Optimal Financing Decision for Manufacturers with Shortage of Emission Reduction Funds

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Abstract: Focusing on the problem of LCER capital constraints of small and medium-sized manufacturing enterprises, a manufacturer financing decision model with no financing decision (MODE1), retailer cost-sharing decision (MODE2), bank loan decision (MODE3) and mixed decision of bank loan and retailer sharing (MODE4) are constructed in the context of considering two financing models of bank loan and retailer cost-sharing to analyze the financing decision of key factors, such as manufacturer's initial capital for emission reduction. The study finds that:(i) manufacturers' optimal financing decision differs at different initial funds for emission reduction; when the funds for emission reduction are insufficient, manufacturers' adoption of the mixed decision of bank loans and retailer sharing (MODE4) is more effective in improving supply chain performance, and when the funds for emission reduction are sufficient, the retailer cost-sharing decision (MODE2) is the optimal choice for supply chain members; (ii) the implementation of the cost-sharing decision and the increase of the low-carbon preference coefficient in the supply chain both increase manufacturers' retailer expected utility, and the increase of retailer expected utility is more significant, which is conducive to promoting the relief of manufacturers' financial pressure and the improvement of the level of LCER.

Keywords: Low Carbon Financing, Cost Sharing; Low-Carbon Emission Reduction (LCER); Initial Funding; Consumer Low Carbon Preference

1. Introduction

Since the industrial revolution, global warming and other environmental pollution problems have become increasingly serious, and in 2022, the United Nations Intergovernmental Panel on Climate Change (IPCC) clearly stated that humans need to peak carbon emissions by 2025 and reduce emissions by 43% by 2030 compared to 2010 in order to achieve the global warming target of 1.5°C. Carbon dioxide and other greenhouse gas emissions are the main contributors to global warming, however, the current LCER measures and carbon capture measures in various countries are not easy to achieve the temperature control target in terms of government control and corporate utilization. With the implicit influence of low-carbon policy on consumers' consumption philosophy and the gradual increase of consumers' low-carbon awareness, the low-carbon attributes of products have gradually become an indispensable element for enterprises to consider when carrying out production activities, and manufacturers must increase their investment in low-carbon production technologies, which will undoubtedly increase their production costs, thus making SMEs face the problem of financial constraints. Therefore, conducting financing activities is an important way for enterprises to get rid of financial constraints and guarantee the normal operation of their production activities.

At present, low-carbon financing methods vary from country to country, but in general, direct financing represented by the application of carbon market and its derivative products is still the main method, and inter indirect financing as a supplementary low-carbon financing method [1]. However, the demand for corporate green financing far exceeds the supply capacity of direct bank financing [2], and there are credit barriers between SMEs and banks, and financing for high-carbon industries is also inhibited by the financing preferences of financial institutions [3], so the problem of high difficulty and high cost of green financing for SMEs still prevails. Therefore, manufacturers need to consider alternative channels to alleviate the growing financial pressure. In the case of the mature development of e-commerce platforms and world-type chains, there is often a situation where retailers have sufficient funds while their upstream small and medium-sized manufacturers are constrained by funds, and retailers choose to shoulder a portion of the LCER expenses for the upstream manufacturing industry in order to ensure the supply chain's long-term stability and competitiveness [4]. Bank loans and cost sharing by retailers have now become important ways for small and medium-sized manufacturing industries to address financing constraints. Therefore, it is crucial to explore the financing models of small and medium-sized manufacturers subject to LCER financing constraints, compare the gaps in financing models under different initial funding scenarios, and explore the impact of different factors on financing decisions.

Current research on corporate low-carbon financing is divided into two main aspects: low-carbon financing paths and low-carbon financing needs. In terms of low-carbon financing paths, most studies focus on the comparison or combination analysis of two different types of financing methods, internal financing and external financing. Internal financing refers to the financing method in which corporate entities obtain funds from other enterprises within the supply chain to ensure that they can carry out normal production and operation activities. For example, Tang and Yang [5] analyzed the overall low carbon level and profit of the supply chain under two financing models, bank credit financing and retailer advance payment when manufacturers are financially constrained, and concluded that advance payment under a retailer-driven power structure is better than bank loan in reducing carbon emissions and increasing social welfare. Ding [6] established a supply chain consisting of an upstream manufacturer and a downstream retailer constrained by LCER financing, and the retailer achieves the dual optimization of investment return and low-carbon technology adoption level by signing a cost-sharing contract with the manufacturer. External financing refers to the financing method in which a company can secure loans from banks and financial institutions to ensure its normal production and operation activities. Zhang Jieran [7] studied a supply chain of small and medium-sized suppliers with financial constraints, and constructed a "government-supplier-manufacturer" game model to analyze the financing of suppliers under government green credit and green product subsidies. The game model of "government-supplier-manufacturer" was developed to analyze the financing and production strategies of suppliers under government green credit and green product subsidies. Wu et al analyzed the optimal financing decision of supply chain expectation and decarbonization level when there are cost-sharing activities among supply chain members by developing three financing decision models, namely, unconstrained financing, trade credit financing and bank credit financing.

In terms of low-carbon financing demand, scholars currently mainly use carbon tax [8] and carbon trading [9-11] as the background to determine the low-carbon financing demand while considering the optimal core corporate revenue and social welfare. Meng Qingchun et al, when considering small and medium-sized suppliers' funding requirements, are determining the abatement cost according to the optimal carbon emission reduction and applying for financing credits from core enterprises. Cheng Yonghong et al [12] similarly determined the manufacturer's optimal carbon emission reduction according to the revenue function for financing and pricing decisions.

Based on the above literature, scholars have studied the financing of upstream enterprises in the supply chain subject to low-carbon financial constraints, and proposed various financing methods considering carbon tax, carbon trading, and carbon quota, which have made significant contributions to the realization of the "double carbon" goal and the production and financing decisions of small and medium-sized enterprises. However, most scholars have equated the cost of LCER with the amount of financing, and in fact, the amount of low-carbon financing is smaller than the cost of LCER when an enterprise has the initial funds for LCER. With this in mind, we will explore the following questions: (1) What financing strategy can be chosen by small and medium-sized manufacturing enterprises constrained by low-carbon funds to get out of the dilemma? Does the manufacturer's initial funding for LCER have an impact on its own production and financing decisions? What kind of impact does it have? (2) Do cost-sharing contracts generate profits for supply chain members? (3) How do key parameters such as bank lending rates and consumer preference coefficients affect optimal decisions?

2. Problem Description and Model Assumptions

To explore these issues, this paper constructs a Stackelberg model under four models to analyse the impact of key parameters, such as producers' and retailers' marginal returns, producers' initial capital for low carbon emission reduction, and bank lending rates, on producers' optimal production decisions and financing strategies.

Hypothesis 1: The supply chain consists of a secondary supply chain consisting of a single manufacturer and a single retailer, where the manufacturer is a small and medium-sized enterprise constrained by abatement costs and the retailer is a risk-averse enterprise not constrained by capital. When a manufacturer is constrained by LCER funds, it can choose between bank financing and seeking retailers to share the cost of emission reduction. Retailers as a sharing party are risk-averse, and their characteristics are measured by the mean-variance function with the expected utility function of. where k_R is the degree of risk aversion, $0 \le k_R \le 1$, and the larger k_R is, the greater the degr $E(U_R(\pi_R)) = E(\pi_R) - k_R\sqrt{Var(\pi_R)}$ ee of risk aversion.

Hypothesis 2: The manufacturer adopts low-carbon abatement technology to produce low-carbon products, and its low-carbon abatement fixed investment cost is $\frac{Ie^2}{2}$, where I is the low-carbon abatement cost coefficient and e is the low-carbon abatement level.

Hypothesis 3: Consumers have a preference for low-carbon products and the market demand is random for $X = q + \varepsilon$, $q = a + \delta e$, q is the output of low-carbon products, a is the basic market size, δ is the degree of consumer preference for low-carbon products, $\varepsilon \in N(0,\sigma^2)$, σ is the variance.

Hypothesis 4: To simplify the calculation process, assume that the marginal revenue of the manufacturer and the retailer are p_M and p_R , respectively, and to comply with the actual loan situation, assume that p_M and p_R meet the $p_R < p_M < 2p_R$ size relationship.

The meanings of other parameters, variables, functions, etc. in the paper are shown in Table 1.

Table 1. Meaning of Parameters, Variables and Functions

Symbol Name	Symbol Meaning
k_R	Retailer Risk Aversion Factor
I	Low Carbon Emission Reduction Cost Factor
e	Low carbon emission reduction level
a	Basic Market Size
X	Market Demand
q	Low Carbon Product Output
δ	Consumer preference coefficient for low carbon products
p_i	Marginal return per unit($i = M, R$)
ϕ^{ij}	Low carbon emission reduction cost sharing ratio under decision i at model j ($i = D, C$、 $j = 1,2,3,4$, D and C are Decentralized Decision, Centralized Decision respectively)
π_l^{ij}	Manufacturer l retailer in mode j under i decision benefit ($l = M, R$、 $i = D, C$、 $j = 1,2,3,4$)
r	Bank loan interest rate
B	Manufacturer's initial capital for low carbon emission reduction

3. Model Construction

3.1 Manufacturer's Low Carbon Emission Reduction Funds are Sufficient

The game sequence of this secondary supply chain is as follows: first, the retailer proposes the order quantity and the cost sharing rate of low carbon emission reduction cost to the manufacturer; then, the manufacturer makes the decision of carbon emission reduction per unit of product according to its own revenue maximization.

3.1.1 MODE1 model

Both the manufacturer and the retailer are not bound by capital under the decentralized decision. At this moment, the manufacturer's and retailer's expected utilitarian function is:

$$E(U_M(\pi_M^1)) = p_M q - \frac{Ie^2}{2} \quad (1)$$

$$E(U_R(\pi_R^1)) = p_R q - k_R p_R \sigma \quad (2)$$

The optimal expected utility of the manufacturer and retailer in the MODE1 model can be derived:

$$E(U_M(\pi_M^{1*})) = aP_M + \frac{\delta^2 P_M^2}{2I} \quad (3)$$

$$E(U_R(\pi_R^{1*})) = aP_R - \sigma k_R P_R + \frac{\delta^2 P_M P_R}{I} \quad (4)$$

3.1.2 MODE2 model

Under decentralized decision making, both the manufacturer and the retailer consider their own revenue maximization without considering the optimal benefit of the supply chain as a whole. At this time, the expected utility functions of the manufacturer and the retailer are:

$$E(U_M(\pi_M^{D2})) = P_M q - (1-\phi)\frac{Ie^2}{2} \quad (5)$$

$$E(U_R(\pi_R^{D2})) = P_R q - \phi\frac{Ie^2}{2} - k_R P_R \sigma \quad (6)$$

The optimal share ratio under the retailer's decision is:

$$\phi^{D2*} = \frac{2P_R - P_M}{2P_R + P_M} \quad (7)$$

The optimal expected utility of each supply chain member under decentralised decision making in MODE2 model is:

$$E(U_M(\pi_M^{D2*})) = aP_M + \frac{\delta^2 (P_M^2 + 2P_M P_R)}{4I} \quad (8)$$

$$E(U_R(\pi_R^{D2*})) = aP_R - \sigma k_R P_R + \frac{\delta^2 (P_M^2 + 4P_M P_R + 4P_R^2)}{8I} \quad (9)$$

The expected utility of the supply chain as a whole under centralised decision making is:

$$E(U_S(\pi_S^{C2})) = P_M q + P_R q - \frac{Ie^2}{2} - k_R P_R \sigma \quad (10)$$

The expected utility of the manufacturer and retailer under centralised decision making is:

$$E(U_M(\pi_M^{C2*})) = aP_M + \frac{\delta^2 (P_M^2 + P_M P_R)}{2I} \quad (11)$$

$$E(U_R(\pi_R^{C2*})) = aP_R - \sigma k_R P_R + \frac{\delta^2 (P_M P_R + P_R^2)}{2I} \quad (12)$$

3.2 Constrained Scenario of Low Carbon Emission Reduction Funds for Manufacturers

3.2.1 MODE3 model

The expected utility functions of manufacturers and retailers are:

$$E(U_M(\pi_M^3)) = p_M q - B - (\frac{Ie^2}{2} - B)(1+r) \quad (13)$$

$$E(U_R(\pi_R^3)) = P_R q - k_R P_R \sigma \quad (14)$$

The expected utility of the MODE3 model manufacturer and retailer under decentralised decision making is:

$$E(U_M(\pi_M^{3*})) = ap_M + Br + \frac{\delta^2 P_M^2}{2I(1+r)} \quad (15)$$

$$E(U_R(\pi_R^{3*})) = aP_R - \sigma k_R P_R + \frac{\delta^2 P_M P_R}{I(1+r)} \quad (16)$$

3.2.2 MODE4 model

Under decentralized decision making, the expected utility functions of manufacturers and retailers are:

$$E(U_M(\pi_M^4)) = p_M q - B - ((1-\phi)\frac{Ie^2}{2} - B)(1+r) \quad (17)$$

$$E(U_R(\pi_R^4)) = p_R q - \phi\frac{Ie^2}{2}(1+r) - k_R p_R \sigma \quad (18)$$

The optimal sharing ratio under the retailer's decision is:

$$\phi^{D4*} = \frac{2P_R - P_M}{2P_R + P_M} \quad (19)$$

The expected utility of the manufacturer and retailer under decentralised decision making is:

$$E(U_M(\pi_M^{D4*})) = ap_M + Br + \frac{\delta^2 (P_M^2 + 2p_M p_R)}{4I(1+r)} \quad (20)$$

$$E(U_R(\pi_R^{D4*})) = ap_R - \sigma k_R p_R + \frac{\delta^2 (P_M^2 + 4p_M p_R + 4P_R^2)}{8I(1+r)} \quad (21)$$

The overall expected utility of the supply chain under centralized decision making is:

$$E(U_S(\pi_S^{C4})) = p_M q + p_R q - k_R p_R \sigma + Br - \frac{Ie^2}{2}(1+r) \quad (22)$$

Then the overall expected utility of the supply chain is:

$$E(U_S(\pi_S^{C4*})) = ap_R + ap_M - \sigma k_R p_R + Br + \frac{\delta^2 (p_M + p_R)^2}{2I} \quad (23)$$

The expected utility of the manufacturer and retailer under centralised decision making is:

$$E(U_M(\pi_M^{C4*})) = ap_M + Br + \frac{\delta^2 (P_M^2 + p_M p_R)}{2I(1+r)} \quad (24)$$

$$E(U_R(\pi_R^{C4*})) = ap_R - \sigma k_R p_R + \frac{\delta^2 (p_M p_R + P_R^2)}{2I(1+r)} \quad (25)$$

4. Model Analysis

4.1 Optimal Decision Analysis

Proposition 1: (i) The optimal solution exists for supply chain members when the marginal revenue of manufacturer and retailer satisfie $p_R < p_M < 2p_R$. The setting of Assumption 4 is satisfied. (ii) When the manufacturer's abatement funds are sufficient $e^{2*} > e^{1*}$, $q^{2*} > q^{1*}$, $E(U_M(\pi_M^{D2*})) > E(U_M(\pi_M^{1*}))$, $E(U_R(\pi_R^{D2*})) > E(U_R(\pi_R^{1*}))$ and when the manufacturer is constrained by low-carbon funds $e^{4*} > e^{3*}$, $q^{4*} > q^{3*}$, $E(U_M(\pi_M^{D4*})) > E(U_M(\pi_M^{3*}))$, $E(U_R(\pi_R^{D4*})) > E(U_R(\pi_R^{3*}))$.

Proposition 1 shows that when the marginal benefits of manufacturers and retailers satisfy $p_R < p_M < 2p_R$, retailers are willing to carry out emission reduction cost sharing for manufacturers, which can make the supply chain members exist optimal solutions. The MODE2 model outperforms the MODE1 model when the manufacturer has sufficient funds to reduce emissions, and the MODE4 model outperforms the MODE3 model when the manufacturer is constrained by low-carbon funds. Regardless of whether the manufacturer's LCER funds are sufficient, the retailer's adoption of the sharing decision will lead to the improvement of the supply chain members' LCER level, order quantity, and expected utility.

To analyze the situation when the manufacturer is constrained by LCER funds, it is assumed that: the manufacturer's initial funds for LCER can only be used for that activity, and the loan strategy can only be adopted when that fund is insufficient, i.e., the manufacturer does not take a loan at $B \ge \frac{Ie^2}{2}$

To optimize the manufacturer and retailer expected utility under decentralized decision, the range of values for the manufacturer's initial funds B under the four models and the impact on the financing decision are analyzed.

Proposition 2: B is positively correlated with $E(U_M(\pi_M^*))$ when the manufacturer is constrained by low-carbon funds; conversely, B is uncorrelated with $E(U_M(\pi_M^*))$.

When the manufacturer's capital is not constrained, the manufacturer's initial capital needs to be greater than the low carbon emission reduction cost it bears if both sides of the decision reach the optimal value of their respective decisions; when the manufacturer's low carbon emission reduction capital is constrained, the manufacturer's initial capital needs to be less than the low carbon emission reduction cost it bears if both sides of the decision reach the optimal value of their respective decisions, otherwise the manufacturer does not need to carry out loan activities.

In MODE1 mode, the value of B is $B \ge B_w = \frac{\delta^2 P_M^2}{2I}$; in MODE2 mode, the value of B is $B \ge B_x = \frac{\delta^2 p_M(p_M + 2p_R)}{4I}$; in MODE3 mode, the value of B is $B \le B_y = \frac{\delta^2 P_M^2}{2I(1+r)^2}$; in MODE4 mode, the value of B is $B \le B_z = \frac{\delta^2 p_M(p_M + 2p_R)}{4I(1+r)^2}$.

Proposition 3: (i) How a manufacturer chooses to make a production decision is influenced by the bank loan rate r . When $\frac{-2p_M + \sqrt{2P_M^2 + 4p_M p_R}}{2p_M} < r < 1$, the size of the critical value of the initial funds in the four modes is ordered as $B_y \le B_z \le B_w \le B_x$.(ii) When $0 < r < \frac{-2p_M + \sqrt{2P_M^2 + 4p_M p_R}}{2p_M}$, the size of the critical value of the initial funds in the four modes is ordered as $B_y \le B_w \le B_z \le B_x$.

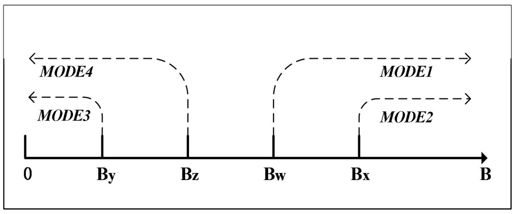

Figure 1. Proposition 3(i) is a Schematic Representation of the Initial Funding Threshold

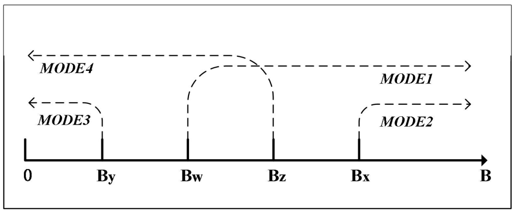

Figure 2. Proposition 3(ii) is a Schematic Representation of the Initial Funding Threshold

Corollary 1: Proposition 3 (i) combined with Proposition 1, from Figure 1 can be visualized when $\frac{-2p_M + \sqrt{2P_M^2 + 4p_M p_R}}{2p_M} < r < 1$, the manufacturer's choice decision: ① $B \ge B_x$, choose MODE2 mode; ② $B_w \le B \le B_x$, choose

MODE1 mode; ③ $B_z \le B \le B_w$, there is no alternative mode. In this interval, the manufacturer can lean towards the mode MODE1 mode and MODE4 mode on both sides of the interval. It is calculated that the manufacturer chooses to lean towards MODE4 mode when its expected utility is higher due to the expansion of production, and MODDE4 mode can be selected. ④ When $B_y \le B \le B_z$, MODE4 mode is selected; ⑤ When the manufacturer's initial capital $B \le B_y$, MODE4 mode is selected.

(ii) Similarly, the choice decision of the manufacturer at the time when $0 < r < \frac{-2p_M + \sqrt{2P_M^2 + 4p_M p_R}}{2p_M}$ can be visualized from Figure 2: the manufacturer's decisions in paragraphs ①, ②, ④, ⑤ are the same as those in Corollary 1; (iii) when $B_w \le B \le B_z$, MODE4 is chosen; at the same low carbon abatement cost, the manufacturer's expected utility in MODDE4 is higher than that when MODE1 is chosen; at this time, whether or not the retailer's expected utility grows depends on bank lending interest rate r. When the bank lending rate $0 < r < \frac{P_M^2 - 4p_M p_R + 4P_R^2}{8p_M p_R}$, the expected utility of the retailer in MODE4 is higher than that in MODE1, and when the interest rate is low, choosing MODE4 can realize a win-win situation for the manufacturer and the retailer; when the bank lending rate $\frac{P_M^2 - 4p_M p_R + 4P_R^2}{8p_M p_R} < r < \frac{-2p_M + \sqrt{2P_M^2 + 4p_M p_R}}{2p_M}$, the expected utility of the retailer in MODE4 is lower than that in MODE1, and at this time, the retailer is not willing to share the cost of LCER; when the bank lending rate $r = \frac{P_M^2 - 4p_M p_R + 4P_R^2}{8p_M p_R}$ the manufacturer's choice of decision does not affect the retailer's expected utility.

4.2 Parameter Impact Analysis

4.2.1 Analysis of low carbon emission reduction levels

Proposition 4: In a retailer-led secondary supply chain, e is positively correlated with P_M and δ; e is positively correlated with ϕ and P_R when retailers share the cost of LCERs; and e is negatively correlated with r when manufacturers are externally financed.

Proposition 4 suggests that retailers adopting cost-sharing measures is crucial for encouraging manufacturers to reduce emissions. Consumer preferences for low-carbon products often lead them to pay higher prices, boosting manufacturers' and retailers' returns. This improved market response drives manufacturers to enhance low-carbon efforts, motivating retailers to increase their share, thus establishing a causal link between emission reduction, utility, and the supply chain market.

4.2.2 Analysis of loan interest rates

Proposition 5: When the manufacturer is in a state subject to low-carbon funding constraints and B is held constant, e^* and q^* are decreasing functions with respect to r, while $E(U_M(\pi_M^*))$ and $E(U_R(\pi_R^*))$ are also decreasing functions with respect to r.

Proposition 5, regarding manufacturers facing financial constraints with fixed initial capital for emission reduction, finds a negative relationship between bank loan interest rates, order amount, and expected utility for both the producer and retailer. When initial capital is insufficient, external financing becomes inevitable. In response to higher loan interest rates, rational decision-makers reduce loan amounts and emission reduction efforts to optimize expected utility. This reduction in emission reduction levels subsequently decreases retailer order quantities and the expected utility of both parties.

4.2.3 Sharing ratio analysis

Proposition 6: (i) ϕ is positively correlated with p_R and negatively correlated with p_M. (ii) When $0 \le \phi \le \frac{2P_R - P_M}{2P_R}$, both manufacturers and retailers expect utility to increase from the unshared model; when $1 \ge \phi > \frac{2P_R - P_M}{2P_R}$, retailers expect utility to decrease from the unshared model.

Proposition 6(i) suggests that retailers' willingness to share costs and the proportion of sharing are mainly influenced by the expected utility of manufacturers and retailers. The larger the retailer's share of the supply chain's expected utility, the stronger its willingness to share; conversely, the weaker its willingness to share.

Proposition 6(ii) shows that under decentralized decision-making, when the retailer leads and decides the sharing ratio, $\phi^{D2*} \in [0, \frac{2P_R - P_M}{2P_R}]$, $\phi^{D4*} \in [0, \frac{2P_R - P_M}{2P_R}]$, the degree of LCER increases, the expected utility of the retailer increases, and the retailer is more willing to share the LCER cost for the manufacturer; under centralized decision-making, when the sharing ratio is decided by the supply chain as a whole, $\phi^{C2*} \in (\frac{2P_R - P_M}{2P_R}, 1]$, $\phi^{C4*} \in (\frac{2P_R - P_M}{2P_R}, 1]$, the manufacturer expects utility to be significantly increased, but the expected utility of the retailer is lower than that in the sharing model, and the retailer will not choose to share the cost, and the Pareto optimality cannot be achieved.

4.2.4 Low carbon preference coefficient analysis

Proposition 7: $E(U_M(\pi_M^*))$ and $E(U_R(\pi_R^*))$ are increasing functions with respect to δ.

Proposition 7 indicates that as the low carbon preference coefficient rises, both manufacturer and retailer expected utility increases. Consumer preference coefficients have become crucial for firms in production decisions. However, these coefficients impact supply chain members' expected utility to varying degrees, leading to Corollary 2.

Corollary 2: The low carbon preference coefficient δ affects the expected utility of retailers more than that of manufacturers, and retailers are the largest beneficiaries of the low carbon preference coefficient among supply chain members.

5. Conclusions

The results of this paper show that: Manufacturers' production and financing choices vary based on their initial emission reduction capital. With sufficient capital, they should engage retailers in cost-sharing, while constrained capital should lead to prioritizing loans. Manufacturers facing emission reduction fund constraints can optimize their utility by using a blend of bank loans and retailer cost-sharing. When the bank loan interest rate is below a specific threshold, it's a win-win for both manufacturers and retailers. However, if it exceeds that threshold, retailers might be hesitant to share costs. In practice, bank loan rates are often lower than this threshold, making cost-sharing contracts profitable for supply chain members. High bank loan rates deter loans for emission reduction by manufacturers and discourage retailers from cost-sharing. Yet, these rates don't greatly affect supply chain's financing and production decisions. The consumer low-carbon preference coefficient is pivotal, favoring retailers with a bigger impact on their utility than manufacturers. This boosts retailer's cost-sharing willingness, enhancing emission reduction and creating a positive cycle. This paper is limited to the study of the optimal financing decision when the marginal revenue of manufacturers and retailers is fixed, while in practice, the marginal revenue is influenced by the output. Therefore, in the subsequent study, marginal revenue is included in the research variables to analyze their optimal decisions.

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