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Research Article

Optimal Operation Strategies under a Carbon Cap-and-Trade Mechanism: A Capital-Constrained Supply Chain Incorporating Risk Aversion

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Many small and medium enterprises (SMEs) with capital constraints often have no access or find it costly to obtain a loan from a bank; the retailer tends to borrow money from other enterprises in the supply chain by trade credit financing. We consider an emission-dependent supply chain with one emission-dependent manufacturer and one capital-constrained retailer in need of financing to explore the optimal operational and environmental strategies of a low-carbon supply chain under trade credit financing. We use a Stackelberg game model to depict the low-carbon supply chain. We analyse the optimal carbon-emission reduction effort, wholesale price, and order quantity in the equilibrium state. The impacts of key parameters, such as the retailer's internal working capital, the manufacturer's risk-aversion degree, and the carbon-trading price on the supply chain operation, are analysed. The results show that the retailer's capital constraint causes the carbon-emission reduction effort, wholesale price, and order quantity to improve synchronously. The supply chain achieves a win-win outcome for both the manufacturer and the retailer when the capital-constrained retailer is funded via trade credit from the manufacturer. The in-depth development of financing is beneficial to the manufacturer but is a disadvantage for the retailer. When the initial carbon-emission quota is low, the manufacturer benefits from a relatively lower carbon-trading price. Otherwise, a higher carbon-trading price is better for the manufacturer. The "carbon-trading price trap" ensures that the retailer's profit is minimal. We further investigate the scenario in which the manufacturer is risk averse and find that the retailer will purchase fewer products and that the manufacturer will gain less profit to decrease the carbon-emission reduction effort. The manufacturer's risk aversion is unfavourable to both the economic and environmental outcomes of the whole supply chain. This research provides strategic support for a low-carbon supply chain to carry out operational decisions in the context of enterprise capital constraint. To examine the theoretical results, the data used in the existing literature are further used to simulate the corresponding conclusions. Our research enriches the existing supply chain finance literature and provides decision support for the supply chain core enterprise.

1. Introduction

Carbon emissions are believed to be one of the main causes of global warming, whose costly effects have attracted significant concerns from policy makers and scholars in recent decades. To solve the problem, many nations and supranational organizations have vigorously developed a green economy and are curbing carbon emissions through legislation and economic mechanisms, such as carbon tax, carbon subsidy, and cap and trade. For example, according to China's National Plan on Climate Change (2014–2020), the Chinese government announced it would decrease its carbon dioxide emission per unit of GDP by 40 to 45 percent from 2005 to 2020. The European Council endorsed a binding EU target of at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990. There is a general consensus among policy makers and scholars regarding the need for carbon-emission reduction within supply chain activities. The supply chain is an important area of operations management and its activities have been deemed a major source of carbon emissions [1]. Given the vast carbon emissions of production processes, manufacturers play a vital role in supply chain carbon control. Although products with fewer carbon emissions are friendlier to the environment, they increase the cost of production for the manufacturers in managing carbon emissions. It is therefore important to explore the manufacturer's incentives for carbon abatement when studying operation management. In recent decades, carbon cap and trade has become one of the popular regulatory policies worldwide aimed at mitigating carbon emissions [2]. There are several famous carbon-trading markets, including the European Climate Exchange, the Chicago Climate Exchange, and the Australia Climate Exchange, among others, around the world [3]. Many studies have proved the effectiveness and efficiency of this market-based mechanism in reducing carbon emissions [4]. Specifically, producers or manufacturers are first allocated initial quotas for carbon emissions. When these are exhausted, they can then purchase or sell on carbon-trading markets to support their extra production. With such a mechanism, the amount of allocated permit quotas and the trading price (cost) of permits will significantly affect a firm's operational decisions [5].

Firms operating under capital constraints may not be able to order or produce optimally. Thus, it is important for firms to incorporate their capital situation into their operational decisions. Due to its flexibility and efficiency, trade credit has gradually become a significant means of short-term financing available to most firms and has received considerable attention in operations management research [6]. Existing studies find that trade credit is a popular financing method among subsidiaries of multinational corporations [7] and is used more widely in economies with less developed financial markets or weak bank-firm relationships. Under this financing mode, sellers extend credit, such as short-term delay in payments, to their buyers for the purchase of products. Trade credit can improve the operational performance in a traditional newsvendor model [8].

There exist many practical examples showing that, in the supply chain, the manufacturer is emission-dependent and uses trade credit to finance the retailer. For example, Walmart, as a retailing company, has been requiring its suppliers to provide trade credit [9, 10]. In addition, more than 1,000 Walmart suppliers committed to Project Gigaton have conserved an astounding 93 million metric tons of emissions through a combination of energy efficiency, renewable energy, and sustainable packaging projects. To keep pace with their commitment, the suppliers must reduce their emissions by a minimum of 83 million metric tons annually (https://www.greenbiz.com/node/112912). Some large corporations, such as HP, IBM, and Sony, even provide payment delay policies to their distributors and/or retailers [10]. They have also paid considerable attention to eliminating emissions from their supply chain, greening their products and their supply chain processes [11]. Given the increasing recognition of carbon control, it is more important to investigate the optimal decisions of supply chain members under cap-and-trade regulation and trade credit. Based on the latest developments in existing scholarship, our study aims to answer the following research questions:

(1) How does the carbon cap-and-trade mechanism affect each member's optimal operation strategy?

(2) How can the retailer's financing and internal working capital influence his or her order quantity and also influence the manufacturer's reduction of carbon emissions?

(3) What if the manufacturer were risk averse?

To answer the three questions above, a two-echelon supply chain comprising one risk-averse supplier and one capital-constrained retailer is considered. By adopting backward induction and a Stackelberg game method, we begin by solving the retailer's optimal order decision, after which the supplier's optimal trade credit contract design is analysed. The analysis thus makes a valuable contribution to the literature assessing carbon emissions across a budget-constrained supply chain structure. Moreover, this research is expected to guide the development and operation of the interface field of sustainable supply chain and supply chain finance.

The remainder of the paper is organized as follows. Section 2 reviews the related literature. Section 3 discusses the assumptions and presents notations. Section 4 formulates the models and the equilibrium decisions. Section 5 extends the model when the manufacturer is risk averse. Section 6 provides numerical examples to illustrate the previous results. The conclusion, managerial implications and future research directions are presented in Section 7.

2. Literature Review

Our study is related to three streams of research. The first stream studies firms' operational decisions in a low-carbon supply chain; the second stream investigates firms' operational decisions under capital constraint; and the third stream analyses the impacts of risk aversion on operations management.

2.1. Low-Carbon Supply Chain. Carbon emission is an important factor since its cost can change the optimal configuration of the supply chain. Some researchers have addressed this problem from an operation management perspective. From the point of view of pricing and production decisions, Xu et al. [12, 13] explored the joint production and pricing problem of the supply chain with the cap-and-trade regulation. Feng et al. [14] studied the influence of the government's carbon tax policy and the retailer's risk-averse attitude on optimal pricing and carbon-emission reduction decisions of the supply chain. Du et al. [15] explored the impacts of the carbon footprint and low-carbon preference on the manufacturer's production strategy under the cap-and-trade regulation. From an inventory perspective, Hua et al. [4] investigated how firms manage carbon footprints in inventory management under the carbon-trading regulation. Benjaafar et al. [16] developed relatively simple models under low-carbon policies, including strict emission caps, taxes on emissions, cap-and-offset, and cap and trade, to examine their impact on production and inventory decisions. Consumers also play an important role at the end of the supply chain. Du et al. [17] and Xia et al. [18] analysed the impact of consumers' preferences for low carbon in the emission-concerned supply chain and found that the decision maker of the supply chain would choose different emission-reduction strategies for different cases. Scholars also studied carbon emission-reduction strategies in different supply chain structures. Wang et al. [19], He et al. [20], Ji et al. [21], and Yang et al. [22] focused on the reduction of carbon emissions driven by cap-and-trade regulation in the dual-channel supply chain, dual-channel closed supply chain, O2O retail supply chain, and competing supply chains, respectively. In addition, He et al. [23] addressed the impact of cap-and-trade regulation on a firm's carbon-emission decisions. They noted that the differentiated permits' trading prices play a decisive role in a firm's decisions regarding optimal emissions and permit trading. Ren et al. [11] focused on the emission-abatement decisions in the make-to-order supply chain.

In short, almost all the abovementioned papers are restricted to the well-funded supply chain while neglecting to consider the capital-constrained mode. Therefore, our paper addresses these limitations in current research by studying the supply chain members' emission-reduction behaviours from the perspective of a capital-constrained supply chain.

2.2. Capital-Constrained Supply Chain. Given the importance of capital flow to operational decisions, scholars have carried out significant research on the integrated field of operation and finance. Buzacott and Zhang [24] explored the inventory decision-making problem under asset financing. Chao et al. [25] and Protopappa-Sieke and Seifert [26] analysed the impacts of firms' capital constraint on the stochastic inventory control problem. Yang et al. [27] found three effects of retailer bankruptcy-predation, bail out, and abetment effects. Feng et al. [28] and Yan and Wang [29] analysed the newsboy ordering problem under capital-constraint and information-update conditions. Wang et al. [30] found that a manufacturer's capital constraint can encourage him to produce much higher quality remanufacture products. To sum up, an enterprise's capital constraint has a profound impact on that enterprise's traditional operation decision-making.

When facing capital constraints, a retailer fails to procure or order optimally, which not only significantly influences his or her own profitability but also harms the competitiveness of the upstream manufacturer. Therefore, as a core firm of a supply chain, the manufacturer generally has an incentive to offer trade credit to alleviate the retailer's capital constraint problem. As a financing tool, trade credit has received extensive attention in the supply chain finance literature. Scholars have extended their research to the supply chain level. Gupta and Wang [31] analysed the impacts of trade credit period on the optimal inventory decision of the supply chain. Luo et al. [32] further extended the research on trade credit finance to include information asymmetry and found that information asymmetry creates an uncoordinated supply chain. Lee and Rhee [33] and Chen and Wang [34] research found that trade credit finance plays an active role in supply chain coordination. In addition, scholars designed new contracts to achieve the coordination of the trade credit supply chain. For example, Zhang et al. [35] designed a quantity discount contract to coordinate the trade credit supply chain, while Wu et al. [10] extended research to the one-supplier/two-retailers structure mode, analysing the impact of retail market competition on trade credit financing.

In addition, financing mode comparison is another hot topic of concern to researchers. Current research compared trade credit finance and bank finance. For example, Chen [36] found that trade credit makes both channel members better off and forms a unique financing equilibrium. Jing et al. [37], Cai et al. [38], and Kouvelis and Zhao [39] found that firms' financing mode selection decisions are determined by factors such as production cost, capital market competition degree, and enterprise credit rating, respectively. Yang et al. [40] compared delay-in-payment and supply chain carbon finance; they found that a supply chain carbon finance pattern can help increase the emission-reduction rate of the whole supply chain. As we can see, most studies on supply chain finance are primarily aimed at the traditional supply chain, with little research on the impact of capital constraint on the low-carbon supply chain.

2.3. Risk Aversion. These studies remain incomplete, as they have not considered the impact of decision-makers' risk preference behaviour. A financing system's members must bear part of the financing risk, and their risk preference plays a crucial role in operational decision-making [41]. However, few have experienced the impact of decision makers' risk preference on the equilibrium and coordination of the financing system. The most widely used risk measure criteria are mean-variance (MV), value at risk (VaR), and conditional value at risk (CVaR). In particular, CVaR has a number of advantages in terms of its ability to reflect excess losses, its applicability to nonnormal distributions, and its equivalence to the convex programming, which has emerged as a practical approach to modelling risk aversion, with widespread applications in economics, finance, and insurance [42, 43]. Earlier, Gotoh and Takano [44] applied CVaR to the operation management field and used it to describe the impact of Newsvendors' risk aversion on optimal inventory decision-making. Chen et al. [41] further analysed the joint decision of price and inventory in a risk-averse setting. In follow-up studies, scholars have considered the impact of target management [45], supply uncertainty [46], and partial demand information [47] on the risk-averse buyer's optimal decision. Yang et al. [48] expanded research to the supply chain level to analyse the supply chain coordination and sales discount strategies in a risk-averse setting. Furthermore, researchers have made innovations primarily in the supply chain structure, such as the three-tier [49] and dual-channel supply chains [50]. Yang et al. [51], considering the supplier and the retailer to be risk averse, investigated the impact of firms' risk-averse attitudes on supply chain performance. They also designed three-part tariff revenue sharing and buy-back contracts to achieve the Pareto optimality maximizing the combined supply chain CVaR. However, their research work assumes that all supply chain members are capital adequate. To sum up, although existing research has included the impact of decision makers' risk preference on the operational decision with a CVaR criterion, few have considered a firm's capital situation. Related conclusions are no longer applicable to the widespread supply chain with capital-constrained enterprises.

2.4. Our Contributions. Our contributions can be summarized as follows. (1) We obtain the equilibrium joint decisions of the operation, environment, and finance of the low-carbon supply chain. (2) We explore the impacts of enterprise capital constraint on the carbon-emission decision of the supply chain. (3) We extend the interface of operation and finance to the low-carbon supply chain, which breaks through the limitations of current research. (4) Current research has only considered the financing choice of one participant (the manufacturer or the retailer), whereas our study discusses the financing choice game between the manufacturer and the retailer. (5) We analysed the impacts of a manufacturer's risk attitude on the low-carbon and budget-constrained supply chain.

3. Model Description and Notations

This model investigates a make-to-order supply chain consisting of one manufacturer M (described as "she") and one retailer R (described as "he") under a carbon cap-and-trade regulation. The manufacturer is constrained by the carbon cap-and-trade regulation as the principal source of carbon emissions and organizes the production of a certain type of product according to the retailer's orders. The retailer is capital constrained and in need of financing, for which trade credit financing is viable. Similar to Wu et al. [10], Zhang et al. [35], Jing et al. [37], Cai et al. [38], and Kouvelis and Zhao [39], we assume that the retailer follows the "lot-for-lot" policy and that the retail price p to customers is constant, which is a common assumption in the related literature.

The optimal strategy of the manufacturer is to maximize its own profit by properly setting the wholesale price w to the retailer and level of carbon-emissions reduction effort e under carbon cap-and-trade regulation. The optimal strategy of the retailer is to maximize its profit by properly choosing the order quantity q. The manufacturer produces products with cost c. The market demand X is stochastic in $[0, +\infty]$. If the market demand does not exceed the retailer's order quantity q, the retailer must dispose the unsold products with salvage value s per unsold product. When the demand is too low, here we set the threshold θ; when the market demand is in $[0, \theta]$, the retailer will go bankrupt. Under the carbon cap-and-trade mechanism, the manufacturer initially obtains a certain number of carbon emission quotas e_g over a governmental scheme. The carbon emissions per unit product of the manufacturer is e_0. If carbon emissions exceed (are below) the manufacturer's carbon cap, she can buy (sell) carbon emission quotas in the carbon market at a carbon-trading price per unit product of t. The manufacturer can choose to invest in carbon-emission reduction technology or project; we use e to represent the level of carbon-emission reduction per unit product of the manufacturer. After making efforts to reduce carbon emissions, the corresponding cost is $(1/2)ke^2$, where k is a constant, which is called the carbon emission cost coefficient [12, 14, 18, 21].

The retailer's internal working capital is η. To order a q unit of product, the retailer's required capital amount is wq. Obviously, when $\eta \geq wq$, the retailer is well funded (Mode A). When $\eta < wq$, the retailer is capital constrained and can opt to obtain financing via trade credit (Mode T). The loan size is $(wq - \eta)^+$ under trade credit. Since the manufacturer can gain interest by charging a higher wholesale price, we assumed the interest rate to be zero, which means that the retailer will need to repay $(wq - \eta)$ at the end of the marketing period. There remains the case whereby the retailer cannot be financed by trade credit, so we use Mode N to denote the retailer being capital constrained but without access to trade credit. Here, we neglect the case of the retailer financed by a bank. In practice, many firms, especially SMEs, often have no access or find it costly to obtain a bank loan.

We use $i, i = M, R$ to denote the decision maker, $j, j = T, A, N$ to denote the capital mode, and $l, l = A, N$ to denote the no credit-trading mode. The major notations used in this paper are listed in Table 1. The sequence of events is illustrated by Figure 1.

According to the abovementioned hypotheses, the manufacturer's and the retailer's expected profit functions in Mode l (represented in the cases of both Mode A and Mode N) and Mode T are expressed as follows:

$$
\begin{aligned}
\Pi_R^l &= \left(p - w^l\right)q^l - (p - s)\int_0^{q^l} F(x)\mathrm{d}x, \\
\Pi_M^l &= \left(w^l - c\right)q^l - t\left(\left(e_0 - e^l\right)q^l - e_g\right) - \frac{1}{2}k\left(e^l\right)^2, \\
\Pi_R^T &= -\eta + (p - s)\int_\theta^{q^T} \overline{F}(x)\mathrm{d}x, \\
\Pi_R^T &= \left(p - w^T\right)\int_\theta^{q^T} F(x)\mathrm{d}x - (p - s)\left(q^T - \int_\theta^{q^T} F(x)\mathrm{d}x\right) \\
&\quad - w^T q^T - \eta, \\
\Pi_M^T &= \left(w^T - c\right)q^T - t\left(\left(e_0 - e^T\right)q^T - e_g\right) - \frac{1}{2}k\left(e^T\right)^2 \\
&\quad - (p - s)\int_0^{\theta} F(x)\mathrm{d}x.
\end{aligned}
\tag{1}
$$

In the supply chain operation system, the manufacturer and the retailer launch a Stackelberg game, with the manufacturer as the leader.

Table 1: Major notations and explanations.

Notation	Explanation
c	The cost per unit product of the manufacturer
w^l	The wholesale price per unit product decided by the manufacturer when a retailer adopts no credit-trading (decision variable)
w^T	The wholesale price per unit product decided by the manufacturer when a retailer adopts credit-trading (decision variable)
p	The retail price per unit product of the retailer
X	Market demand
θ	The threshold of market demand: when the demand is lower than the threshold, the retailer will be bankrupt
$F(x)$	The cumulative distribution function of market demand
$\overline{F}(x)$	The complementary cumulative distribution function of market demand
$q^{A(N)}$	The ordering quantity decided by the retailer when the retailer adopts no credit-trading (decision variable)
q^T	The ordering quantity decided by the retailer when the retailer adopts credit-trading (decision variable)
s	The salvage value per unsold product
e_g	The initial carbon cap (carbon quotas) of the manufacturer
e_0	The carbon emissions per unit product of the manufacturer
e	The carbon-emissions reduction per unit product of the manufacturer
t	The carbon-trading price per unit product of the manufacturer
η	The internal working capital of the retailer
k	The carbon emission cost coefficient
Π_M^l	The total profit of the manufacturer when the retailer adopts no credit-trading
Π_R^l	The total profit of the retailer when the retailer adopts no credit-trading
Π_R^T	The total profit of the manufacturer when the retailer adopts credit-trading
Π_M^T	The total profit of the retailer when the retailer adopts credit-trading

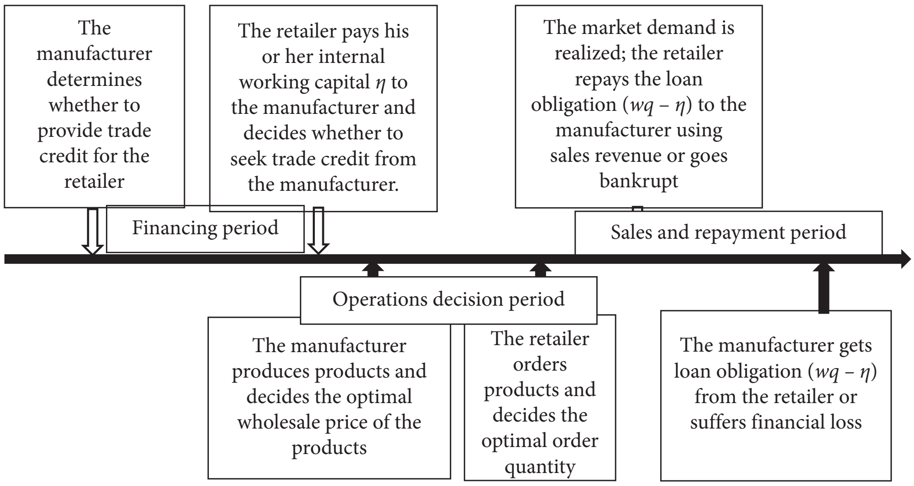

Figure 1: The sequence of events.

4. Equilibrium Analysis

We now analyse the equilibrium decision of the supply chain. The optimal production volume and carbon-emission effort in a centralized supply chain satisfy the following lemma.

Lemma 1. *The optimal order quantity of the retailer q^0 and the optimal carbon-emission reduction per unit product of the manufacturer e^0 in a centralized supply chain satisfy*

$$(p-c)-(p-s)F\left(q^0\right)-t\left(e_0-\frac{tq^0}{k}\right)=0, \tag{2}$$

$$e^0=\frac{tq^0}{k}. \tag{3}$$

4.1. Equilibrium Decision. In a decentralized supply chain, the manufacturer first decides the optimal wholesale price and carbon-emission reduction effort level. Then, the retailer decides the optimal order quantity. The optimal equilibrium operation decisions under different capital situations can be obtained by applying the Backward Induction Method. We first analyse the equilibrium decision in Mode A.

Proposition 1. *When $t<\sqrt{k\left(q^{A*}f'\left(q^{A*}\right)+2(p-s)f\left(q^{A*}\right)\right)}$, the optimal equilibrium decisions of Mode A can be obtained by*

$$\begin{aligned}\left(q^{A*},w^{A*},e^{A*}\right)=&\left(F^{-1}\left(\frac{p-w^{A*}}{p-s}\right),c\right.\\&\left.+\tau_R(p-s)q^{A*}f\left(q^{A*}\right),\frac{tq^{A*}}{k}\right).\end{aligned} \tag{4}$$

Proof. Computing

$$\frac{\mathrm{d}^2\Pi_R^A}{\mathrm{d}\left(q^A\right)^2} = -(p-s)f\left(q^A\right) < 0, \tag{5}$$

yields that Π_R^A is a concave function with respect to q^A. Next, solving

$$\frac{\mathrm{d}\Pi_R^A}{\mathrm{d}q^A} = \left(p - w^A\right) - (p-s)F\left(q^A\right) = 0, \tag{6}$$

we can obtain the optimal order decision in Mode A, that is,

$$q^{A*} = F^{-1}\left(\frac{p - w^{A*}}{\tau_R k}\right). \tag{7}$$

The abovementioned equation is equivalent to

$$w^{A*} = p - (p-s)F\left(q^A\right). \tag{8}$$

We then obtain

$$\Pi_M^A = \left(w^{A*}\left(q^A\right) - c\right)q^A - t\left(\left(e_0 - e^A\right)q^A - e_g\right) - \frac{1}{2}k\left(e^A\right)^2. \tag{9}$$

The first-order condition of Π_M^A with respect to q^A is

$$\frac{\mathrm{d}\Pi_M^A}{\mathrm{d}q^A} = (p-s)\overline{F}\left(q^A\right)\left[1 - \frac{q^A f\left(q^A\right)}{\overline{F}\left(q^A\right)}\right] - (c-s) - t\left(e_0 - e^A\right). \tag{10}$$

Let $q_1 = \{q^A \mid (q^A f(q^A)/\overline{F}(q^A)) = 1\}$. It is obvious to see that $1 - (q^A f(q^A)/\overline{F}(q^A))$ is decreasing and positive in $[0, q_1]$, which means that $(\mathrm{d}\Pi_M^A/\mathrm{d}q^A) \geq 0$ in $[0, q_1]$. In $[q_1, +\infty]$, $1 - (q^A f(q^A)/\overline{F}(q^A))$ is decreasing and negative, and

$$\frac{\mathrm{d}\Pi_M^A}{\mathrm{d}q^A} < \left.\frac{\mathrm{d}\Pi_M^A}{\mathrm{d}q^A}\right|_{q^A = q_1} = -(c-s) - t\left(e_0 - e^A\right) < 0. \tag{11}$$

The abovementioned analysis shows that Π_M^A is a concave function with respect to q^A. That is $(\mathrm{d}^2\Pi_M^A/\mathrm{d}(q^A)^2) < 0$. The determinant of the Hessian Matrix

$$\begin{aligned} &\frac{\mathrm{d}^2\Pi_M^A}{\mathrm{d}\left(q^A\right)^2}\frac{\mathrm{d}^2\Pi_M^A}{\mathrm{d}\left(e^A\right)^2} - \frac{\mathrm{d}^2\Pi_M^A}{\mathrm{d}q^A e^A}\frac{\mathrm{d}^2\Pi_M^A}{\mathrm{d}e^A q^A} \\ &\quad = k\left(q^A f'\left(q^A\right) + 2(p-s)f\left(q^A\right)\right) - t^2 > 0, \end{aligned} \tag{12}$$

if and only if $t < \sqrt{k(q^A f'(q^A) + 2(p-s)f(q^A))}$.

By solving

$$\begin{cases} \dfrac{\mathrm{d}\Pi_M^A}{\mathrm{d}q^A} = (p-s)\overline{F}\left(q^A\right)\left[1 - \dfrac{q^A f\left(q^A\right)}{\overline{F}\left(q^A\right)}\right] - (c-s) - t\left(e_0 - e^A\right) = 0, \\ \dfrac{\mathrm{d}\Pi_M^A}{\mathrm{d}e^A} = tq^A - ke^A = 0, \end{cases} \tag{13}$$

we can obtain the optimal decisions, which satisfy Proposition 1. ☐

We then analyse the optimal decision in Mode N. The following proposition is established.

Proposition 2. *The equilibrium decisions of Mode N are*

$$\left(w^{N*}, q^{N*}, e^{N*}\right) = \left(w_1, \frac{\eta}{w_1}, \frac{tq^{N*}}{k}\right). \tag{14}$$

Proof. Limited by budgetary constraints, the retailer can only make an order using the initial capital η. His or her order is η/w^N. At this moment, the manufacturer's utility function changes to

$$\Pi_M^N = \left(w^N - c\right)\frac{\eta}{w^N} - t\left(\left(e_0 - e^N\right)q^N - e_g\right) - \frac{1}{2}k\left(e^N\right)^2. \tag{15}$$

It is easy to see that Π_M^N is a concave function with respect to e^N, and the optimal carbon-emission reduction e^{N*} can be obtained by solving the first-order condition $(\mathrm{d}\Pi_M^N/\mathrm{d}e^N) = 0$, that is, $e^{N*} = ((tq^{N*})/k)$.

It is then easy to obtain $((\mathrm{d}\Pi_M^N(w^N, e^{N*}(w^N), q^{N*}(w^N)))/\mathrm{d}w^N) < 0$ when $w > (\eta t^2/(kc + e_0 t))$ and $(\mathrm{d}\Pi_M^N(w^N, e^{N*}(w^N), q^{N*}(w^N))/\mathrm{d}w^N) > 0$, otherwise. That is, $\Pi_M^N(w^N)$ is first a decreasing and then an increasing function with respect to w^N. The optimal wholesale price w^{N*} can only be obtained at the endpoint of the effective decision interval of Mode N. Assume that the effective decision interval is N (the concrete form of domain N will be described in Table 2). Given the other parameters, let w_1 and w_2 denote the left point and the right point of N, respectively. Then, $w^{N*} = w_1$ when $\Pi_M^N(w_1) > \Pi_M^N(w_2)$ and $w^{N*} = w_2$, otherwise.

Next, we analyse Mode T. The following conclusion is established. That is, when parameters satisfy

$$\begin{aligned} &(p-s)\Big\{\Big(\left(w^T - c - t\left(e_0 - e^T\right) - \left(w^T - s\right)F(\theta)\right)\left((p-s) - \left(w^T - s\right)q^{T*}H(\theta)\right) + \left(w^T - s\right)q^{T*}\overline{F}(\theta)\left(\left(w^T - s\right)H(\theta) - (p-s)H\left(q^{T*}\right)\right)\Big)'_{w^T} \\ &\left(\left(w^T - s\right)\left(\left(w^T - s\right)H(\theta) - (p-s)H\left(q^{T*}\right)\right)\right) - \Big(\left(w^T - c - t\left(e_0 - e^T\right) - \left(w^T - s\right)F(\theta)\right)\left((p-s) - \left(w^T - s\right)q^{T*}H(\theta)\right) \\ &\quad + \left(w^T - s\right)q^{T*}\overline{F}(\theta)\left(\left(w^T - s\right)H(\theta) - (p-s)H\left(q^{T*}\right)\right)\Big) \times \left(\left(w^T - s\right)\left(\left(w^T - s\right)H(\theta) - (p-s)H\left(q^{T*}\right)\right)\right)'_{w^T}\Big\}/ \\ &\left(\left(w^T - s\right)^2\left(\left(w^T - s\right)H(\theta) - (p-s)H\left(q^{T*}\right)\right)^2\right)^{-1} > t^2, \end{aligned} \tag{16}$$

Table 2: The occurrence conditions of different capital modes can be formulated.

Conditions			Equilibrium result
$w^{T*}q^{T*} < w^{A*}q^{A*}$	$\eta < w^{T*}q^{T*}$	$\Pi_M^{T*} > \Pi_M^{N*}, \Pi_R^{T*} > \Pi_R^{N*}$	T
		$\Pi_M^{N*} > \Pi_M^{T*}$ or $\Pi_R^{N*} > \Pi_R^{T*}$	N
	$w^{T*}q^{T*} < \eta < w^{A*}q^{A*}$		N
	$\eta > w^{A*}q^{A*}$		A
$w^{A*}q^{A*} < w^{T*}q^{T*}$	$\eta < w^{A*}q^{A*}$	$\Pi_M^{T*} > \Pi_M^{N*}, \Pi_R^{T*} > \Pi_R^{N*}$	T
		$\Pi_M^{N*} > \Pi_M^{T*}$ or $\Pi_R^{N*} > \Pi_R^{T*}$	N
	$\eta > w^{A*}q^{A*}$		A

the equilibrium decisions in Mode T satisfy Proposition 3. ☐

Proposition 3. *If $f(x)/\overline{F}(x)$ is a concave function, the equilibrium decisions of Mode T can be determined by*

$$(p-s)\overline{F}\left(q^{T*}\right) = \left(w^{T*}-s\right)\overline{F}\left(\theta\left(q^{T*}, w^{T*}\right)\right), \tag{17}$$

$$ke^{T*} = tq^{T*}, \tag{18}$$

$$\begin{aligned}&\left(w^{T*}-c-t\left(e_0-e^{T*}\right)-\left(w^{T*}-s\right)F(\theta)\right)\left((p-s)-\left(w^{T*}-s\right)q^{T*}H(\theta)\right)+\\&\left(w^{T*}-s\right)q^{T*}\overline{F}(\theta)\left(\left(w^{T*}-s\right)H(\theta)-(p-s)H\left(q^{T*}\right)\right)=0.\end{aligned} \tag{19}$$

Proof. By

$$\begin{aligned}\frac{\mathrm{d}^2\Pi_R^T}{\mathrm{d}^2\left(q^T\right)^2} &= -\overline{F}\left(q^T\right)\left[\frac{(p-s)f\left(q^T\right)}{\overline{F}\left(q^T\left(q^T\right)\right)}-\frac{\left(w^T-s\right)^2 f(\theta)}{(p-s)\overline{F}\left(q^T\right)}\right]\\&= -\overline{F}\left(q^T\right)\left[\frac{(p-s)f\left(q^T\right)}{\overline{F}\left(q^T\right)}-\frac{\left(w^T-s\right)f(\theta)}{\overline{F}(\theta)}\right]\\&< -\left(w^T-s\right)\overline{F}\left(q^T\right)\left[\frac{f\left(q^T\right)}{\overline{F}\left(q^T\right)}-\frac{f(\theta)}{\overline{F}(\theta)}\right]<0,\end{aligned} \tag{20}$$

we can see that Π_R^T is concave in q^T. q^{T*} can be obtained by solving

$$\frac{\mathrm{d}\Pi_R^T}{\mathrm{d}q^T} = (p-s)\overline{F}\left(q^T\right)-\left(w^T-s\right)\overline{F}\left(\theta\left(q^T, w^T\right)\right)=0. \tag{21}$$

Substituting $q^{T*}(w^T)$ into Π_M^T yields that $\Pi_M^T = (w^T-c)q^{T*}(w^T) - (p-s)\int_0^{\theta(q^{T*}(w^T), w^T)} F(x)\mathrm{d}x - t((e_0-e^N)q^{T*}(w^T) - e_g) - (1/2)k(e^N)^2$. Solving the first-order condition of Π_M^T with respect to w^T derives that

$$\begin{aligned}\frac{\mathrm{d}\Pi_M^T}{\mathrm{d}w^T} &= \left(w^T-c-t\left(e_0-e^T\right)-\left(w^T-s\right)F(\theta)\right)\frac{\mathrm{d}q^{T*}}{\mathrm{d}w^T}+q^{T*}(1-F(\theta))\\&= \frac{\left\{\left(w^T-c-t\left(e_0-e^T\right)-\left(w^T-s\right)F(\theta)\right)\left((p-s)-\left(w^T-s\right)q^{T*}H(\theta)\right)+\left(w^T-s\right)q^{T*}\overline{F}(\theta)\left(\left(w^T-s\right)H(\theta)-(p-s)H\left(q^{T*}\right)\right)\right\}}{\left(w^T-s\right)\left(\left(w^T-s\right)H(\theta)-(p-s)H\left(q^{T*}\right)\right)}\\&= \frac{\left(w^T-s\right)(p-s)\overline{F}(\theta)\left(1-q^{T*}H\left(q^{T*}\right)\right)}{\left(w^T-s\right)\left(\left(w^T-s\right)H(\theta)-(p-s)H\left(q^{T*}\right)\right)}-\frac{\left((p-s)-\left(w^T-s\right)q^{T*}H\left(q^{T*}\right)\right)(c-s)}{\left(w^T-s\right)\left(\left(w^T-s\right)H(\theta)-(p-s)H\left(q^{T*}\right)\right)}\\&= \left[\frac{\left(w^T-s\right)(p-s)\overline{F}(\theta)\left(1-q^{T*}H\left(q^{T*}\right)\right)}{(p-s)-\left(w^T-s\right)q^{T*}H(\theta)}-\left(c+t\left(e_0-e^T\right)-s\right)\right]\times\frac{\mathrm{d}q^{T*}}{\mathrm{d}w^T},\end{aligned} \tag{22}$$

as $(w^T-s)(p-s)\overline{F}(\theta)$ is increasing in w^T. To prove the monotonicity of $\mu(w^T)$, we only need to prove the monotonicity of

$$\varphi\left(w^T\right) = \frac{1-q^{T*}H\left(q^{T*}\right)}{(p-s)-\left(w^T-s\right)q^{T*}H(\theta)}, \tag{23}$$

for w^T. First, we have

$$\frac{\mathrm{d}\theta\left(w^T\right)}{\mathrm{d}w^T}-\frac{\mathrm{d}q^{T*}\left(w^T\right)}{\mathrm{d}w^T}=\frac{q^{T*}\left(w^T\right)-\left(p-w^T\right)\left(\mathrm{d}q^{T*}\left(w^T\right)/\mathrm{d}w^T\right)}{k}>0. \tag{24}$$

Then, $(\mathrm{d}H(q^{T*})/\mathrm{d}q^{T*}) > (\mathrm{d}H(\theta)/\mathrm{d}\theta)$ is established because $f(x)/\overline{F}(x)$ is an incremental function. Solving the first-order condition yields

$$\begin{aligned}
\frac{\mathrm{d}\varphi(w^T)}{\mathrm{d}w^T} &= (\{[-H(q^{T*})(\mathrm{d}q^{T*}/\mathrm{d}w^T) - q^{T*}(\mathrm{d}H(q^{T*})/\mathrm{d}q^{T*}) \cdot (\mathrm{d}q^{T*}/\mathrm{d}w^T)][(p-s) - (w^T - s)q^{T*}H(\theta)] \\
&\quad -(1 - q^{T*}H(q^{T*}))(-(w^T - s)H(\theta)(\mathrm{d}\theta/\mathrm{d}w^T) - (w^T - s)q^{T*}(\mathrm{d}H(\theta)/\mathrm{d}\theta) \cdot (\mathrm{d}\theta/\mathrm{d}w^T) \\
&\quad \cdot ((w^T - s)/(p-s)))\})(((p-s) - (w^T - s)q^{T*}H(\theta))^2)^{-1} \\
&> (\{(1 - q^{T*}H(q^{T*}))[-(p-s)H(q^{T*})(\mathrm{d}q^{T*}/\mathrm{d}w^T) - (p-s)q^{T*}(\mathrm{d}H(q^{T*})/\mathrm{d}q^{T*}) \\
&\quad \cdot (\mathrm{d}q^{T*}/\mathrm{d}w^T) + (w^T - s)H(\theta)(\mathrm{d}\theta/\mathrm{d}w^T) + (w^T - s)q^{T*}(\mathrm{d}H(\theta)/\mathrm{d}\theta) \cdot (\mathrm{d}\theta/\mathrm{d}w^T) \cdot ((w^T - s)/(p-s))]\}) \\
&\quad \cdot (((p-s) - (w^T - s)q^{T*}H(\theta))^2)^{-1} \\
&> (\{(1 - q^{T*}H(q^{T*}))[-(p-s)H(q^{T*}) - (p-s)q^{T*}(\mathrm{d}H(q^{T*})/\mathrm{d}q^{T*}) + (w^T - s)H(\theta) \\
&\quad + ((w^T - s)^2 q^{T*}/p - s)(\mathrm{d}H(\theta)/\mathrm{d}\theta)](\mathrm{d}q^{T*}/\mathrm{d}w^T)\})(((p-s) - (w^T - s)q^{T*}H(\theta))^2)^{-1} \\
&> 0,
\end{aligned} \tag{25}$$

which indicates that $\varphi(w^T)$ is increasing in w^T. Obviously, $\mu(w^T)$ is also increasing in w^T.

(1) When $w^T \longrightarrow p$, we obtain $\theta(q^{T*}, w^T) \longrightarrow q^{T*}$, which is established according to the equation $(p-s)\overline{F}(q^{T*}) = (w^T - s)\overline{F}(\theta)$. At this moment,

$$\begin{aligned}
\mu(w^T) \longrightarrow (p-s)\overline{F}(q^{T*}) &> (p-s)\overline{F}(q^{T0}) \\
&= c + t(e_0 - e^T) - s.
\end{aligned} \tag{26}$$

That is, $(\mathrm{d}\Pi_M^T/\mathrm{d}w^T) < 0$ is established.

(2) We assume that w_L is the minimum value of w^T in the effective interval $(w_L > c)$. When $w^T \longrightarrow w_L$, there exists no double marginal effect in the supply chain. At this time, we have $q^{T*} \longrightarrow q^{T0}$. Using Proposition 4, we have

$$1 - q^{T*}(w^T)H(q^{T*}(w^T)) \longrightarrow 1 - q^{T0}H(q^{T0}) \longrightarrow 0. \tag{27}$$

That is, $\mu(w^T) \longrightarrow 0$, $(\mathrm{d}\Pi_M^T/\mathrm{d}w^T) \longrightarrow (-c - t(e_0 - e^T) + s)\ ((\mathrm{d}q^{T*}(w^T))/\mathrm{d}w^T) > 0$.

The abovementioned analysis indicates that Π_M^T is a unimodal function with respect to w^T when $w^T \in [w_L, p]$.

Based on the abovementioned analysis, we can see that, regardless of the kind of capital mode, the manufacturer's carbon-emission effort level is always proportional to the retailer's order quantity and the carbon-trading price and is inversely proportional to the coefficient of scale carbon-emission reduction cost. This is because the increase in the retailer's order quantity signifies the increase in the manufacturer's production quantity, which leads to an increase in carbon emissions. The manufacturer must pay more for the excess carbon emissions. To decrease the carbon-trading cost, the manufacturer chooses to improve the carbon-emission reduction effort to increase the carbon-emission reduction amount. With the increase in carbon-trading price, the manufacturer can lower its carbon-trading cost and even benefit from carbon trading by implementing carbon-emission reduction. As a result, the increase in carbon-trading price encourages the manufacturer to improve its carbon-emission reduction efforts. Conversely, the carbon-emission reduction invested cost increases with the increase of k, which also dampens the manufacturer's carbon-emission reduction enthusiasm.

We analysed the abovementioned equilibrium decisions of different capital modes. We now further analyse the impacts of a retailer's capital amount on the equilibrium decision. □

4.2. Impacts of Retailer's Initial Capital

Lemma 2

(i) q^{T*} and e^{T*} are decreasing in w^T. (ii) Given w^T, q^{T*}, and e^{T*} are increasing in η, and Π_R^{T*} is decreasing in η.

Proof. Because

$$(p-s)\overline{F}(\theta)-\left(w^{T}-s\right)q^{T*}f(\theta)>(p-s)\left(\overline{F}\left(q^{T*}\right)-q^{T*}f\left(q^{T*}\right)\right)>(p-s)\left(\overline{F}\left(q^{T0}\right)-q^{T0}f\left(q^{T0}\right)\right)=0, \tag{28}$$

we obtain

$$\begin{aligned}\frac{\mathrm{d}q^{T*}}{\mathrm{d}w^{T}}&=-\frac{(p-s)\overline{F}(\theta)-(w^{T}-s)q^{T*}f(\theta)}{(p-s)^{2}f(q^{T*})-(w^{T}-s)^{2}f(\theta)}<0,\\ \frac{\mathrm{d}q^{T*}}{\mathrm{d}\eta}&=-\frac{(w^{T}-s)f(\theta)}{(p-s)^{2}f(q^{T*})-(w^{T}-s)^{2}f(\theta)}<0,\\ \frac{\mathrm{d}\Pi_{R}^{T*}}{\mathrm{d}\eta}&=\left(\left(p-w^{T}\right)-\left((p-s)F\left(q^{T*}\right)-\left(w^{T}-s\right)F(\theta)\right)\right)\frac{\mathrm{d}q^{T*}}{\mathrm{d}\eta}\\ &\quad-F(\theta)<0.\end{aligned} \tag{29}$$

It is easy to understand that q^{T*} and e^{T*} are decreasing in w^{T}. However, why are q^{T*} and e^{T*} increasing in η? The reason is as follows. The retailer with low internal working capital faces a high bankruptcy risk. We have shown that the retailer goes bankrupt when the market demand X is in $[0,\theta]$. Thus, the lower the η, the higher the θ; the greater the retailer's bankruptcy risk is, the higher the amount of money the retailer does not have to repay to the manufacturer and the more the retailer benefits from the manufacturer's risk sharing are. The retailer's expected utility function can reflect this idea. As we can see,

$$\begin{aligned}\Pi_{R}^{T}=-\eta+(p-s)\int_{\theta}^{q^{T}}\overline{F}(x)\mathrm{d}x&=\left(p-w^{T}\right)q^{T}\\ &\quad-(p-s)\int_{\theta}^{q^{T}}F(x)\mathrm{d}x.\end{aligned} \tag{30}$$

The lower the η, the higher the θ, risk sharing of the manufacturer and utility of the retailer. The retailer tends to order more products, thus benefiting from the manufacturer's risk sharing. Thus, the manufacturer needs to produce more products. Hence, more carbon is emitted and the manufacturer will expend more efforts to implement carbon-emission reduction. Thus, the manufacturer's optimal carbon-emission reduction amount increases in the retailer's internal working capital. Therefore, trade credit has a positive effect on environmental benefits. We then further analyse the impact of a retailer's internal working capital on the low-carbon supply chain operation. The results can be shown as follows. □

Proposition 4. *When* $\eta\longrightarrow 0$, $q^{T*}\longrightarrow q^{T0}$, $e^{T*}\longrightarrow e^{T0}$, $\Pi_{M}^{T*}\longrightarrow \Pi^{T0}$,

$$\begin{aligned}&\Pi_{R}^{T*}\longrightarrow 0,\\ &q^{T*}f\left(q^{T*}\right)-\overline{F}\left(q^{T*}\right)\longrightarrow q^{T0}f\left(q^{T0}\right)-\overline{F}\left(q^{T0}\right)=0.\end{aligned} \tag{31}$$

Corollary 1. *There exists* $\widehat{\eta}$ *to produce* $0<\eta<\widehat{\eta}$,

$$\begin{aligned}&q^{T*}>q^{A*}>q^{N*},\\ &e^{T*}>e^{A*}>e^{N*},\\ &\Pi_{M}^{T*}>\Pi_{M}^{A*}>\Pi_{M}^{N*},\\ &\Pi_{R}^{A*}>\max\left\{\Pi_{R}^{T*},\Pi_{R}^{N*}\right\}.\end{aligned} \tag{32}$$

The abovementioned results indicate that when a retailer's internal working capital is close to 0, the retailer's order quantity, the manufacturer's carbon-emission reduction effort, and the manufacturer's expected profit are closed to the centralized order, the centralized carbon-emission effort, and the centralized profit, respectively. Thus, the in-depth development of trade credit finance benefits the manufacturer, the environment, and the whole supply chain. However, it is worth noting that when the retailer's internal working capital approaches 0, the retailer's expected profit also approaches 0. This implies that too much reliance on financing is bad for the retailer.

The following reasons can be used to interpret the abovementioned phenomena. As Lemma 2 shows, the risks undertaken by the retailer and the manufacturer decrease and increase as the retailer's internal working capital decreases, respectively. Therefore, the manufacturer compensates for the risk loss by increasing the wholesale price. From the retailer's perspective, the decrease in η has two effects: the manufacturer's risk-sharing effect benefits the retailer, while the wholesale price's increasing effect damages the retailer. It is worth noting that θ and the risk-sharing effect of the manufacturer increases in q^{T}. The retailer will increase the order quantity to improve the risk-sharing effect. However, when η is low enough, the bankruptcy risk of the retailer also becomes high. The manufacturer then sets a high wholesale price to cover the retailer's default risk. At this time, the manufacturer benefits from increases in order quantity and wholesale price. Her profit increases with respect to the decrease in the retailer's initial capital. Nevertheless, an excessive wholesale price hurts the retailer's interest when the retailer's initial capital amount is low.

The abovementioned analysis shows that the retailer's capital constraint (trade credit finance) is beneficial to the manufacturer and the supply chain, which can be a win-win situation for both the economic and environmental benefits of the supply chain. The manufacturer should actively provide financing for budget-constrained retailers and give priority to financing retailers low on cash.

Proposition 4 and Lemma 2 analysed the impacts of retailer capital constraint on the supply chain operation in Mode T. Nevertheless, what is the occurrence condition for each capital mode? We arrive at the following conclusion.

Table 2 can be interpreted as follows. Obviously, $w^{A*}q^{A*}$ is the critical point for the retailer capital constraint. When $\eta>w^{A*}q^{A*}$, the retailer is well funded and Mode A occurs. When $\eta<w^{A*}q^{A*}$, only when $\eta<w^{T*}q^{T*}$ is satisfied can the retailer also be capital constrained in Mode T (his financing amount will be $w^{T*}q^{T*}-\eta$). We must therefore compare $w^{T*}q^{T*}$ and $w^{A*}q^{A*}$. When $w^{T*}q^{T*}<w^{A*}q^{A*}$, the retailer can obtain trade credit financing when $\eta<w^{T*}q^{T*}$. However,

only when all profits of the manufacturer and retailer in Mode T are higher than those in Mode N, that is, $\Pi_M^{T*} > \Pi_M^{N*}$ and $\Pi_R^{T*} > \Pi_R^{N*}$, can Mode T occur. In other words, as long as one side chooses Mode N (the manufacturer never provides financing or the retailer does not participate in the financing), Mode T will not occur. The equilibrium capital mode will then be Mode N. When $w^{T*}q^{T*} < \eta < w^{A*}q^{A*}$, the retailer is capital adequate compared with Mode A, but is capital constrained compared with Mode T. Obviously, the retailer can obtain no trade credit finance at this time. The equilibrium capital mode is then also Mode N. Similar to the abovementioned analysis, we can also obtain the equilibrium capital mode when $w^{A*}q^{A*} < w^{T*}q^{T*}$ and η changes. The concrete descriptions are omitted.

Using the abovementioned analysis, this paper focuses on discussing the influence of capital constraint on the low-carbon supply chain. We now further analyse the impacts of the carbon-trading price. Applying Envelope Theorem,

$$\frac{\mathrm{d}\Pi_M^{T*}}{\mathrm{d}t} = \left.\frac{\partial \Pi_M^{T*}}{\partial t}\right|_{w^T = w^{T*}} = -\left(\left(e_0 - e^{j*}\right)q^{j*} - e_g\right), \tag{33}$$

which yields the following proposition.

Proposition 5. *When* $e_g < (e_0 - e^{j*})q^{j*}$, Π_M^{j*} *is decreasing in* t*; when* $e_g > (e_0 - e^{j*})q^{j*}$, Π_M^{j*} *is increasing in* t.

When the initial carbon quotas are low, the manufacturer must purchase a carbon emission amount from the carbon-trading market. Therefore, the manufacturer's profit decreases in the carbon-trading price t. When the initial carbon quotas are high, the manufacturer can benefit from carbon sales. Her profit increases in the carbon-trading price.

5. Impacts of Manufacturer Risk Aversion

In a traditional capital-sufficient supply chain, the manufacturer need not bear a market risk. Her risk attitude has no bearing on the operation decision. Conversely, the manufacturer must bear the retailer's bankruptcy risk in Mode T. One must discuss the impacts of a manufacturer's risk attitude on optimal operation decision-making.

In conclusion, the common risk measurement criteria include Mean-Variance, VaR, and CVaR. Compared with Mean-Variance and VaR, CVaR is more effective. It can reflect excess losses, applicability to nonnormal distributions, and equivalence to convex programming [42, 43]. Thus, we use CVaR criteria to depict the manufacturer's risk attitude.

Definition 1. Let $\alpha_M \in [0,1]$ denote the manufacturer's risk preference factor, π_M^T denote the manufacturer's profit respecting market demand, and

$$\xi_{\alpha_M}\left(\pi_M^T\left(w^T, X\right)\right) = \sup\left\{v_M^T \,\middle|\, \Pr\left[\pi_M^T\left(w^T, X\right) \le v_M^T\right] \le \alpha_M\right\}, \tag{34}$$

denote the fractile quantile. The manufacturer's conditional value at risk (CVaR) can be expressed by

$$\alpha_M - \text{CVaR: } C\left(\pi_M^T\left(w^T, X\right)\right) = E\left[\pi_M^T\left(w^T, Z\right) \,\middle|\, \pi_M^T\left(w^T, X\right) \le \xi_{\alpha_M}\left(\pi_M^T\left(w^T, X\right)\right)\right]. \tag{35}$$

Let $u_M^T(w^T, v_M^T) = v_M - (1/\alpha_M)E[v_M^T - \pi_M^T(w^T, X)]^+$.

After a brief derivation, we can see that the manufacturer's CVaR utility can be simplified by

$$\text{CVaR}\left(\pi_M^T\left(w^T, X\right)\right) = \max_{v_M^T \in \mathfrak{R}}\left\{v_M^T - \frac{1}{\alpha_M}E\left[v_M^T - \pi_M^T\left(w^T, X\right)\right]^+\right\} = \max_{v_M \in \mathfrak{R}} u_M^T\left(w^T, v_M^T\right). \tag{36}$$

Lemma 3. *There exists an optimal fractile quantile to obtain*

$$\text{CVaR}\left(\pi_M^T\right) = u_M^T\left(w^T, v_M^{T*}\right). \tag{37}$$

Thus,

$$v_M^{T*} = \begin{cases} z_2, & \text{if } \theta\left(q^T, w^T\right) < F^{-1}\left(\alpha_M\right), \\ z_1 + kF^{-1}\left(\alpha_M\right), & \text{if } \theta \ge F^{-1}\left(\alpha_M\right), \end{cases}$$
$$z_2 = \left(w^T - c\right)q^T > z_1 = \eta - (c - s)q^T. \tag{38}$$

Proof. The manufacturer's profit function is

$$\pi_M^T = \begin{cases} \eta + pX + s\left(q^T - X\right) - cq^T, & \text{if } 0 < X < \theta, \\ \left(w^T - c\right)q^T, & \text{if } X \ge \theta. \end{cases} \tag{39}$$

According Definition 1, u_M^T can be expressed by

$$u_M^T\left(q^T, v_M^T\right) = v_M^T - \frac{1}{\alpha_M}\left(\int_0^\theta \left(\left(v_M^T - z_1\right) - (p-s)x\right)^+ f(x)\mathrm{d}x + \int_\theta^{+\infty} \left(v_M^T - z_2\right)^+ f(x)\mathrm{d}x\right)$$
$$= \begin{cases} (1)\ v_M^T, & \text{if } v_M^T \le z_1, \\ (2)\ v_M^T - \dfrac{1}{\alpha_M}\left(\displaystyle\int_0^{\left(v_M^T - z_1\right)/(p-s)} \left(\left(v_M^T - z_1\right) - (p-s)x\right) f(x)\mathrm{d}x\right), & \text{if } z_1 < v_M^T \le z_2, \\ (3)\ v_R^T - \dfrac{1}{\alpha_M}\left(\displaystyle\int_0^\theta \left(v_M^T - z_1\right) f(x)\mathrm{d}x + \int_\theta^{+\infty} \left(v_M^T - z_2\right) f(x)\mathrm{d}x\right), & \text{if } v_M^T \ge z_2. \end{cases} \quad (40)$$

We then analyse the concavity of $u_M^T(q^T, v_M^T)$. Solving the second condition of $u_M^T(q^T, v_M^T)$ with respect to v_M^T yields

$$0 \ge \frac{\partial^2 u_M^T(q^T, v_M^T)}{\partial \left(v_M^T\right)^2} = \begin{cases} -\dfrac{1}{\alpha_M (p-s)} f\left(\dfrac{v_M^T - z_1}{p-s}\right), & \text{if } z_1 \le v_M^T \le z_2, \\ 0, & \text{others}. \end{cases} \quad (41)$$

This implies that $u_M^T(q^T, v_M^T)$ is a concave function with respect to v_M^T. Solving the first-order condition of $u_M^T(q^T, v_M^T)$ in v_M^T yields

$$\frac{\partial u_M^T(q^T, v_M^T)}{\partial v_M^T} = \begin{cases} 1, & v_M^T \le z_1, \\ 1 - \dfrac{1}{\alpha_M} F\left(\dfrac{v_M^T - z_1}{p-s}\right), & z_1 \le v_M^T \le z_2, \\ 1 - \dfrac{1}{\alpha_M}, & v_M^T \ge z_2. \end{cases} \quad (42)$$

The optimal fractile quantile can by determined by

$$v_M^{T*} = \begin{cases} z_1 + (p-s)F^{-1}(\alpha_M), & \text{if } \theta \ge F^{-1}(\alpha_M), \\ z_2, & \text{if } \theta < F^{-1}(\alpha_M). \end{cases} \quad (43)$$

The corresponding CVaR utility function is

$$\mathrm{CVaR}\left(\pi_M^T\right) = \begin{cases} (w^T - c)q^T - \dfrac{1}{\alpha_M}(p-s)\displaystyle\int_0^\theta F(x)\mathrm{d}x, & \text{if } \theta < F^{-1}(\alpha_M), \\ \eta - (c-s)q^T + (p-s)F^{-1}(\alpha_M) - \dfrac{1}{\alpha_M}(p-s)\displaystyle\int_0^{F^{-1}(\alpha_M)} F(x)\mathrm{d}x, & \text{if } \theta \ge F^{-1}(\alpha_M). \end{cases} \quad (44)$$

It is obvious to see that $(\partial CVaR\ (\pi_M^T)/\partial w^T) = -(c + t(e_0 - e^T) - s)(\partial q^T/\partial w^T) > 0$ in Case 2 of equation (43). That is, $\mathrm{CVaR}(\pi_M^T)$ is increasing in w^T.

Analysing Case 1 of equation (43), we can see that $\mathrm{CVaR}(\pi_M^T)$ is a joint differentiable concave function with respect to w^T and e^T. There is optimal w^{T*} and e^{T*} to make $\mathrm{CVaR}(\pi_M^T)$ reach the maximum point. After solving the first-order conditional equations and analysing the size of the Hessian matrix of $\mathrm{CVaR}(\pi_M^T)$ with respect to w^T and e^T, we can obtain that when

$$\begin{aligned}
&\Big((p-s)\Big\{\Big(\Big(w^{T}-c-t\big(e_0-e^{T}\big)-\Big(\frac{1}{\alpha_M}\Big)\big(w^{T}-s\big)F(\theta)\Big)\big((p-s)\big)-\big(w^{T}-s\big)q^{T*}H(\theta)\big)+\big(w^{T}-s\big)q^{T*}\Big(1-\Big(\frac{1}{\alpha_M}\Big)F(\theta)\Big)\\
&\big(\big(w^{T}-s\big)H(\theta)-(p-s)H\big(q^{T*}\big)\big)\big)\Big)_{w^{T}}{}'\big(\big(w^{T}-s\big)\big(\big(w^{T}-s\big)H(\theta)-(p-s)H\big(q^{T*}\big)\big)\big)\\
&\quad-\Big(\Big(w^{T}-c-t\big(e_0-e^{T}\big)-\Big(\frac{1}{\alpha_M}\Big)\big(w^{T}-s\big)F(\theta)\Big)\big((p-s)-\big(w^{T}-s\big)q^{T*}H(\theta)\big)+\big(w^{T}-s\big)q^{T*}\Big(1-\Big(\frac{1}{\alpha_M}\Big)F(\theta)\Big)\\
&\big(\big(w^{T}-s\big)H(\theta)-(p-s)H\big(q^{T*}\big)\big)\big)\times\big(\big(w^{T}-s\big)\big(\big(w^{T}-s\big)H(\theta)-(p-s)H\big(q^{T*}\big)\big)\big)_{w^{T}}{}'\Big\}\Big/\Big(\big(w^{T}-s\big)^{2}\big(\big(w^{T}-s\big)H\\
&(\theta)-(p-s)H\big(q^{T*}\big)\big)^{2}\Big)^{-1}>t^{2},
\end{aligned}\tag{45}$$

the equilibrium decision of the supply chain satisfies the following proposition. □

Proposition 6. *If $f(x)/\overline{F}(x)$ is a concave function, the equilibrium decision of Mode T can be determined by*

$$(p-s)\overline{F}\big(q^{T*}\big)=\big(w^{T*}-s\big)\overline{F}\big(\theta\big(q^{T*},w^{T*}\big)\big),\tag{46}$$

$$ke^{T*}=tq^{T*},\tag{47}$$

$$\begin{aligned}
&\Big(w^{T*}-c-t\big(e_0-e^{T*}\big)-\frac{1}{\alpha_M}\big(w^{T*}-s\big)F(\theta)\Big)\big((p-s)-\big(w^{T*}-s\big)q^{T*}H(\theta)\big)+\\
&\big(w^{T*}-s\big)q^{T*}\Big(1-\frac{1}{\alpha_M}F(\theta)\Big)\big(\big(w^{T*}-s\big)H(\theta)-(p-s)H\big(q^{T*}\big)\big)=0.
\end{aligned}\tag{48}$$

Proposition 7. *Π_M^{T*} is increasing in α_M.*

Proposition 7 indicates that the manufacturer's risk-averse attitude harms her. Although adopting a risk-aversion measure can reduce the manufacturer's risk, it can also lead to a decrease in her profit. This is because the risk faced by the manufacturer is the default risk of the retailer. The default risk is caused primarily by the excessive order behaviour of the retailer (the more the retailer's orders are excessive, the more credit he or she must obtain from the manufacturer and the higher the probability that the retailer cannot repay the full credit). The risk-averse manufacturer tends to make conservative decisions, for example, increasing the wholesale price to restrain the retailer's excessive order to avoid losses caused by the retailer's bankruptcy. Nevertheless, the decrease in order also signals a decrease in the manufacturer's sales volume, which leads to a decrease in the manufacturer's expected utility. Meanwhile, the manufacturer's risk-aversion behaviour also leads to a decrease in her carbon-emission reduction effort. It is thus evident that the manufacturer's risk-averse behaviour causes adverse effects on both economic and environmental benefits.

6. Numerical Studies

We have analysed a capital-constrained low-carbon supply chain operation in theory. To further illustrate and expand the abovementioned results, we present some numerical examples in this section. Some parameters are established as follows: $p=8$, $c=3$, $s=2$, $k=2$, $e_0=e_g=10$, and $t=0.2$. The market demand X obeys normal distribution. The mean and variance are set by 50 and 20, respectively.

We first carry out a sensitivity analysis for η; see Figures 2–4.

(1) As we can see, when the retailer's initial capital is high, e.g., $\eta>\eta_2$, the retailer's own funds are sufficient to make an order; then, Mode A occurs. When $\eta<\eta_2$, the retailer is capital constrained. The optimal strategy for the retailer is to seek financing. However, as we can see, the retailer's initial capital interval ($\eta\in[\eta_1,\eta_2]$) makes the retailer whose capital amount is in this range unable to obtain financing. This is because the manufacturer's profit in Mode N is higher than that in Mode T at this time. Thus, the manufacturer refuses to provide financing for the capital-constrained retailer. Therefore, the equilibrium capital mode is Mode N when $\eta\in[\eta_1,\eta_2]$. When η is low enough, financing can bring a win-win situation to both the manufacturer and the retailer ($\Pi_M^{T*}>\Pi_M^{N*}$ and $\Pi_R^{T*}>\Pi_R^{N*}$ are established at his or her time). Thus, the equilibrium financing mode is Mode T.

(2) Observing Mode T, we can see that Π_M^{T*} and Π_R^{T*} are increasing and decreasing with respect to the decrease in η, respectively. In particular, when η approaches 0

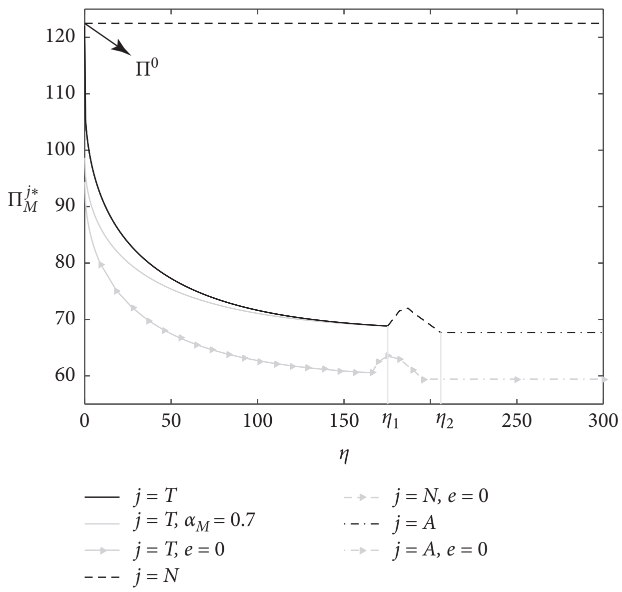

Figure 2: Impacts of the retailer's internal working capital on the manufacturer's profit.

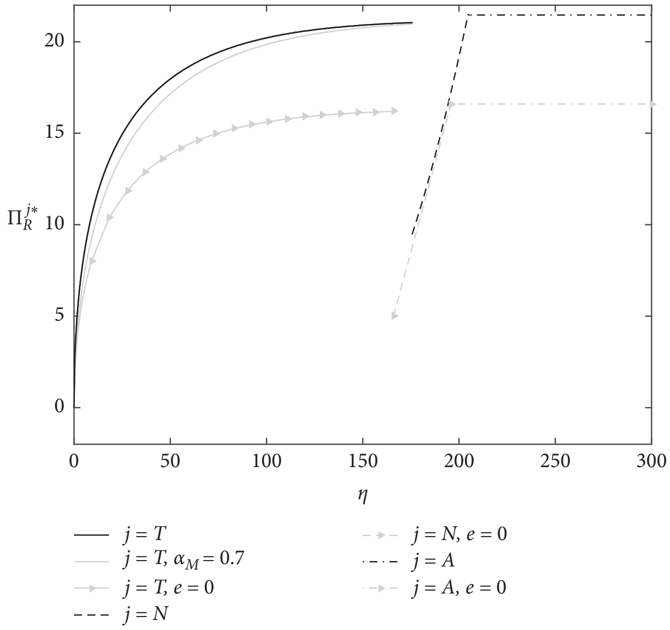

Figure 3: Impacts of the retailer's internal working capital on the retailer's profit.

($\eta \longrightarrow 0$), Π_M^{T*} increases to the centralized supply chain profit level ($\Pi_M^{T*} \longrightarrow \Pi^0$). Nevertheless, the retailer's profit decreases to 0. Tracing it to its cause, the decrease in the retailer's internal working capital has two effects: a risk-sharing effect and a wholesale price-increasing effect. The manufacturer's risk-taking ratio rises with the decrease in η. In particular when $\eta \longrightarrow 0$, all the market risks are borne by the manufacturer. The retailer will order more because the manufacturer bears his or her risks. Lastly, the increases in both the order and in wholesale price lead to an increase in the manufacturer's expected profit. However, the wholesale price's increase and the over-order behaviour lead to a decrease in the retailer's profit. In particular when $\eta \longrightarrow 0$, the retailer loses all bargaining power and all supply chain profits are garnered by the manufacturer. That is, the more the retailer relies on financing, the worse his barging power is. Although financing is beneficial to the retailer ($\Pi_R^{T*} > \Pi_R^{N*}$), he or she should not rely too much on financing. Nevertheless, from the manufacturer's perspective, she should not avoid financing the capital-constrained retailer and should choose a low-cash retailer as her object of the financial support.

(3) Figure 4 shows that the carbon-emission reduction effort is highest in Mode T and, in turn, in Modes A

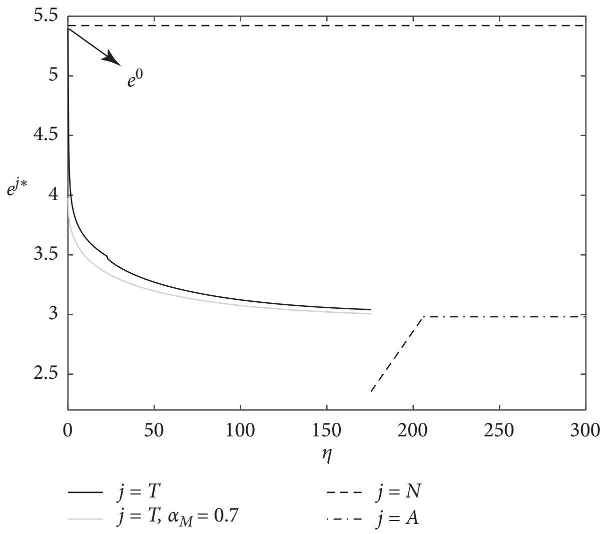

Figure 4: Impacts of the retailer's internal working capital on carbon-emission reduction.

Table 3: Impacts of the carbon-trading price on the supply chain operation.

t			$e_g = 10$					$e_g = 500$		
	0.1	0.2	0.3	0.4	0.5	0.1	0.2	0.3	0.4	0.5
w^{T*}	7.14	7.24	7.27	7.22	7.05	7.14	7.24	7.27	7.22	7.05
e^{T*}	1.79	3.47	5.14	6.98	9.21	1.79	3.47	5.14	6.98	9.21
q^{T*}	34.85	34.65	34.25	34.91	36.83	34.85	34.65	34.25	34.91	36.83
Π_M^{T*}	110.46	85.52	66.90	54.25	48.32	159.46	183.52	213.90	250.25	293.32
Π_R^{T*}	20.48	17.42	16.49	18.03	23.31	20.48	17.42	16.49	18.03	23.31
Π^*	130.94	102.94	83.39	72.28	71.63	179.94	200.94	230.39	268.28	316.63

and N. This phenomenon illustrates that the retailer's capital constraint has a positive effect on the environment; for the retailer low in cash, financing can have both environmental and economic benefits. When $\eta \in [\eta_1, \eta_2]$, the manufacturer can obtain a higher profit in Mode N than in mode T, but at the expense of environmental benefits.

(4) Compared with the noncarbon-emission reduction mode $(e = 0)$, implementing carbon-emission reduction can achieve a win-win situation for supply chain members $(\Pi_M^{j*} > \Pi_M^{j*}|_{e=0}, \Pi_R^{j*} > \Pi_R^{j*}|_{e=0})$. This is because implementing carbon-emission reduction decreases the manufacturer's carbon-purchasing cost, which in turn, leads a decrease in the manufacturer's overall operating costs. The manufacturer will then choose to decrease the wholesale price, which encourages the retailer to increase his or her order. Therefore, regardless of the kind of capital mode, implementing carbon-emission reduction helps realize environmental and economic win-win situations.

(5) Figures 2–4 show that the manufacturer's carbon-emission reduction effort and the manufacturer's and the retailer's profits all decrease according to the degree of the manufacturer's risk aversion. This phenomenon occurs because the risk-averse manufacturer tends to make a more conservative decision, e.g., it increases the wholesale price to reduce the retailer's excessive order behaviour. As a result, the double marginal effect increases, which leads to a decrease in the supply chain social welfare. Therefore, the manufacturing enterprise should choose its operational decision maker more rationally so as to avoid excessive risk aversion.

Fixing $\eta = 30$ and $\alpha_M = 1$, we then carry out a sensitivity analysis to the carbon-trading price t (see Table 3).

The results show that, with the increase in carbon-trading price, the wholesale price first increases and then decreases. The order quantity first decreases and then increases. The carbon-emission reduction effort increases. The retailer's profit first decreases and then increases. The manufacturer's and the supply chain's profits decrease and increase according to the decrease in carbon-trading price when the manufacturer's initial carbon quota is low and high, respectively.

Tracing it to its cause, the manufacturer's carbon-emission reduction effort increases according to the carbon-trading price. When the carbon price is below a critical point, the manufacturer compensates for the invested carbon-emission reduction cost by increasing the wholesale price. The order quantity decreases as a result. When the carbon price is higher than the critical point, the manufacturer can benefit from carbon trading. The manufacturer then chooses to lower the wholesale price, which leads to an increase in the retailer's order. Therefore, the retailer's order quantity first increases and then decreases according to the increase in the carbon-trading price.

Furthermore, analysis shows that the manufacturer's profit decreases and increases in relation to the carbon price when the initial carbon quota is low and high, respectively. This is because the manufacturer must spend substantial funds to buy the carbon quota when her initial carbon quota is low. Conversely, she can sell the excess carbon quota to the carbon-trading market. Thus, a higher carbon price benefits her at this time.

From the retailer's perspective, regardless of how the initial carbon quota changes, the retailer's expected profit first decreases then increases in relation to the carbon price. That is, when the carbon price is in the medium position, the retailer's gains are lowest. This phenomenon is caused by the manufacturer making a higher wholesale price when the carbon-trading price is medium. Thus, there is a "low-income trap" in the carbon-trading market for the retailer. We can also see that the initial capital quota has no effect on the operational decisions regarding wholesale price, carbon-emission reduction effort, or order quantity.

It is thus clear that, from an environmental perspective, a higher carbon price is better. From an economics perspective, a higher carbon price is better when the initial carbon quota is high. The government should release carbon quotas for the manufacturer as much as possible, as this will not only improve the manufacturer's carbon-emission reduction initiative but also enhance the manufacturer's profit. The carbon-trading price should be properly regulated. A higher carbon price can mean a win-win situation for the manufacturer, retailer, supply chain, and environment.

7. Conclusion and Remarks

As climate change has become more visible in recent years, SMEs are starting to feel greater regulatory and social pressure to adopt environmental strategies [40]. Enterprises' capital flow seriously affects their operation and management. This paper explores the impacts of capital constraint on their carbon-emission reduction operation strategy. We first provide the manufacturer's optimal carbon-emission reduction operational strategy when the retailer is capital constrained. We also analyse the impacts of key parameters such as the retailer's internal working capital and the manufacturer's risk attitude to operational decision-making.

The results show that (1) the retailer's capital constraint can help encourage the manufacturer to improve its carbon-emission reduction efforts while improving the overall revenue of the supply chain, thus achieving a win-win situation for both the environment and economics. (2) Financing helps achieve a win-win situation between the manufacturer and retailer. The in-depth development of trade credit finance benefits the manufacturer but is bad for the retailer. (3) When the initial carbon quota is low, the manufacturer benefits from a relatively lower carbon-trading price. Conversely, she benefits from a higher carbon price.

This research has managerial implications for the development of low-carbon supply chain finance.

The results of our study confirm that manufacturers are more likely to pursue carbon-emission reduction and offer credit to their retailers as a part of their strategy for increasing their corporate financial performance. The results of our study also show that a developed market credit system is crucial for the economic and environmental performance of the supply chain.

Our research has a number of policy and managerial implications. (1) The manufacturer should improve its wholesale price and carbon-emission reduction efforts when the retailer is capital constrained. The retailer should improve the order quantity. (2) The manufacturer should provide financing for a retailer low in cash and should not be too risk averse. (3) The retailer should provide more self-owned funds when participating in trade credit financing. He or she should pay attention to the carbon-trading price and avoid falling into the "price trap." (4) The government should take measures to activate the carbon-trading market to promote the carbon-trading price.

This research provides a theoretical basis for decision makers to implement low-carbon supply chain management from the perspective of the interface of operations and finance. It has positive driving significance for the development of a sustainable supply chain. However, some limitations leave room for future research.

First, we investigate the case in which the retailer is assumed to be capital constrained and financed by the manufacturer through trade credit. In practice, the manufacturer may limit the retailer's credit line to control the potential loss risk. As a result, the capital-constrained retailer may adopt other financing tools, such as bank credit, to satisfy his or her financing needs. Thus, one possible direction is to consider a capital-constrained retailer that can be financed by a bank or a manufacturer. Second, this paper only examines a manufacturer constrained by the carbon cap-and-trade regulation as the principal source of carbon emission. Actually, retailers must also consider the environmental impact caused by their packaging and distribution processes. Retailers may also be confronted with environmental regulations. Thus, another possible direction is to study an emission-dependent supply chain comprising more manufactures and retailers in which both manufacturers and retailers must abide by a carbon-emission policy.

Data Availability

In this study, we use the theoretical model method to carry out our research. Our conclusions are obtained primarily by using theoretical deduction and numerical study. Of these, numerical study data are derived from the author's assumptions, also illustrated in Figures 2–4 and Table 2. We thereby declare that no further external data were used to support this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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References

[1] Q. Qi, J. Wang, and Q. Bai, "Pricing decision of a two-echelon supply chain with one supplier and two retailers under a carbon cap regulation," *Journal of Cleaner Production*, vol. 151, no. 5, pp. 286–302, 2017.

[2] J. Sun, Z. Wang, and G. Li, "Measuring emission-reduction and energy-conservation efficiency of Chinese cities considering management and technology heterogeneity," *Journal of Cleaner Production*, vol. 175, no. 2, pp. 561–571, 2018.

[3] B. Zhang and L. Xu, "Multi-item production planning with carbon cap and trade mechanism," *International Journal of Production Economics*, vol. 144, no. 1, pp. 118–127, 2013.

[4] G. Hua, T. C. E. Cheng, and S. Wang, "Managing carbon footprints in inventory management," *International Journal of Production Economics*, vol. 132, no. 2, pp. 178–185, 2011.

[5] Z. Wang, B. Zhang, and H. Zeng, "The effect of environmental regulation on external trade: empirical evidences from Chinese economy," *Journal of Cleaner Production*, vol. 114, no. 2, pp. 55–61, 2016.

[6] J. R. Stokes, "Dynamic cash discounts when sales volume is stochastic," *The Quarterly Review of Economics and Finance*, vol. 45, no. 1, pp. 144–160, 2005.

[7] E. Cao and M. Yu, "Trade credit financing and coordination for an emission-dependent supply chain," *Computers & Industrial Engineering*, vol. 119, no. 5, pp. 50–62, 2018.

[8] Y.-G. Zhong and Y.-W. Zhou, "Improving the supply chain's performance through trade credit under inventory-dependent demand and limited storage capacity," *International Journal of Production Economics*, vol. 143, no. 2, pp. 364–370, 2013.

[9] Y.-W. Zhou, Y. Zhong, and J. Li, "An uncooperative order model for items with trade credit, inventory-dependent demand and limited displayed-shelf space," *European Journal of Operational Research*, vol. 223, no. 1, pp. 76–85, 2012.

[10] D. Wu, B. Zhang, and O. Baron, "A trade credit model with asymmetric competing retailers," *Production and Operations Management*, vol. 28, no. 1, pp. 206–231, 2019.

[11] J. Ren, Y. Bian, X. Xu, and P. He, "Allocation of product-related carbon emission abatement target in a make-to-order supply chain," *Computers & Industrial Engineering*, vol. 80, no. 2, pp. 181–194, 2015.

[12] J. Xu, Y. Chen, and Q. Bai, "A two-echelon sustainable supply chain coordination under cap-and-trade regulation," *Journal of Cleaner Production*, vol. 135, no. 1, pp. 42–56, 2016.

[13] X. Xu, P. He, H. Xu, and Q. Zhang, "Supply chain coordination with green technology under cap-and-trade regulation," *International Journal of Production Economics*, vol. 183, no. 1, pp. 433–442, 2017.

[14] Y. Feng, J. Shen, and X. Li, "Pricing and carbon emission reduction decisions in a supply chain with a risk-averse retailer under carbon tax regulation," *Mathematical Problems in Engineering*, vol. 2020, Article ID 5351867, 9 pages, 2020.

[15] S. Du, L. Hu, and M. Song, "Production optimization considering environmental performance and preference in the cap-and-trade system," *Journal of Cleaner Production*, vol. 112, no. 20, pp. 1600–1607, 2016.

[16] S. Benjaafar, Y. Li, and M. Daskin, "Carbon footprint and the management of supply chains: insights from simple models," *IEEE Transactions on Automation Science and Engineering*, vol. 10, no. 1, pp. 99–116, 2013.

[17] S. Du, J. Zhu, H. Jiao, and W. Ye, "Game-theoretical analysis for supply chain with consumer preference to low carbon," *International Journal of Production Research*, vol. 53, no. 12, pp. 3753–3768, 2015.

[18] L. Xia, T. Guo, J. Qin, X. Yue, and N. Zhu, "Carbon emission reduction and pricing policies of a supply chain considering reciprocal preferences in cap-and-trade system," *Annals of Operations Research*, vol. 268, no. 1-2, pp. 149–175, 2018.

[19] X. Wang, M. Xue, and L. Xing, "Analysis of carbon emission reduction in a dual-channel supply chain with cap-and-trade regulation and low-carbon preference," *Sustainability*, vol. 10, no. 3, p. 580, 2018.

[20] R. He, Y. Xiong, and Z. Lin, "Carbon emissions in a dual channel closed loop supply chain: the impact of consumer free riding behavior," *Journal of Cleaner Production*, vol. 134, no. 1, pp. 384–394, 2016.

[21] J. Ji, Z. Zhang, and L. Yang, "Comparisons of initial carbon allowance allocation rules in an O2O retail supply chain with the cap-and-trade regulation," *International Journal of Production Economics*, vol. 187, no. 5, pp. 68–84, 2017.

[22] L. Yang, Q. Zhang, and J. Ji, "Pricing and carbon emission reduction decisions in supply chains with vertical and horizontal cooperation," *International Journal of Production Economics*, vol. 191, no. 6, pp. 286–297, 2017.

[23] P. He, W. Zhang, X. Xu, and Y. Bian, "Production lot-sizing and carbon emissions under cap-and-trade and carbon tax regulations," *Journal of Cleaner Production*, vol. 103, no. 15, pp. 241–248, 2015.

[24] J. A. Buzacott and R. Q. Zhang, "Inventory management with asset-based financing," *Management Science*, vol. 50, no. 9, pp. 1274–1292, 2004.

[25] X. Chao, J. Chen, and S. Wang, "Dynamic inventory management with cash flow constraints," *Naval Research Logistics*, vol. 55, no. 8, pp. 758–768, 2008.

[26] M. Protopappa-Sieke and R. W. Seifert, "Interrelating operational and financial performance measurements in inventory control," *European Journal of Operational Research*, vol. 204, no. 3, pp. 439–448, 2010.

[27] S. A. Yang, J. R. Birge, and R. P. Parker, "The supply chain effects of bankruptcy," *Management Science*, vol. 61, no. 10, pp. 2320–2338, 2015.

[28] Y. Feng, Y. Mu, B. Hu, and A. Kumar, "Commodity options purchasing and credit financing under capital constraint," *International Journal of Production Economics*, vol. 153, no. 7, pp. 230–237, 2014.

[29] X. Yan and Y. Wang, "A newsvendor model with capital constraint and demand forecast update," *International Journal of Production Research*, vol. 52, no. 17, pp. 5021–5040, 2014.

[30] Y. Wang, W. Chen, and B. Liu, "Manufacturing/remanufacturing decisions for a capital-constrained manufacturer considering carbon emission cap and trade," *Journal of Cleaner Production*, vol. 140, no. 3, pp. 1118–1128, 2017.

[31] D. Gupta and L. Wang, "A stochastic inventory model with trade credit," *Manufacturing & Service Operations Management*, vol. 11, no. 1, pp. 4–18, 2009.

[32] J. Luo and Q. Zhang, “Trade credit: a new mechanism to coordinate supply chain,” *Operations Research Letters*, vol. 40, no. 5, pp. 278–384, 2012.

[33] C. H. Lee and B.-D. Rhee, “Trade credit for supply chain coordination,” *European Journal of Operational Research*, vol. 214, no. 1, pp. 136–146, 2011.

[34] X. Chen and A. Wang, “Trade credit contract with limited liability in the supply chain with budget constraints,” *Annals of Operations Research*, vol. 196, no. 1, pp. 153–165, 2012.

[35] Q. Zhang, M. Dong, J. Luo, and A. Segerstedt, “Supply chain coordination with trade credit and quantity discount incorporating default risk,” *International Journal of Production Economics*, vol. 153, no. 4, pp. 352–360, 2014.

[36] X. Chen, “A model of trade credit in a capital-constrained distribution channel,” *International Journal of Production Economics*, vol. 159, no. 1, pp. 347–357, 2015.

[37] B. Jing, X. Chen, and G. G. Cai, “Equilibrium financing in a distribution channel with capital constraint,” *Production and Operations Management*, vol. 21, no. 6, pp. 1090–1101, 2012.

[38] G. G. Cai, X. Chen, and Z. Xiao, “The roles of bank and trade credits: theoretical analysis and empirical evidence,” *Production and Operations Management*, vol. 23, no. 4, pp. 583–598, 2014.

[39] P. Kouvelis and W. Zhao, “Who should finance the supply chain? Impact of credit ratings on supply chain decisions,” *Manufacturing & Service Operations Management*, vol. 20, no. 1, pp. 19–35, 2018.

[40] L. Yang, Y. Chen, and J. Ji, “Cooperation modes of operations and financing in a low-carbon supply chain,” *Sustainability*, vol. 10, no. 3, pp. 821–846, 2018.

[41] Y. Chen, M. Xu, and Z. G. Zhang, “Technical note—a risk-averse newsvendor model under the CVaR criterion,” *Operations Research*, vol. 57, no. 4, pp. 1040–1044, 2009.

[42] R. T. Rockafellar and S. Uryasev, “Conditional value-at-risk for general loss distributions,” *Journal of Banking & Finance*, vol. 26, no. 7, pp. 1443–1471, 2002.

[43] G. J. Alexander and A. M. Baptista, “A comparison of VaR and CVaR constraints on portfolio selection with the mean-variance model,” *Management Science*, vol. 50, no. 9, pp. 1261–1273, 2004.

[44] J.-Y. Gotoh and Y. Takano, “Newsvendor solutions via conditional value-at-risk minimization,” *European Journal of Operational Research*, vol. 179, no. 1, pp. 80–96, 2007.

[45] L. Chen, D. Long, and G. Perakis, “The impact of a target on newsvendor decisions,” *Manufacturing & Service Operations Management*, vol. 17, no. 1, pp. 78–86, 2015.

[46] M. Wu, S. X. Zhu, and R. H. Teunter, “The risk-averse newsvendor problem with random capacity,” *European Journal of Operational Research*, vol. 231, no. 2, pp. 328–336, 2013.

[47] R. Qiu, J. Shang, and X. Huang, “Robust inventory decision under distribution uncertainty: a CVaR-based optimization approach,” *International Journal of Production Economics*, vol. 153, no. 7, pp. 13–23, 2014.

[48] L. Yang, M. Xu, G. Yu, and H. Zhang, “Supply chain coordination with CVaR Criterion,” *Asia-Pacific Journal of Operational Research*, vol. 26, no. 1, pp. 135–160, 2009.

[49] X. Xu, Z. Meng, and R. Shen, “A tri-level programming model based on conditional value-at-risk for three-stage supply chain management,” *Computers & Industrial Engineering*, vol. 66, no. 2, pp. 470–475, 2013.

[50] B. Li, P.-W. Hou, P. Chen, and Q.-H. Li, “Pricing strategy and coordination in a dual channel supply chain with a risk-averse retailer,” *International Journal of Production Economics*, vol. 178, no. 8, pp. 154–168, 2016.

[51] L. Yang, G. G. Cai, and J. Chen, “Push, pull, and supply chain risk-averse attitude,” *Production and Operations Management*, vol. 27, no. 8, pp. 1534–1552, 2018.