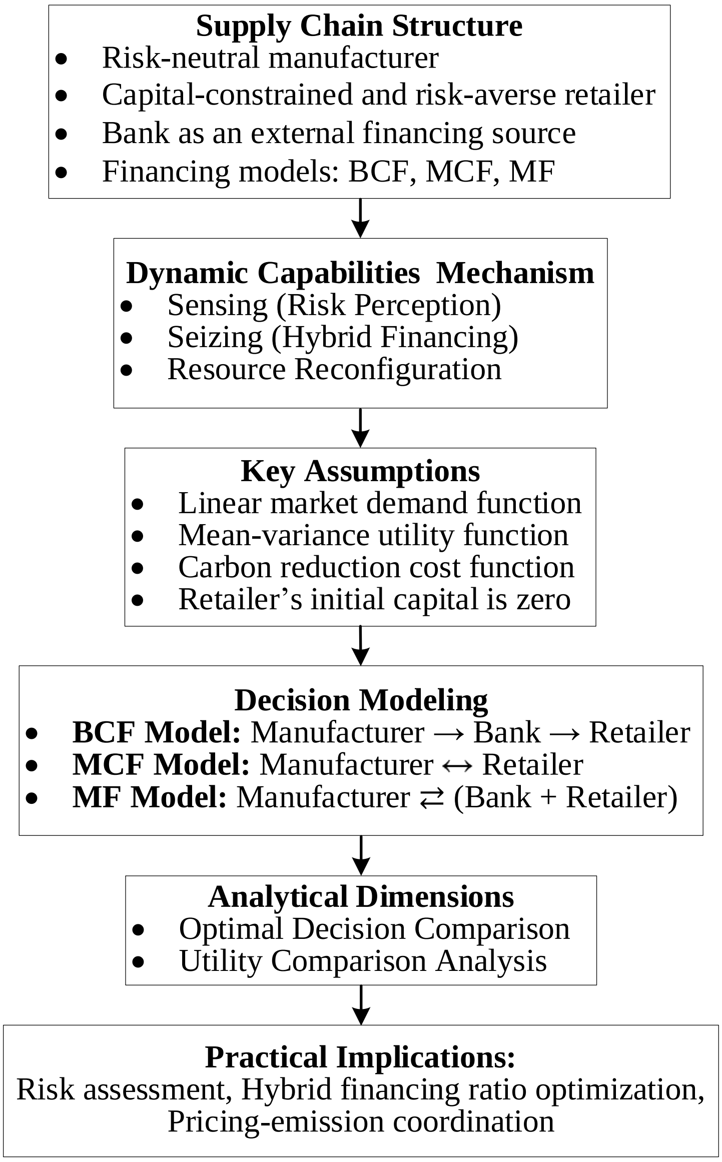

Figure 1: Methodology Framework

As illustrated in Figure 1, the methodology framework outlines the key components of this study. The framework emphasizes how dynamic capabilities theory informs the decision-making process of risk-averse SME retailers, guiding them through various financing options—BCF, MCF, and MF. This framework is the foundation for the model construction and decision-making processes discussed in the following sections.

This study investigates the financing decision-making issue within a risk-averse supply chain framework under carbon emission reduction constraints. The supply chain comprises risk-neutral manufacturers and capital-constrained, risk-averse retailers. Retailers have the option to choose among BCF, MCF, or MF. This research aims to identify the optimal financing strategy that maximizes retailer utility while reducing carbon emissions. To achieve this, the study incorporates the Behavioral and Rational decision-making models. The Behavioral Model focuses on decision-making under conditions of bounded rationality, where SMEs may adopt simplified strategies due to incomplete information and cognitive limitations. This model highlights the role of emotional factors such as risk aversion in decision-making, which may lead SMEs to prefer manufacturer credit over bank credit, even if it comes with higher costs (Settembre-Blundo et al., 2021). This phenomenon can be explained by heuristic decision-making in the Behavioral Model, which indicates non-rational behavior when facing complex financing choices (Colombo & Steenbergen, 2020). On the other hand, the Rational Model assumes that decision-makers systematically maximize utility by clearly defining financial constraints, setting evaluation criteria, and analyzing options to select the optimal decision (Nguyen & Canh, 2020). This approach ensures that SMEs can effectively balance their financial needs with carbon reduction goals, optimizing their financing strategy.

Building on Teece's dynamic capabilities framework (sensing-seizing reconfiguring)(Teece et al., 1997), the SME retailer's financing strategy is modeled as a risk-aversion-driven capability cascade. The sensing capability operates through dual dimensions: the retailer's risk aversion coefficient (λ) quantifies its perception of financial uncertainties, while consumers' emission sensitivity (ϑ) mirrors market-driven low-carbon transition risks. This compound risk cognition activates the seizing capability, manifested in the strategic balancing of bank credit (r_b) and manufacturer credit (r_t) through a hybrid financing ratio (Φ). These financing decisions subsequently trigger the reconfiguring capability, evidenced by the manufacturer's adaptive adjustments in wholesale pricing (w) and per-unit carbon emissions (e). The framework reveals a self-reinforcing transmission chain: heightened risk sensitivity ($\lambda\uparrow$) drives financing diversification ($\Phi\uparrow$), which transmits market signals to incentivize emission reduction ($e\downarrow$) through operational reconfiguration—all while maintaining full compatibility with the original Stackelberg game structure and mathematical formulations. Table 1 summarizes the key notations and their definitions, which will be applied throughout the analysis to facilitate understanding of the following financing model. These symbols are essential for modeling the retailer's financing decisions under risk aversion and carbon emission constraints.

Table 1
Notations

Symbol	Description
D	Total market demand
a	Market potential demand
p	Selling price of unit product
ϑ	Consumers' sensitivity coefficient of emission mitigation
e	Final carbon emissions per unit product
e_0	Initial carbon emissions per unit product
δ	Market demand uncertainty represents the volatility of market demand, with a standard deviation of δ.
U_r	Utility of the retailer
U_m	Utility of the manufacturer
λ	The degree of risk-aversion
w	Wholesale price per product
r_b	Bank's interest rate
r_t	Manufacturer's interest rate
k	Carbon emission reduction cost factor
Φ	Retailer's MF ratio
c	Manufacturing cost per product
BCF^*	Optimal value for BCF model
MCF^*	Optimal value for MCF model
MF^*	Optimal value for MF model

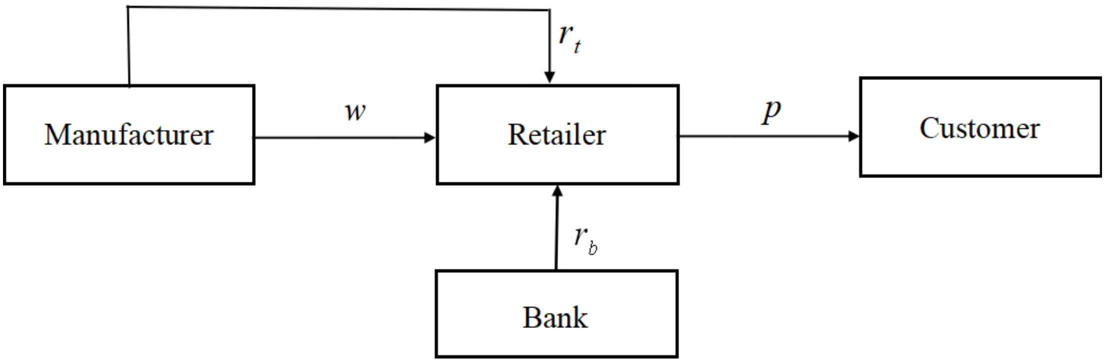

Figure 2. Supply chain structure.

Figure 2 illustrates the supply chain structure and shows how the retailer, constrained by capital, can obtain financing from a bank, the manufacturer, or a combination of both. The model involves various components that are directly influenced by these notations. The manufacturer incurs a unit production cost (c) and sells the product to the retailer at a wholesale price (w), while the retailer sets the retail price (p) for consumers. The interactions between these entities, including financing options from the bank (r_b) and manufacturer (r_t), are central to understanding the retailer's financing decisions. The model operates under the following assumptions:

Assumption 1. Building on established demand models (Xu et al., 2019), market demand is modeled as a linear function of selling price and carbon emissions. Consumers' preferences for lower prices and reduced carbon emissions negatively impact market demand. The demand function can be described as follows:

$$D = a - p - \theta e + \delta$$

Assumption 2. As the retailer faces financial constraints and is sensitive to the uncertain risk performance of the market, this paper assumes that the retailer is risk-averse, whereas the manufacturer is risk-neutral. This assumption is consistent with previous studies, showing that retailers often exhibit risk-averse behavior under financial constraints (Cao & Yu, 2018; Xie et al., 2011). The utility function is defined as:

$$U_j = E(\pi_j) - \lambda_j \sqrt{\operatorname{var}(\pi_j)}$$

Where U_j represents the utility of player j, $E(\pi_j)$ is the expected profit of player j, λ_j is the degree of risk-aversion for player j, which helps us to more accurately reflect the decision-making behavior of SMEs when faced with market uncertainties, and $\operatorname{var}(\pi_j)$ is the variance of the profit of player j.Here, $\lambda_j \geq 0$ indicates the degree of risk-aversion, and in the special case where $\lambda_j = 0$, the function represents a risk-neutral behavior.

Assumption 3. The manufacturer's carbon reduction cost is a one-time investment, which can be expressed as $(1/2)k(e_0 - e)^2$, k is the carbon emission reduction cost factor (Sun & Yang, 2021).

Assumption 4. To reflect the retailer's capital shortage and simplify the analysis process, the initial capital of retailers is set to zero (Cao et al., 2019). It is assumed that manufacturers' capital is sufficient to meet the investment in production and emission reduction.

Model Construction and Decision Framework

The optimal solutions under the BCF model, the MCF model, and the MF model are explored in this section.

BCF Model

In the BCF model, the manufacturers first set the wholesale price and the final carbon emission, then the retailer sets the optimal selling price. Expected utilities for the manufacturer and the retailer are listed below:

$$U_m^{BCF} = (w-c)(a-p-\theta e)-(1/2)k(e_0-e)^2$$

$$U_r^{BCF} = (p-w-wr_b)(a-p-\theta e)-\lambda(p-w-wr_b)\sigma$$

The retailer borrows $w(a-p-\theta e)$ from the bank and needs to repay $w(a-p-\theta e)(1+r_b)$ to the bank at the end of the sales period.

Proposition 1. In the BCF model, the optimal solutions for the selling price, wholesale price, and final carbon emission per unit are determined as follows:

$$e^{BCF*} = \frac{cr_b\theta + 4e_0kr_b - \lambda\sigma\theta - a\theta + c\theta + 4ke_0}{4kr_b - \theta^2 + 4k},$$

$$w^{BCF*} = \frac{2cr_bk - c\theta^2 - 2e_0k\theta + 2k\lambda\sigma + 2ak + 2ck}{4kr_b - \theta^2 + 4k},$$

$$p^{BCF*} = \frac{-\theta e^{BCF*} - \lambda\sigma + w^{BCF*}r_b + a + w^{BCF*}}{2}.$$

Proof: Refer to the appendix.

MCF Model

In the MCF model, the sequence of events unfolds as follows: (i) The manufacturer concurrently determines the wholesale price and the final carbon emission; (ii) The retailer then sets the optimal selling price. Expected utility functions for both manufacturers and retailers are:

$$U_m^{MCF} = (w-c)(a-p-\theta e)-(1/2)k(e_0-e)^2 + wr_t(a-p-\theta e)$$

$$U_r^{MCF} = (p-w-wr_t)(a-p-\theta e)-\lambda(p-w-wr_t)\sigma$$

The retailer obtains a loan of $w(a-p-\theta e)$ from the manufacturer. The retailer needs to repay $w(a-p-\theta e)(1+r_t)$ to the manufacturer at the end of the sales period, covering both the principal and interest of the loan.

Proposition 2. In the MCF model, the optimal solutions for the final carbon emission per unit, wholesale price, and selling price are as follows:

$$e^{MCF*} = \frac{-\lambda\sigma\theta - a\theta + c\theta + 4ke_0}{4k - \theta^2},$$

$$w^{MCF*} = \frac{-c\theta^2 - 2e_0k\theta + 2k\lambda\sigma + 2ak + 2ck}{-r_t\theta^2 + 4kr_t - \theta^2 + 4k},$$

$$p^{MCF*} = \frac{-\theta e^{MCF*} - \lambda\sigma + w^{MCF*}r_t + a + w^{MCF*}}{2}.$$

Proof: Refer to the appendix.

MF Model of Bank Credit and Trade Credit

Within the MF model, the manufacturer first sets both the optimal wholesale price and the final carbon emission. The retailer then determined the best-selling price. The expected utility functions for manufacturers and retailers are as follows:

$$U_m^{MF} = (w-c)(a-p-\theta e)$$
$$-(1/2)k(e_0-e)^2 + \phi w r_t (a-p-\theta e)$$
$$U_r^{MF} = \left[p-w-(1-\phi)wr_b-\phi wr_t\right](a-p-\theta e)$$
$$-\lambda\left[p-w-(1-\phi)wr_b-\phi wr_t\right]\sigma$$

The retailer secures loans of $\phi w\left(a-p-\theta e\right)$ from the manufacturer and $(1-\phi)w\left(a-p-\theta e\right)$ from the bank. The retailer must repay $(1-\phi)w\left(a-p-\theta e\right)(1+r_b)$ to the bank and $\phi w\left(a-p-\theta e\right)(1+r_t)$ to the manufacturer at the end of the sales period.

Proposition 3. Within the MF model incorporating bank and trade credit, the optimal solutions for the selling price, wholesale price, and final carbon emissions per unit product are as follows:

$$e^{MF*} = \begin{bmatrix} (\phi-1)(r_b c\theta + 4r_b e_0 k) + (\phi r_t + 1)(\lambda\sigma\theta + \theta a - \\ c\theta - 4e_0 k) \end{bmatrix}$$
$$/\left[(1+\phi r_t)\theta^2 + 4(kr_b\phi - kr_t\phi - r_b k - k)\right]$$
$$w^{MF*} = \begin{bmatrix} 2cr_b k(\phi-1) + (\phi r_t + 1)(2e_0\theta k - 2\lambda\sigma k \\ -2ak - 2ck + c\theta^2) \end{bmatrix}$$
$$/\left[(1+\phi r_t)[(1+\phi r_t)\theta^2 + 4(kr_b\phi - kr_t\phi - r_b k - k)]\right]$$
$$p^{MF*} = \frac{w^{MF*}(-r_b\phi + \phi r_t + r_b + 1) - \theta e^{MF*} - \lambda\sigma + a}{2}.$$

Proof: Refer to the appendix.

Analysis Model and Proposition Model

This section explores the impact of RLRA on the optimal wholesale prices and final carbon emissions within various financing models. Furthermore, the differences in retailer utilities between the MF strategy and BCF strategy are analyzed.

Model Optimization

The effects of RLRA on optimal wholesale prices and final carbon emissions across different models are examined. The influence of RLRA on final carbon emissions across various financing models, as discussed in Proposition 4, is investigated.

Proposition 4. (i) $\frac{\partial e^{BCF*}}{\partial \lambda_r} < 0$; (ii) $\frac{\partial e^{MCF*}}{\partial \lambda_r} < 0$; (iii) $\frac{\partial e^{MF*}}{\partial \lambda_r} < 0$.

Proposition 4 (i) shows that the final carbon emission decreases with the RLRA under the BCF model. Proposition 4 (ii) shows that the final carbon emission under the MCF strategy decreases with the RLRA. Proposition 4 (iii) indicates that the final carbon emission under the MF model decreases with the RLRA. Thus, the retailer’s risk aversion will decrease final carbon emissions, reducing carbon across the supply chain and attracting more environmentally conscious consumers.

Subsequently, the influence of RLRA on wholesale prices in Proposition 5 is explored.

Proposition 5. (i) $\frac{\partial w^{BCF*}}{\partial \lambda_r} > 0$; (ii) $\frac{\partial w^{MCF*}}{\partial \lambda_r} > 0$; (iii) $\frac{\partial w^{MF*}}{\partial \lambda_r} > 0$.

Proposition 5 (i) illustrates that increasing RLRA under the BCF model increases the wholesale price. (ii) illustrates that the wholesale price ascends with higher RLRA in the MCF model. (iii) reveals that the wholesale price grows with increasing RLRA in the MF model. As a result, a rise in the retailer's risk aversion ultimately leads to higher wholesale prices. Therefore, the risk-aversion behaviors of retailers will cause manufacturers to raise wholesale prices, thus increasing manufacturers' incomes.

Comparison Analysis of the Retailer's Utilities

The retailer's utilities under the MF strategy are compared with those under the BCF and MCF strategies, respectively, in Proposition 6.

Proposition 6. Given $r_b = r_t = r$, (i) It follows that $U_r^{MF*} > U_r^{BCF*}$ if $Lc + e_0\theta - \lambda\sigma - a < 0$, and $\frac{\max\{1, \min\{M_1, M_2\}\} - 1}{r} < \phi < \frac{\min\{2, \max\{M_1, M_2\}\} - 1}{r}$ (ii) It follows that $U_r^{MF*} > U_r^{MCF*}$ if $2\lambda\sigma\theta^4 - (e_0\theta + 7\lambda\sigma - a + c)\theta^2 k < 0$, and $\frac{\max\{1, \min\{M_3, M_4\}\} - 1}{r} < \phi < \frac{\min\{2, \max\{M_3, M_4\}\} - 1}{r}$

The detailed formula for M can be found in the appendix within the proof of Proposition 6.

Proposition 6 compares the retailer's utilities under the BCF and MCF strategies, respectively, with the retailer's utilities under the MF strategy if there is no difference between the interest rates of the three models. The analysis reveals that: (i) Under certain conditions, the retailer's optimal utility under the MF strategy surpasses that under the BCF strategy. This is due to the MF strategy reducing financial costs and increasing flexibility, enabling retailers to manage their risk aversion better. (ii) Similarly, under certain conditions, the optimal utility for the retailer when adopting the MF strategy exceeds that achieved under the MCF strategy. This is attributed to the balanced financial burden between the retailer and manufacturer, leading to more efficient supply chain operations. Therefore, when managing risk aversion is crucial, the MF strategy often emerges as the optimal financing choice for the retailer.

In Proposition 7, the manufacturer's utilities under the MF strategy are compared with those under the BCF and MCF strategies.

Proposition 7. Given $r_b = r_t = r$, (i) It follows that $U_m^{MF*} > U_m^{BCF*}$ if $\phi < \frac{1 - M_5}{r}$,

(ii) It follows that $U_m^{MF*} > U_m^{MCF*}$ if $\phi > \frac{1 - M_6}{r}$.

In Proposition 7, the manufacturer's utilities under the BCF and MCF strategies are compared with those under the MF strategy, assuming no difference between the interest rates of the three models. It is found that (i) under specific conditions, the manufacturer's optimal utility when employing the MF strategy surpasses that of the BCF strategy; (ii) the manufacturer's optimal utility with the MF strategy is also higher than that with the MCF strategy. Therefore, under certain scenarios, the MF strategy is preferred by the manufacturer.

Numerical Analysis and Practical Implications

Numerical analysis is used to illustrate some of the relevant issues. Numerical experiments were conducted to assess the impact of RLRA on decision-making, profit, and utility under varying MF ratios. It is assumed that a=100, e_0=7, c=20, θ=1, k=20, r=0.4, σ=4, Φ=0.5 (Sun & Yang, 2021).

The Impacts of RLRA on Decisions

This section examines the actual effects of RLRA on final carbon emissions, wholesale prices, and selling prices under different models.

Figure 3 shows that the BCF model has the highest final carbon emissions, followed by the MCF and MF models. In addition, with the gradual increase of RLRA, the final carbon emissions of all financing models are reduced to varying degrees. This suggests that risk-averse retailers' sensing capability (via risk aversion coefficient λ and emission sensitivity ϑ) drives them to adopt low-carbon strategies. By prioritizing low-carbon products to mitigate market uncertainties, they enhance supply chain coordination, leading to stable demand and reduced emissions.

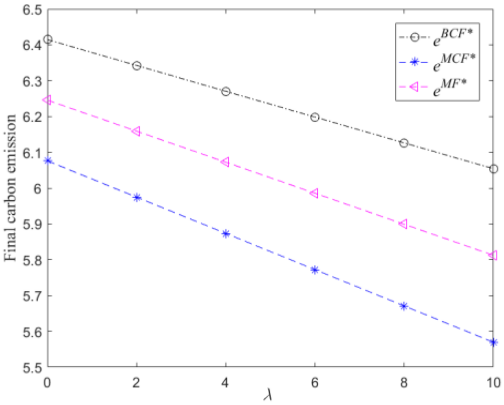

Figure 3. Final carbon emissions under different models

Figure 4 shows that the wholesale price of products under the BCF model is larger than that under the MCF and MF models. In addition, under the three different financing models, the wholesale price increases with the increase of the RLRA. This is because manufacturers' reconfiguring capability adapts wholesale prices (w↑) to retailers' risk signals (λ↑), balancing financial stability and emission goals. Such adaptive pricing ensures profitability while incentivizing low-carbon transitions.

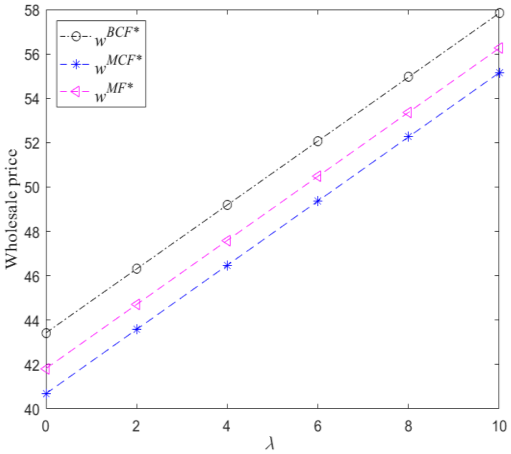

Figure 4. Wholesale prices under different models

Figure 5 shows that the selling prices of products under the BCF model are more significant than those under the MCF and MF models. In addition, under the three different financing models, the selling price of the product decreases with the decrease of the RLRA. Risk-averse retailers can increase market demand by reducing retail prices to offset the risks associated with market demand uncertainty. In practice, this means that with varying degrees of risk aversion, retailers need to be more flexible in their pricing strategies to adapt to changes in the market.

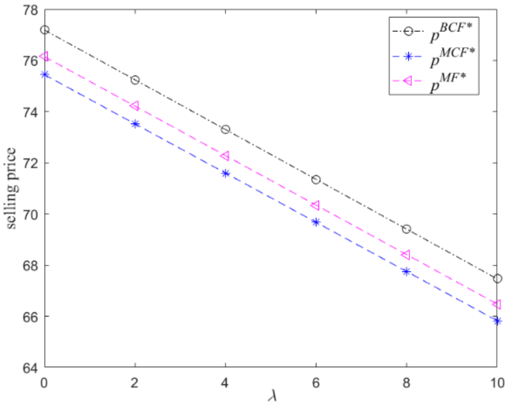

Figure 5. Selling prices under different models

The Impacts of the Retailer's Risk-Averse Level on Utilities

This subsection analyzes the impacts of RLRA on the utilities of supply chain members under different models.

Figure 6 shows the retailer's utilities first decrease with the RLRA and then increase with the RLRA under different financing strategies. This U-shaped utility pattern reflects retailers' seizing capability: balancing price adjustments and financing strategies (Φ) under high RLRA to mitigate risks. By dynamically seizing hybrid financing opportunities, they optimize utility despite financial constraints.

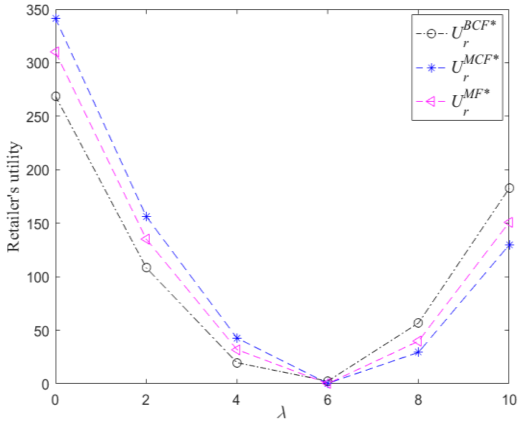

Figure 6. Retailer’s utilities under different models

Figure 7 shows that the manufacturer can obtain higher utility under the MCF model than the MF and BCF models. Moreover, the manufacturer’s utility increases with the RLRA under different financing strategies. This is because the risk-averse retailer lowers the retail prices and increases market demand, and then the manufacturer can get more excellent utility by raising wholesale prices. In practical terms, retailers should select financing strategies that align with their level of risk aversion to optimize their utility.

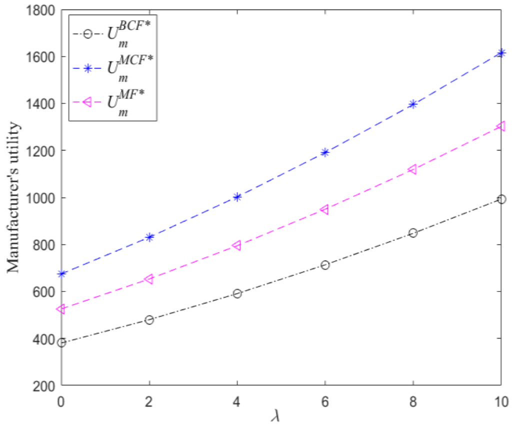

Figure 7. Manufacturer’s utilities under different models

The Impacts of the Retailer’s Risk-Averse Level on the Utilities Considering Different MF Ratio of the Retailer

The impacts of the RLRA on the utilities of the supply chain members considering different MF ratios are investigated. Figure 8 illustrates how the RLRA influences the retailer's utility under different MF ratios. It shows that the retailer's utility decreases as the MF ratio increases. When the MF ratio increases from 0.1 to 0.9, the retailer’s utility decreases from 175 to 133. This is because, with a higher MF ratio, retailers face reconfiguring capacity limitations (excessive reliance on manufacturer credit increases financial rigidity), decreasing utility despite stronger risk perception (sensing capability). The practical implication is that retailers should balance the MF ratio and financial costs when choosing a mixed financing strategy to optimize their utility.

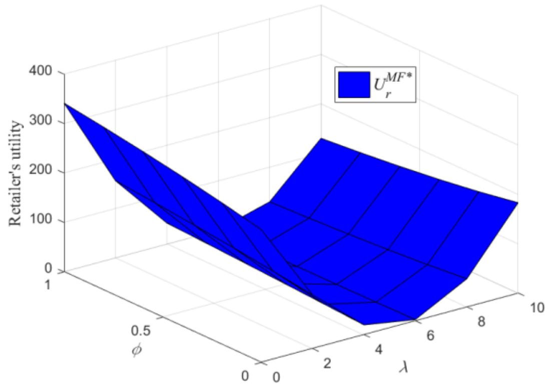

Figure 8. Retailer’s profit under MF model

Figure 9 investigates the impacts of the RLRA on the manufacturer’s utility, considering different MF ratios. Figure 9 indicates the manufacturer can obtain a more considerable utility when the MF ratio is relatively high. When the MF ratio increases from 0.1 to 0.9, the manufacturer’s utility increases from 1553 to 1055. A higher MF ratio reflects retailers’ enhanced seizing capability (capturing manufacturer credit opportunities), which transmits market signals to manufacturers. Manufacturers leverage this to optimize wholesale pricing (w↑) and emission reduction (e↓), achieving higher utility through adaptive reconfiguration. In practical terms, manufacturers should consider the retailer's level of risk aversion and the MF ratio when formulating financing strategies to maximize their utility.

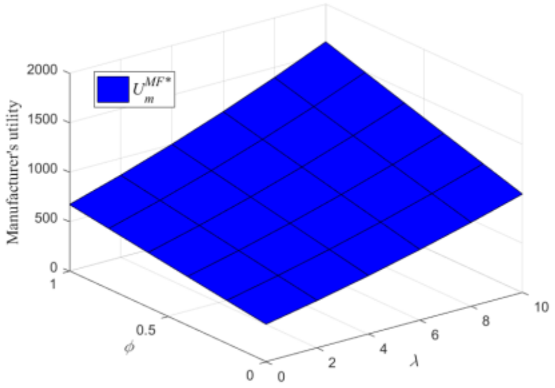

Figure 9. Manufacturer’s profit under MF model

The following conclusions can be drawn by comparing Figures 8 and 9: Figure 8 shows that when the MF ratio is relatively high, the retailer's utility decreases under the MF strategy due to higher financial costs. In contrast, Figure 9 demonstrates that the manufacturer’s utility increases with a higher MF ratio because the increased financial burden on retailers reduces the manufacturers' costs, thereby increasing their utility. This indicates a dynamic capability trade-off: retailers’ risk aversion (sensing) drives MF ratio adjustments (seizing), which in turn triggers manufacturers’ operational reconfiguration (wholesale price and emission adaptations). The balance between these capabilities determines supply chain performance. As the retailer's risk aversion increases, they tend to choose a lower MF ratio to reduce financial burdens, thereby improving their utility.

Conclusions

This study identifies optimal financing decisions for retailers in risk-averse supply chains under carbon abatement constraints. First, the impact of RLRA on retailers' optimal decisions is quantified across financing models, followed by a comparative analysis of utility under MF and MCF strategies. The study finds that manufacturers are more inclined to adopt stringent carbon reduction measures, leading to decreased carbon emissions across all financing models. Additionally, wholesale prices increase with the rise of RLRA, indicating that risk-averse retailers are more willing to accept higher costs from manufacturers, thereby enhancing supply chain stability. Under certain conditions, MF strategies provide higher utility for retailers than BCF and MCF strategies, highlighting their potential to balance risk and profitability.

Furthermore, the research shows a non-linear relationship between RLRA and retailer utility across all financing strategies: utility decreases initially with RLRA and then increases. This suggests that while moderate risk aversion can be detrimental, higher levels of risk aversion may lead retailers to make more prudent financial decisions. Conversely, the manufacturer's utility continuously increases with RLRA as higher RLRA drives wholesale prices.

These findings have significant practical implications. Firstly, retailers should assess their risk aversion levels when choosing financing strategies, as mixed financing offers substantial benefits if appropriately managed. Secondly, policymakers should design hybrid financing instruments (e.g., risk-sharing mechanisms between banks and manufacturers) to alleviate SMEs’ financial burdens under risk aversion, thereby incentivizing their participation in low-carbon supply chains. Lastly, effective coordination in pricing and financing strategies between manufacturers and retailers is crucial for optimizing overall supply chain performance. Manufacturers can leverage retailers' risk aversion to enhance their benefits while supporting retailers' financial stability.

The limitations of this study mainly include: firstly, the assumptions about market demand and financial constraints may not fully reflect the complexity of actual supply chains. Future research should incorporate more dynamic and stochastic models to capture market fluctuations and other external factors better. Secondly, the financing options considered are relatively limited. Future studies should explore other financing options, such as government grants or third-party financing platforms, to better understand optimal financing decisions. Applying the proposed models to specific industries could reveal variations in optimal financing strategies and their impact on carbon emissions and financial performance. Including more participants in the supply chain, such as suppliers and logistics providers, could provide a more holistic view of supply chain financing and emission reduction strategies.

In conclusion, this study advances our understanding of optimal financial strategies within risk-averse supply chains, particularly under carbon emission reduction constraints. The research highlights that under certain conditions, mixed financing strategies can significantly improve retailer utility by leveraging dynamic capabilities (sensing risks, seizing hybrid financing, reconfiguring operations), demonstrating their effectiveness in balancing risk and profitability. By integrating behavioral and rational decision-making models, this study clarifies how SMEs make financing decisions in the face of risk aversion and offers practical guidance for applying these theories in real-world scenarios. The findings highlight the importance of mixed financing strategies for retailers facing financial constraints and carbon reduction pressures. SMEs can stabilize operations and drive green transitions by aligning financing decisions with emission reduction goals through dynamic capability development (sensing→seizing→reconfiguring). Future research could extend the DC framework by modeling capability evolution (e.g., how sensing-seizing-reconfiguring capabilities adapt over time) and testing industry-specific applications. Policymakers should design dynamic capability-enabling incentives (e.g., risk-sharing mechanisms for seizing hybrid financing and subsidies for emission reconfiguration) to support SMEs' low-carbon transitions and supply chain coordination.

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Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Cao, E., Du, L., & Ruan, J. (2019). Financing preferences and performance for an emission-dependent supply chain: Supplier vs. bank. *International Journal of Production Economics*, *208*, 383-399. https://doi.org/10.1016/j.ijpe.2018.08.001

Cao, E., & Yu, M. (2018). Trade credit financing and coordination for an emission-dependent supply chain. *Computers & Industrial Engineering*, *119*, 50-62. https://doi.org/10.1016/j.cie.2018.03.024

Chen, J., Hou, R., Zhang, T., & Zhou, Y. (2024). Newsvendor model for a dyadic supply chain with push-pull strategy under shareholding and risk aversion. *Mathematics and Computers in Simulation*, *221*, 645-662. https://doi.org/10.1016/j.matcom.2024.03.012

Chen, J., Zheng, J., Zhang, T., Hou, R., & Zhou, Y. (2022). Dynamical complexity of pricing and green level for a dyadic supply chain with capital constraint. *Mathematics and Computers in Simulation*, *195*, 1-21. https://doi.org/10.1016/j.matcom.2021.12.015

Colombo, C., & Steenbergen, M. R. (2020). Heuristics and Biases in Political Decision Making. In *Oxford Research Encyclopedia of Politics*. https://doi.org/10.1093/acrefore/9780190228637.013.974

Hamidoğlu, A., & Weber, G.-W. (2024). A novel Nash-based low-carbon implementation in agricultural supply chain management. *Journal of Cleaner Production*, *449*, 141846. https://doi.org/10.1016/j.jclepro.2024.141846

He, X., Sethi, S., Xu, X., & Yan, N. (2024). Financing a capital-constrained supply chain: Equity or debt. *Transportation Research Part E: Logistics and Transportation Review*, *188*, 103614. https://doi.org/10.1016/j.tre.2024.103614

Huang, X. (2023). Dynamic analysis of dual-market low-carbon supply chain: Considering government intervention and joint promotion. *Journal of Cleaner Production*, *411*, 137361. https://doi.org/10.1016/j.jclepro.2023.137361

Liu, Z., Sun, W., Hu, B., Han, C., Ieromonachou, P., Zhao, Y., & Zheng, J. (2023). Research on Supply Chain Optimization Considering Consumer Subsidy Mechanism in the Context of Carbon Neutrality. *Energies*, *16*(7), 3147. https://doi.org/10.3390/en16073147

Ma, P., & Lu, Y. (2023). Operational decisions of low-carbon supply chains with triple bottom line under carbon tax policy. *Kybernetes*, *53*(5), 1888-1919. https://doi.org/10.1108/k-07-2022-1055

Meng, C., Zhang, R., & Liu, B. (2022). Energy Performance Contracting in a Supply Chain under Cap-and-Trade Regulation and Carbon Tax Policy. *International Transactions on Electrical Energy Systems*, *2022*(1), 1-10. https://doi.org/10.1155/2022/1716380

Nguyen, B., & Canh, N. P. (2020). Formal and informal financing decisions of small businesses. *Small Business Economics*, *57*(3), 1545-1567. https://doi.org/10.1007/s11187-020-00361-9

Occhipinti, Z. (2023). Environmental and Accounting Regulation: Lessons from The EU ETS. *International Journal of Academic Research in Accounting, Finance and Management Sciences*, *13*(2), 71-96. https://doi.org/10.6007/IJARAFMS/v13-i2/16597

Qi, Q., Li, S., & Zhang, R.-Q. (2023). Optimal joint decisions of production and emission reduction considering firms' risk aversion and carbon tax rate. *International Journal of Production Research*, *62*(4), 1189-1205. https://doi.org/10.1080/00207543.2023.2178833

Settembre-Blundo, D., González-Sánchez, R., Medina-Salgado, S., & García-Muiña, F. E. (2021). Flexibility and Resilience in Corporate Decision Making: A New Sustainability-Based Risk Management System in Uncertain Times. *Global Journal of Flexible Systems Management*, *22*(S2), 107-132. https://doi.org/10.1007/s40171-021-00277-7

Siemens. (2024). *Sustainability Report 2024*. https://assets.new.siemens.com/siemens/assets/api/uuid:32a7154d-edba-47bc-8e9b-9761617ba774/sustainability-report.pdf

Song, H., Wang, Y., Mao, X., & Wang, C. (2024). Decision-making in a low-carbon supply chain considering consumers' fairness concerns. *Expert Systems with Applications*, *237*, 121606. https://doi.org/10.1016/j.eswa.2023.121606

Sun, H., & Yang, J. (2021). Optimal decisions for competitive manufacturers under carbon tax and cap-and-trade policies. *Computers & Industrial Engineering*, *156*, 107244. https://doi.org/10.1016/j.cie.2021.107244

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, *18*(7), 509-533. https://doi.org/10.1002/(sici)1097-0266(199708)18:7

Thakker, S. V., Rane, S. B., & Narwane, V. S. (2024). Implementation of blockchain – IoT-based integrated architecture in green supply chain. *Modern Supply Chain Research and Applications*, *6*(2), 122-145. https://doi.org/10.1108/mscra-01-2023-0005

Tian, B., Lu, Y., Yu, L., & Chang, X. (2023). Optimal financing strategies for a risk-averse supplier under the CVaR criterion in a capital-constrained supply chain. *Journal of the Operational Research Society*, *75*(8), 1643-1661. https://doi.org/10.1080/01605682.2023.2269192

Vu, T. L., Nguyen, D. N., Luong, T. A., Nguyen, T. T. X., Nguyen, T. T. T., & Doan, T. D. U. (2022). The impact of supply chain financing on SMEs performance in Global supply chain. *Uncertain Supply Chain Management*, *10*(1), 255-270. https://doi.org/10.5267/j.uscm.2021.9.003

Wang, Y., Lin, F., Cheng, T. C. E., Jia, F., & Sun, Y. (2023). Carbon allowance approach for capital-constrained supply chain under carbon emission allowance repurchase strategy. *Industrial Management & Data Systems*, *123*(10), 2488-2521. https://doi.org/10.1108/imds-12-2022-0749

Wu, Q., Xu, X., Lin, R., & Tian, Y. (2024). Effect of risk aversion on the performance of supply chain and carbon reducing initiatives under asymmetric information. *Managerial and Decision Economics*, *45*(4), 1835-1867. https://doi.org/10.1002/mde.4080

Xie, G., Yue, W., Wang, S., & Lai, K. K. (2011). Quality investment and price decision in a risk-averse supply chain. *European Journal of Operational Research*, *214*(2), 403-410. https://doi.org/10.1016/j.ejor.2011.04.036

Xie, X., Chen, X., Xu, X., & Gu, J. (2024). Financing a dual capital-constrained supply chain: Profit enhancement and diffusion effect of default risk. *Transportation Research Part E: Logistics and Transportation Review*, *181*, 103388. https://doi.org/10.1016/j.tre.2023.103388

Xie, X., Shi, X., Gu, J., & Xu, X. (2023). Examining the Contagion Effect of Credit Risk in a Supply Chain under Trade Credit and Bank Loan Offering. *Omega*, *115*, 102751. https://doi.org/10.1016/j.omega.2022.102751

Xu, L., Xie, F., Yuan, Q., & Chen, J. (2019). Pricing and carbon footprint in a two-echelon supply chain under cap-and-trade regulation. *International Journal of Low-Carbon Technologies*, *14*(2), 212-221. https://doi.org/10.1093/ijlct/ctz013

Zang, L., Liu, M., Wang, Z., & Wen, D. (2022). Coordinating a two-stage supply chain with external failure cost-sharing and risk-averse agents. *Journal of Cleaner Production*, *334*, 130012. https://doi.org/10.1016/j.jclepro.2021.130012

Zhang, X., Li, Z., & Li, G. (2024). Grandfather-based or benchmark-based: Strategy choice for carbon quota allocation methods in the carbon neutrality era. *Renewable and Sustainable Energy Reviews*, *192*, 114195. https://doi.org/10.1016/j.rser.2023.114195

Zhen, Z., Jiang, L., & Yan, Q. (2024). The evolution of portfolio financing equilibrium in a risk-averse supply chain under a partial trade credit policy. *Finance Research Letters*, *62*, 105125. https://doi.org/10.1016/j.frl.2024.105125

Zong, S., & Huang, N. (2023). Optimal financing decision with financial constraints for a manufacturer in a low-carbon supply chain. *Environmental Science and Pollution Research*, *30*(37), 86998-87015. https://doi.org/10.1007/s11356-023-28173-w

Appendix A

Proof of proposition 1. By computing the first-order partial derivative of U_r^{BCF} in relation to p^{BCF}, the following results are derived::

$$\partial U_r^{BCF} / \partial p^{BCF} = -\theta e^{BCF} - \lambda\sigma + w^{BCF} r_b + a - 2p^{BCF} + w^{BCF}$$

Let $\partial U_r^{BCF} / \partial p^{BCF} = 0$, the selling price is obtained as:

$$p^{BCF} = \frac{-\theta e^{BCF} - \lambda\sigma + w^{BCF} r_b + a + w^{BCF}}{2}.$$

By substituting p^{BCF} into U_m^{BCF}, the Hessian matrix of U_m^{BCF} is derived, as shown below:

$$H = \begin{pmatrix} -(r_b+1) & -\frac{\theta}{2} \\ -\frac{\theta}{2} & -k \end{pmatrix}$$

The Hessian matrix of U_m^{BCF} is considered to be negative definite, provided the following condition holds true: $4k(r_b+1) - \theta^2 > 0$.

By combining $\partial U_m^{BVF} / \partial e^{BCF} = 0$ and $\partial U_m^{BCF} / \partial w^{BCF} = 0$, it can be obtained that:

$$e^{BCF*} = \frac{cr_b\theta + 4e_0kr_b - \lambda\sigma\theta - a\theta + c\theta + 4ke_0}{4kr_b - \theta^2 + 4k},$$ a

$$w^{BCF*} = \frac{2cr_bk - c\theta^2 - 2e_0k\theta + 2k\lambda\sigma + 2ak + 2ck}{4kr_b - \theta^2 + 4k}.$$

Substituting e^{BCF*} and w^{BCF*} into p^{BCF}, p^{BCF*} is obtained.

Proof of proposition 2. By computing the first-order partial derivative of U_r^{MCF} in relation to p^{MCF}, and the derivation results are as follows:

$$\partial U_r^{MCF} / \partial p^{MCF} = -\theta e^{MCF} - \lambda\sigma + w^{MCF} r_t + a - 2p^{MCF} + w^{MCF}$$

Let $\partial U_r^{MCF} / \partial p^{MCF} = 0$, the selling price is obtained as:

$$p^{MCF} = \frac{-\theta e^{MCF} - \lambda\sigma + w^{MCF} r_t + a + w^{MCF}}{2}.$$

By substituting p^{MCF} into U_m^{MCF}, the Hessian matrix of U_m^{MCF} is derived, as shown below:

$$H = \begin{pmatrix} -(r_t+1)^2 & -\frac{\theta}{2}(r_t+1) \\ -\frac{\theta}{2}(r_t+1) & -k \end{pmatrix}$$

The Hessian matrix of U_m^{MCF} is considered to be negative definite, provided the following condition holds true: $(r_t+1)^2(k - \frac{\theta^2}{4}) > 0$.

By combining $\partial U_m^{BCF} / \partial e^{BCF} = 0$ and $\partial U_m^{BCF} / \partial w^{BCF} = 0$, it can be obtained that:

$$e^{MCF*} = \frac{-\lambda\sigma\theta - a\theta + c\theta + 4ke_0}{4k - \theta^2},$$

$$w^{MCF*} = \frac{-c\theta^2 - 2e_0 k\theta + 2k\lambda\sigma + 2ak + 2ck}{-r_t\theta^2 + 4kr_t - \theta^2 + 4k}.$$

Substituting e^{MCF*} and w^{MCF*} into p^{MCF}, p^{MCF*} is obtained.

Proof of proposition 3. By computing the first-order partial derivative of U_r^{MF} in relation to p^{MF}, and the derivation results are as follows:

$$\partial U_r^{MF} / \partial p^{MF} = w^{MF}(-r_b\phi + \phi r_t + r_b + 1) - \theta e^{MF} - \lambda\sigma + a$$

Let $\partial U_r^{MF} / \partial p^{MF} = 0$, the selling price is obtained as:

$$p^{MF} = \frac{w^{MF}(-r_b\phi + \phi r_t + r_b + 1) - \theta e^{MF} - \lambda\sigma + a}{2}.$$

By substituting p^{MF} into U_m^{MF}, the Hessian matrix of U_m^{MF} is derived, as shown below:

$$H = \begin{pmatrix} ((r_b - r_t)\phi - r_b - 1)(\phi r_t + 1) & -\frac{1}{2}\theta(\phi r_t + 1) \\ -\frac{1}{2}\theta(\phi r_t + 1) & -k \end{pmatrix}$$

The Hessian matrix of U_m^{MF} is considered to be negative definite, provided the following condition holds true: $(1+\phi r_t)\left[(1+\phi r_t)\theta^2 + 4(kr_b\phi - kr_t\phi - r_bk - k)\right] < 0$.

By combining $\partial U_m^{MF} / \partial e^{MF} = 0$ and $\partial U_m^{MF} / \partial w^{MF} = 0$, it can be obtained that:

$$e^{MF*} = \frac{(\phi - 1)(r_bc\theta + 4r_be_0k) + (\phi r_t + 1)(\lambda\sigma\theta + \theta a - c\theta - 4e_0k)}{(1+\phi r_t)\theta^2 + 4(kr_b\phi - kr_t\phi - r_bk - k)},$$

$$w^{MF*} = \frac{2cr_bk(\phi - 1) + (\phi r_t + 1)(2e_0\theta k - 2\lambda\sigma k - 2ak - 2ck + c\theta^2)}{(1+\phi r_t)\left[(1+\phi r_t)\theta^2 + 4(kr_b\phi - kr_t\phi - r_bk - k)\right]}.$$

Substituting e^{MF*} and w^{MF*} into p^{MF}, p^{MF*} is obtained.

Proof of proposition 4. To find the desired results, the first-order partial derivatives of e^{BCF*}, e^{MCF*}, and e^{MF*} with regard to λ_r are computed. The resulting expressions are as follows:

$$\partial e^{BCF*} / \partial\lambda_r = \frac{-\sigma\theta}{4k(1+r_b) - \theta^2} < 0,$$

$$\partial e^{MCF*} / \partial\lambda_r = \frac{-\sigma\theta}{4k - \theta^2} < 0,$$

$$\partial e^{MF*} / \partial\lambda_r = \frac{\sigma\theta(1+\phi r_t)}{(1+\phi r_t)\theta^2 + 4k\phi(r_b - r_t) - 4k(1+r_b)} < 0.$$

Proof of proposition 5. To find the desired results, the first-order partial derivatives of w^{BCF*}, w^{MCF*}, and w^{MF*} with regard to λ_r are computed. The resulting expressions are as follows:

$$\partial w^{BCF*} / \partial\lambda_r = \frac{2k\sigma}{4k(1+r_b) - \theta^2} > 0,$$

$$\partial w^{MCF*} / \partial\lambda_r = \frac{2k\sigma}{(4k - \theta^2)(1+r_t)} > 0,$$

$$\partial w^{MF*} / \partial \lambda_r = \frac{-2k\sigma}{(1+\phi r_t)\theta^2 + 4k\phi(r_b - r_t) - 4k(1+r_b)} > 0 .$$

Proof of proposition 6. (i) Assuming $r_b = r_t = r$ and comparing the values of U_r^{MF*} and U_r^{BCF*}, it can be derived that

$$U_r^{MF*} - U_r^{BCF*} = \frac{\theta^2(Lc + e_0\theta - \lambda\sigma - a)M - Lc(4Lk - \theta^2))L(M-1)k}{M(-M\theta^2 + 4Lk)(4Lk - \theta^2)}$$

if $Lc + e_0\theta - \lambda\sigma - a < 0$, then $U_r^{MF*} > U_r^{BCF*}$ is obtained when

$$\frac{\max\{1, \min\{M_1, M_2\}\} - 1}{r} < \phi < \frac{\min\{2, \max\{M_1, M_2\}\} - 1}{r} .$$

Where $M_1 = 1$, $M_2 = \frac{Lc(4Lk - \theta^2)}{\theta^2(Lc + e_0\theta - \lambda\sigma - a)}$, $M = 1 + \phi r$, $L = 1 + r$.

(ii) Assuming $r_b = r_t = r$ and comparing the values of U_r^{MF*} and U_r^{MCF*}, it can be derived that

$$U_r^{MF*} - U_r^{MCF*} = \frac{1}{M(-M\theta^2 + 4Lk)(4k - \theta^2)}((-(e_0\theta + 7\lambda\sigma - a + c)\theta^2 k + 2\lambda\sigma\theta^4)M^2 +$$
$$(4L(2e_0\theta + 6\lambda\sigma - 2a + c)k^2 + L(-e_0\theta - 7\lambda\sigma + a)\theta^2 k)M - L^2 c\theta^2 k + 4L^2 ck^2)$$

if $2\lambda\sigma\theta^4 - (e_0\theta + 7\lambda\sigma - a + c)\theta^2 k < 0$, then $U_r^{MF*} > U_r^{BCF*}$ is obtained when

$$\frac{\max\{1, \min\{M_3, M_4\}\} - 1}{r} < \phi < \frac{\min\{2, \max\{M_3, M_4\}\} - 1}{r} .$$

Where

$$M_3 = \frac{1}{2\theta^2(2\lambda\sigma\theta^2 - e_0\theta k - 7k\lambda\sigma + ak - ck)}((e_0\theta^3 k + 7\lambda\sigma k\theta^2 - ak\theta^2 - 8e_0 k^2\theta - 24k^2\lambda\sigma$$
$$+8ak^2 - 4ck^2 + (8ck\lambda\sigma\theta^6 + e_0^2 k^2\theta^6 + 14e_0 k^2\lambda\sigma\theta^5 + 49k^2\lambda^2\sigma^2\theta^4 - 2ae_0 k^2\theta^5 - 14ak^2\lambda\sigma\theta^4 -$$
$$4ce_0 k^2\theta^5 - 60ck^2\lambda\sigma\theta^4 - 16e_0{}^2 k^3\theta^4 - 160e_0 k^3\lambda\sigma\theta^3 - 336k^3\lambda^2\sigma^2\theta^2 + a^2k^2\theta^4 + 4ack^2\theta^4$$
$$+32ae_0 k^3\theta^3 + 160ak^3\lambda\sigma\theta^2 - 4c^2k^2\theta^4 + 8ce_0 k^3\theta^3 + 56ck^3\lambda\sigma\theta^2 + 64e_0{}^2 k^4\theta^2 + 384e_0 k^4\lambda\sigma\theta + 576k^4\lambda^2\sigma^2$$
$$-16a^2k^3\theta^2 - 8ack^3t^2 - 128ae_0 k^4\theta - 384ak^4\lambda\sigma + 16c^2k^3\theta^2 + 64ce_0 k^4\theta + 192ck^4\lambda\sigma + 64a^2k^4 - 64ack^4$$
$$+16c^2k^4)^{\frac{1}{2}}) / L$$

$$M_4 = -\frac{1}{2\theta^2(2\lambda\sigma\theta^2 - e_0\theta k - 7k\lambda\sigma + ak - ck)}((-e_0\theta^3 k - 7\lambda\sigma k\theta^2 + ak\theta^2 + 8e_0 k^2\theta + 24k^2\lambda\sigma$$
$$-8ak^2 + 4ck^2 + (8ck\lambda\sigma\theta^6 + e_0^2 k^2\theta^6 + 14e_0 k^2\lambda\sigma\theta^5 + 49k^2\lambda^2\sigma^2\theta^4 - 2ae_0 k^2\theta^5 - 14ak^2\lambda\sigma\theta^4 -$$
$$4ce_0 k^2\theta^5 - 60ck^2\lambda\sigma\theta^4 - 16e_0{}^2 k^3\theta^4 - 160e_0 k^3\lambda\sigma\theta^3 - 336k^3\lambda^2\sigma^2\theta^2 + a^2k^2\theta^4 + 4ack^2\theta^4$$
$$+32ae_0 k^3\theta^3 + 160ak^3\lambda\sigma\theta^2 - 4c^2k^2\theta^4 + 8ce_0 k^3\theta^3 + 56ck^3\lambda\sigma\theta^2 + 64e_0{}^2 k^4\theta^2 + 384e_0 k^4\lambda\sigma\theta + 576k^4\lambda^2\sigma^2$$
$$-16a^2k^3\theta^2 - 8ack^3t^2 - 128ae_0 k^4\theta - 384ak^4\lambda\sigma + 16c^2k^3\theta^2 + 64ce_0 k^4\theta + 192ck^4\lambda\sigma + 64a^2k^4 - 64ack^4$$
$$+16c^2k^4)^{\frac{1}{2}}) / L$$

Proof of proposition 7. (i) Assuming $r_b = r_t = r$ and comparing the values of U_m^{MF*} and U_m^{BCF*}, it can be derived that

$$U_m^{MF*} - U_m^{BCF*} = -\frac{(L^2c^2k - c^2\theta^2(M+1)L/4 - MS(c\theta^2/2 + Sk))L(M-1)k}{8M(-M\theta^2/4 + Lk)(Lk - \theta^2/4)}$$

if $\phi < \frac{1-M_5}{r}$, then $U_r^{MF*} > U_r^{BCF*}$ is obtained Where

$$M_5 = \frac{Lc^2(4Lk - t^2)}{c^2t^2L + 2Sct^2 + 4S^2k}, M = 1 + \phi r, L = 1 + r, S = e_0\theta - \lambda\sigma - a$$

(ii) Assuming $r_b = r_t = r$ and comparing the values of U_m^{MF*} and U_m^{MCF*}, it can be derived that

$$U_m^{MF*} - U_m^{MCF*} = \frac{((-kS^2 - (S + c/2)c\theta^2/2)M + Lc^2(-\theta^2/4 + k))(-M + L)2k}{M(-M\theta^2 + 4Lk)(4Lk - \theta^2)}$$

if $\phi > \frac{1-M_6}{r}$, then $U_r^{MF*} > U_r^{MCF*}$ is obtained Where $M_6 = \frac{Lc^2(4k - t^2)}{c^2t^2 + 2Sct^2 + 4S^2k}$, $M = 1 + \phi r$, $L = 1 + r$, $S = e_0\theta - \lambda\sigma - a$