GREEN FINANCING STRATEGIES UNDER RISK AVERSION AND MANUFACTURER COMPETITION

GUANGDONG LIU\textsuperscript{1,2,*}, JINGGUI CHEN\textsuperscript{1} AND ZIYANG LI\textsuperscript{1,2}

Abstract. In order to address the financial constraints of enterprises to promote green R&D and industrial green transformation, this study investigated a competitive supply chain consisting of a retailers, a general manufacturer, and a capital-constrained green manufacturer under risk aversion and capital shortage. It established models with and without capital constraints, retailer financing, and bank financing for the green manufacturer and retailer under risk aversion, and explored how the green competitive supply chain could obtain optimal financing strategies. The research findings are as follows: (1) When the financing interest rates are equal, the green manufacturer should prefer the retailer financing model, and regardless of the financing method, the increase in interest rates is extremely detrimental to retailers. (2) The increase in the degree of risk aversion of the green manufacturer is not conducive to the long-term development of competitors and itself, but is beneficial to the retailer, but it will cause further instability in the market. However, the increase in the degree of risk aversion of the retailer is only detrimental to itself and beneficial to the supply chain partners.

Mathematics Subject Classification. 1201.

Received December 8, 2022. Accepted February 23, 2024.

1. Introduction

With increasingly prominent environmental problems such as global warming and energy depletion, countries around the world have begun to explore green and low-carbon development models in order to achieve the coordination between economic and environmental development.

For example, China has formulated the goal of carbon neutrality and emission peak and the action plan for peaking carbon dioxide emissions before 2030 to guide the national economy to green transition and achieve sustainable social development. At the same time, with the improvement of people’s living standards and the enhancement of environmental protection awareness, environment-friendly green products are favored by more and more consumers [1]. In order to actively respond to national environmental protection policies, meet consumers’ green needs, and improve their own competitiveness, many enterprises have begun to increase their investment in the R&D of green products [2,3]. For example, Coca-Cola designs and utilizes recyclable packaging to reduce waste generation, and Haier and TCL invest in R&D and production of green energy-saving products through technological innovation and increased capital investment, which are recognized by China, Europe, the

\textbf{Keywords.} Green competitive supply chain, bank financing, retailer financing, risk aversion.

\textsuperscript{1} School of Information, Chuzhou University, Chuzhou, P.R. China.
\textsuperscript{2} School of Business, Fuyang Normal University, Fuyang, P.R. China.
\textsuperscript{*}Corresponding author: 1359162826@qq.com

© The authors. Published by EDP Sciences, ROADEF, SMAI 2024

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
United States, and other countries [4]. However, the design, R&D, and production of green products necessitate a significant investment in human, material, and financial resources, putting manufacturers under significant financial strain and causing a funding shortfall [5], which may make manufacturers experience the risk of R&D failure and lose market competition, even may eventually lead to bankruptcy, especially in industries such as environmentally friendly buildings, new energy vehicles, and chemicals [6]. Therefore, how to alleviate the capital constraints in enterprises to promote their sustainable development is a problem worthy of study. At present, many enterprises adopt different financing methods to obtain financial support for their customers. For example, Since 2014, JD.com has launched the “Jingxiaodai” business, with a single business loan limit of 2 million yuan, an annualized loan interest rate of 14%-24%. In 2022, the “Jingxiaodai” loan limit was further increased, helping small and medium-sized businesses reduce interest and fees by over 60 million yuan. During the Shopping Festival of 618 and Double 11, a total of nearly 4 billion yuan was temporarily raised for JD merchants. From January 1, 2023, JD.com will open the channel for individual merchants to enter. Natural persons can obtain a maximum credit loan of 200,000 yuan, individual industrial and commercial households can obtain a maximum credit loan of 500,000 yuan, and enterprises can obtain a maximum credit loan of 2 million yuan. The annual interest rate of “Jingxiaodai” is as low as 9.13%, which is lower than the industry level. It brings substantial and accurate financial services for personal employment and entrepreneurship and helps individual merchants to develop. It ensures the funds of merchants and helps them to do business well [7]. According to “China Banking and Insurance News (2019)”, the Industrial and Commercial Bank of China and the Agricultural Bank of China et al. have invested more than 4.4 trillion yuan in green credit projects to promote green production [8].

At the same time, the mutual substitution of heterogeneous products has intensified competition among manufacturers, for example, the new energy vehicle companies such as NIO, Tesla, and Shanghai General Motors can supply new energy vehicles and traditional fuel vehicles for dealerships. The competition of enterprises in the same industry will aggravate trade conflicts and uncertain demand risks, resulting in a more complex decision-making environment for the entire supply chain, which makes the participants face many uncertain risk factors (such as R&D, demand, cost, etc.), supply chain members tend to exhibit varying degrees of risk aversion because of the uncertainties [9]. In particular, emerging manufacturing companies (such as new energy manufacturing companies) would rather sacrifice part of their interests in order to avoid risks. Especially when they are capital-constrained, it will intensify the risk aversion of decision makers, which will affect the pricing, financing, production, and so on [10]. Therefore, under capital constraints, it is an important issue that needs to be paid attention to explore how green manufacturers can finance in a fiercely competitive environment and how risk-averse behavior affects the choice of supply chain strategies.

Based on the above analysis, this paper intends to solve the following problems: First, how to effectively solve the shortage of funds for green manufacturers? Under what conditions, internal or external financing of the supply chain can be chosen? And how does the financing interest rate of different financing methods affect supply chain decisions? Second, how does the competition structure affect the choice of financing methods for green manufacturers? Third, how does the risk-aversion of supply chain members affect the choice of financing modes?

To solve the above problems, we construct a green competitive supply chain consisting of a risk-neutral common manufacturer M1, a risk-averse green manufacturer M2, and a retailer R. And the green manufacturer M2 is capital-constrained and has two financing modes: (1) internal financing of the supply chain-retailer loan financing, (2) external financing of the supply chain-bank loan financing. We established different models of green manufacturer M2 with risk aversion alone or with risk-averse retailer under the modes of internal financing and external financing of the supply chain, compared the results of the models, and tested the validity of the models through sensitivity analysis and numerical simulation.

The contributions of the paper are as follows: First, previous research on supply chain financing focused on a single structure [11]. The paper constructs a green supply chain with heterogeneous product competition and explores the impacts of different competitions on supply chain financing. Second, unlike previous literature on supply chain financing, which assumed that decision makers were risk-neutral [12], this paper introduces the
risk aversion of different members to explore its impacts on green supply chain financing decisions. Third, the paper explores green innovation under competition and risk aversion.

The rest of this paper is as follows: Section 2 introduces the literature review. Section 3 presents the basic models. Section 4 establishes six models under different conditions, and obtains the optimal solutions. Section 5 compares and analyzes the optimal equilibrium results by combining sensitivity analysis and numerical simulation. Section 6 summarizes the paper.

2. Literature review

The paper focuses on how to seek financing for green manufacturers in order to solve the problems of capital constraints and the optimal decision-making of the supply chain under competition and risk aversion. This section reviews and summarizes the literature on green supply chain competition, supply chain financing, and supply chain with risk aversion.

2.1. Green supply chain competition

Supply chain competition refers to horizontal, vertical, and inter-supply competition [13]. Existing research mostly considers the competition among manufacturers. Wu and Kung [14] studied Carbon emissions, technology upgradation and financing risk of the green supply chain competition, and they found that the government plays an important role in upgrading of carbon emission technologies and financing. Yang et al. [15] studied the return policies for two differentiated brands provided by two manufacturers. Li et al. [16] used game theory to study the impacts of the pricing timing of two quality-differentiated brands on supply chain profits. Wu et al. [17] explored the impacts of R&D efficiency and competition level on supply chain decisions by developing different green R&D cooperation models between one supplier and two manufacturers. Ji et al. [18] studied the timing of two competing manufacturers adopting blockchain technology. There is also a small amount of research on competition among retailers or suppliers. For example, Xia et al. [19] studied the competition between two suppliers and found that customer preferences for alternative products can affect the product pricing. Wei and Zhao [20] established two competitive supply chain models to study the optimal pricing and remanufacturing strategies of supply chain members. Chen et al. [21] found that the impact of information sharing on competitive supply chains depends on the degree of channel competition. For individual members, information sharing in the supply chain is always beneficial to the manufacturer but disadvantageous to the retailer. Guo et al. [22] studied the impacts of competition between two brand retailers on green production decisions. Deng et al. [23] explored how supply chain competition affects product sustainability, profit, and corporate strategy development under two competitive supply chains. Cheng et al. [24] used the differential game to analyze the application of corporate social responsibility in competitive supply chains. At the same time, with the deepening of the research, some scholars have started research on the green supply chain competition of heterogeneous products. Zhao et al. [25] considered a price competition model between two heterogeneous participants under carbon trading and found that carbon emission permits play an important role in the duopoly game. Ashkan [26] explored the impacts of government intervention on the competition between green and non-green products. Song et al. [27] studied the supply chain pricing of non-green products and alternative green products and found that the cost-sharing mechanism can coordinate the supply chain.

From the above literature, it can be seen that supply chain competition from multiple perspectives has been studied and rich results have been obtained, but it can be assumed that supply chain companies have sufficient funds, while in practice, especially in emerging green industries such as new energy, green manufacturers are capital-constrained, so how to raise funds to solve the problem has become a major problem faced by green manufacturers [28].

2.2. Supply chain financing

The capital constraint of supply chains has become an important factor that hinders the stable development of supply chains, which has attracted extensive attention from relative enterprise managers and scholars. Li
et al. [29] concluded that capital constraints will not only seriously affect the operation of the enterprise itself but also affect other enterprises in the supply chain. Based on investigations related to financial constraints, Jin et al. [30] found that effective supply chain financing can not only solve the problems of traditional economic transformation but also solve the financing difficulty for small and medium enterprises (SMEs). At present, supply chain financing mainly includes trade credit (internal financing) and bank loan (external financing), which are important ways to ease the capital constraints of supply chain enterprises. External financing of supply chains is one of the most commonly used methods [31]. Buzacott et al. [32] developed a supply chain consisting of one retailer and one bank and examined the impacts of external financing of inventory pledge loan on supply chain decisions. Srinivasa et al. [33] pointed out that supply chain financing will bring a win-win situation for supply chain members and commercial banks. Yan et al. [34] considered how to finance a capital-constrained enterprise to avoid breach of contract. Tunca et al. [35] studied that a capital-constrained supplier can obtain bank loan financing with the retailer as a guarantor. Fang et al. [36] analyzed supply chain decision-making under green credit financing and trade credit financing under capital-constrained manufacturers. Serel et al. [37] concluded that the manufacturer can ensure the supplier’s production capacity by prepayments. Huang et al. [38] analyzed how to select the financing models and creditors’ interest rate considering a capital-constrained retailer. Qin et al. [39] considered a capital-constrained manufacturer under low-carbon constraints, which could obtain the funds by e-commerce platform financing, supplier credit financing, and hybrid financing, and analyzed the impacts of the manufacturer’s carbon reduction, production quantity, and financing strategy on supply chain operations. Jiang et al. [40] studied how to obtain funds for a capital-constrained manufacturer from an operator.

The fierce market competition has forced enterprises in the supply chain to transform and upgrade, expanding their financing needs. Chen et al. [41] studied financing strategies in competitive supply chains and subsequently extended the model to bi-level non-cooperative game with multiple leaders and multiple follower supply chains. Xia et al. [42] analyzed the impact of market competition intensity and consumer low-carbon preferences on corporate financing strategies. Shen et al. [43] found that without retail competition, when the trade interest rate is relatively low, supply chain members could reach a win-win situation in the trade credit financing; with retail competition, supply chain members will not have an all-win situation no matter which specific financing scheme is adopted. Zhi et al. [44] studied the effects on the supply chain of a third-party logistics provider (TPL) providing in-transit inventory financing, and they found that the low logistics cost, the low unit product price without trade credit and a high financing ratio can make in-transit inventory financing more attractive than trade credit. Unlike the above research, our study considers both green investment and the risk preferences of supply chain members.

It can be seen that only a single channel supply chain is studied and supply chain members are risk-neutral from the above literature. This paper explores how to seek financing in a competitive and green supply chain under capital-constraint manufacturers and discusses the impacts of risk aversion behavior on supply chain financing and decision-making.

2.3. Supply chain with risk aversion

With the intensification of economic globalization and market competition, the increasing uncertainties of demand, cost, price, etc. bring some risks to supply chain management [45]. For example, the disruption of global supply chains caused by the Russian–Ukrainian war has led to uncertainties in the prices and costs of many production and living materials. Therefore, it is vital to consider the risk attitude of supply chains. On the risk aversion of supply chains, many scholars have done a lot of meaningful work. Choi et al. [46] constructed a fast-fashion supply chain composed of a risk-averse retailer and a manufacturer and explored how the risk aversion affects the decisions of all parties in the supply chain. Sechan et al. [47] analyzed the effects of uncertainties on risk-averse service providers by using expected utility theory to model pricing problems. Xiao et al. [48] explored the impacts of risk aversion of the manufacturer and retailer on expanding production lines or replacing old products with new ones. Yan et al. [49] considered that the retailer with financial constraints and risk aversion established supplier financing and supplier investment and analyzed the impacts of risk aversion on financing...
Wu et al. [17] – Green products Stackelberg game Green supply chain with competition and cooperation
Guo et al. [19] – Green products Stackelberg game Fashion supply chain with competition
Cheng et al. [21] – Ordinary products Differential game Supply chain with competition
Ashkan [23] – Green and non-green products Stackelberg game Green supply chain with government intervention
Buzacott et al. [29] Inventory pledge loan Ordinary products Analytical modelling Inventory management with financing
Fang et al. [33] Green credit or mixed financing Green products Stackelberg game Green supply chain with capital constraint
Huang et al. [35] Trade credit, credit guarantee and credit guarantee financing Ordinary products Stackelberg game Supply chain with financial constraint
Qin et al. [36] Platform, supplier credit, and mixed financing Low-carbon products Stackelberg game E-commerce supply chain with capital constraint
Yan et al. [49] Supplier financing and supplier investment Ordinary products Stackelberg game Capital-constrained supply chain with loss aversion
Our study Internal and external financing Green and non-green products Stackelberg game Green supply chain with risk aversion and capital constraint

decisions. Wang et al. [50] studied the ordering problem of the service supply chain under demand uncertainty by constructing a Stackelberg model and explored the interaction between risk aversion and peer competition. Bai et al. [51] constructed a low-carbon supply chain consisting of one manufacturer and one retailer under carbon tax policy and analyzed the impacts of risk aversion on green investment and coordination of supply chain. Zhao et al. [52] explored the impacts of risk attitudes on remanufacturing strategies, expected profits, and coordination methods in a remanufacturing supply chain with market fluctuations. Choi et al. [53] studied how the risk aversion affects consumer welfare and optimal decision-making of the supply chain in a competitive environment.

In conclusion, it is seen that the existing literature only involves the risk aversion in supply chain competition or financing, respectively. The paper considers the competition and risk aversion in the green supply chain to discuss the optimal financing strategies, which are helpful to supply chain management.

2.4. Research gaps

From the literature review, we compare the differences between this paper and recent related literature in four aspects to address the research gap, including (1) financing methods, (2) product types, (3) methodologies, and (4) application scenarios. As shown in Table 1, we recognize that there are important areas that have not been adequately studied, and therefore, we discuss our work from the above four aspects.

All in all, many scholars have conducted in-depth research on supply chain competition and capital constraints from different perspectives, which provides a good research basis for the research theme of this paper.
On the basis of previous research, we consider government green subsidies and risk aversion of supply chain enterprises under the background of fierce market competition and strict environmental protection regulations, introduces debt (bank credit and trade credit) financing and equity financing, and studies the selection of financing strategies of green manufacturing enterprises with capital constraints, as well as the operation decisions of supply chain enterprises.

3. Model description

The paper constructs a two-echelon green competitive supply chain consisting of a risk-neutral common manufacturer M1, a risk-averse green manufacturer M2 and a retailer R. M2 has capital constraints and two financing modes: internal financing in the supply chain-retailer loan financing, or external financing in the supply chain-bank loan financing. This paper will consider three models respectively under risk-averse M2 (denoted by \( u_n, u_r, u_b \)) and three models with capital-constraint M2 when M2 and R are risk-averse at the same time (represented by \( t_n, t_r, t_b \)), as shown in Figure 1.

3.1. Parameter settings

For illustrative purposes, the specific meanings of the parameters in this chapter can be found in Table 2.
Table 2. Parameter meaning.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{a} )</td>
<td>Uncertain market potential demand</td>
</tr>
<tr>
<td>( d_i )</td>
<td>Product demand from two manufacturers ( (i = 1, 2) )</td>
</tr>
<tr>
<td>( c )</td>
<td>Production cost per unit of product</td>
</tr>
<tr>
<td>( I )</td>
<td>Green investment cost factor</td>
</tr>
<tr>
<td>( k_i )</td>
<td>Green product manufacturer M2 and retailer risk aversion factor ( (i = m2, r) )</td>
</tr>
<tr>
<td>( b )</td>
<td>The price competition coefficient of the two products</td>
</tr>
<tr>
<td>( r_i )</td>
<td>Interest rate on financing costs ( (i = b, r) )</td>
</tr>
<tr>
<td>( B )</td>
<td>Own funds from green product manufacturer M2</td>
</tr>
<tr>
<td>( w_i )</td>
<td>Wholesale prices of products from both manufacturers ( (i = 1, 2) )</td>
</tr>
<tr>
<td>( p_i )</td>
<td>The selling price of the product of the two manufacturers ( (i = 1, 2) )</td>
</tr>
<tr>
<td>( e )</td>
<td>Product greenness</td>
</tr>
</tbody>
</table>

3.2. Model assumptions and construction

M1 produces common products and M2 produces green products, and the two products can be substituted for each other in function and sold in the market through R. The unit production cost of common products for M1 is C, but the unit cost of green products includes production cost and green investment for M2. In order to analyze and describe the problem more clearly, the paper makes the following assumptions:

Assumption 1. M1 is dominant due to the large scale and sufficient funds, and determines the wholesale prices of M1 and M2 are \( w_1 \) and \( w_2 \), respectively, then the sale prices are \( p_1 \) and \( p_2 \).

Assumption 2. According to Heydari and Xu [54, 55], the green investment cost is \( C(e) = Ie^2 \), where \( e \) is the greenness of the product, and \( I \) is the cost coefficient of green investment. \( C(e) \) satisfies \( C'(e) > 0 \) and \( C''(e) > 0 \).

Assumption 3. The market information is symmetric, where M1 is risk neutral, and M2 and R are risk averse.

Assumption 4. According to Wu and Shi et al. [56, 57], the demand functions of common products and green products are:

\[
\begin{align*}
    d_1 &= \bar{a} - p_1 + bp_2 \\
    d_2 &= \bar{a} - p_2 + bp_1 + \theta e
\end{align*}
\]

where \( \theta \) represents the green preference coefficient of the consumer, which can be regarded as an important motivation to invest in green production, \( e \) is the product green level, \( \bar{a} = a + \varepsilon \) is the scale of market demand, \( \varepsilon \sim N(0, \sigma^2) \), \( b(0 < b < 1) \) is the cross-pricing sensitivity coefficient.

According to Choi and Xiao [3, 9], the paper also adopts the mean-variance method to measure the decision-making utility of M2 and R. The objective utility function \( U(\pi_j) = E[\pi_j] - k_i \sqrt{Var(\pi_j)} \), \( Var(\pi) = E[\pi_i - E[\pi_i]]^2 \), and \( k(k \geq 0)(i = m2, r) \) is the coefficient of risk aversion. It is easy to know that the larger the value of \( k \), the more conservative the behavior of M2 and R, that is, the degree of risk aversion is higher for M2 and R.

When M2 has sufficient funds without the financing, the profit functions of the supply chain are \( (j = u, t) \):

\[
\begin{align*}
    \pi^u_{m1} &= (w_1 - c)(\bar{a} - p_1 + bp_2) \\
    \pi^u_{m2} &= (w_2 - c)(\bar{a} - p_2 + bp_1 + \theta e) - Ie^2 \\
    \pi^u_r &= (p_1 - w_1)(\bar{a} - p_1 + bp_2) + (p_2 - w_2)(\bar{a} - p_2 + bp_1 + \theta e).
\end{align*}
\]
When the private capital $B$ of M2 is insufficient for green investment, it can seek financing from R with sufficient funds. M2 borrows $L = cd2 + I e^2 - B$ from R and returns $(1 + r_b)L$ after the sale. The profit functions of the supply chain are as follows ($j = u, t$):

$$\pi_{m1}^{jr} = (w_1 - c)(\tilde{a} - p_1 + bp_2)$$

$$\pi_{m2}^{jr} = (w_2 - c)[\tilde{a} - p_2 + bp_1 + \theta e] - I e^2 - r_r L$$

$$\pi_{r}^{jr} = (p_1 - w_1)(\tilde{a} - p_1 + bp_2) + (p_2 - w_2)(\tilde{a} - p_2 + bp_1 + \theta e) + r_r L.$$  

And when $B$ is insufficient for green investment, it can also obtain the capital by borrowing from banks. M2 borrows $L = cd2 + I e^2 - B$ and returns $(1 + r_b)L$ after the sale, $r_b$ is the bank interest rate. The profit functions of the supply chain are as follows ($j = u, t$):

$$\pi_{m1}^{ib} = (w_1 - c)(\tilde{a} - p_1 + bp_2)$$

$$\pi_{m2}^{ib} = (w_2 - c)[\tilde{a} - p_2 + bp_1 + \theta e] - I e^2 - r_b L$$

$$\pi_{r}^{ib} = (p_1 - w_1)(\tilde{a} - p_1 + bp_2) + (p_2 - w_2)(\tilde{a} - p_2 + bp_1 + \theta e).$$

4. Model Analysis

4.1. The model of M2 with risk aversion

This section will consider the optimal decisions of supply chain parties under the three models of un, ur, ub when M1 and R are risk-neutral and M2 is risk-averse.

4.1.1. The model without capital constraints (un)

This section considers the optimal decision-making of the supply chain in the absence of capital constraints when M2 has risk aversion. It can be seen that the expected profits for M1 and R are:

$$E[\pi_{m1}^{un}] = (w_1 - c)(a - p_1 + bp_2)$$

$$E[\pi_{r}^{un}] = (p_1 - w_1)(a - p_1 + bp_2) + (p_2 - w_2)(a - p_2 + bp_1 + \theta e).$$

The expected profit and variance of M2 are:

$$E[\pi_{m2}^{un}] = (w_2 - c)(a - p_2 + bp_1 + \theta e) - I e^2$$

$$Var(\pi_{m2}^{un}) = E[\pi_{m2}^{un} - E[\pi_{m2}^{un}]]^2 = (w_2 - c)^2 \sigma^2.$$  

The utility function of M2 is:

$$U_{(\pi_{m2}^{un})} = E[\pi_{m2}^{un}] - k_{m2} \sqrt{Var(\pi_{m2}^{un})} = (w_2 - c)(a - p_2 + bp_1 + \theta e) - I e^2 - k_{m2}(w_2 - c)\sigma.$$  

According to the Stackelberg game between the two manufacturers and the retailer in Assumption 1, the reverse induction method is used to solve the problem. The optimal solution expression of the reference [58] can be obtained. The optimal decision and demand of all parties in the supply chain are:

$$w_{1}^{un*} = \frac{(a + c)(4I(2 + b^2) - \theta^2) - 4Ib(bc + 2k_{m2}\sigma) - bc\theta^2}{2[4I(2 - b^2) - \theta^2]}; \quad w_{2}^{un*} = \frac{4I(a + c + bw_{1}^{un*}) - 8Ik_{m2}\sigma - c\theta^2}{8I - \theta^2};$$

$$p_{1}^{un*} = \frac{a(1 + b) + w_{1}^{un*}(1 - b^2) + b\theta e_{un*}^*}{2(1 - b^2)}; \quad p_{2}^{un*} = \frac{a(1 + b) + w_{2}^{un*}(1 - b^2) + \theta e_{un*}^*}{2(1 - b^2)};$$

$$e_{un*}^* = \frac{(a - c + bw_{1}^{un*} - 2k_{m2}\sigma)\theta}{8I - \theta^2}; \quad d_{1}^{un*} = \frac{(a - c)(8I - \theta^2) + 4Ib(a + c + bc - 2k_{m2}\sigma) - bc\theta^2}{2(8I - \theta^2)};$$

$$d_{2}^{un*} = \frac{(a - c)(8I - \theta^2) + 4Ib(a + c + bc - 2k_{m2}\sigma) - bc\theta^2}{2(8I - \theta^2)};$$
4.1.2. Internal financing from the retailer under risk-averse M2 (ur)

The section considers that M2 is risk-averse and capital-constrained, and obtains the financing from the retailer. The expected profits for M1 and R are:

\[
E[\pi_{m1}^{ur}] = (w_1 - c)(a - p_1 + bp_2)
\]
\[
E[\pi_{r}^{ur}] = (p_1 - w_1)(a - p_1 + bp_2) + (p_2 - w_2)(a - p_2 + bp_1 + \theta c) + r_r L.
\]

The expected profit of M2 is:

\[
E[\pi_{m2}^{ur}] = (w_2 - c)(a - p_2 + bp_1 + \theta c) - Ie^2 - r_r L.
\]

The utility function of M2 is:

\[
U(\pi_{m2}^{ur}) = E[\pi_{m2}^{ur}] - k_{m2}\sqrt{Var(\pi_{m2}^{ur})} = (w_2 - c)(a - p_2 + bp_1 + \theta c) - Ie^2 - r_r L - k_{m2}[w_2 - c(1 + r_r)]\sigma.
\]

Similarly, using the reverse induction method to solve the problem, the optimal decisions of the supply chain can be obtained as follows:

\[
d_1^{ur*} = \frac{(8I - \theta^2)[2I(a - c) + Ib(a + c)] - 4I^2b^2(a + bc) + 8I^2k_{m2}\sigma(4 - 3b^2)}{-4Ik_{m2}\sigma\theta^2(3 - b^2) + Ib^2c(12I - \theta^2) + k_{m2}\sigma\theta^4}.
\]

\[
E\left[\pi_{m1}^{ur*}\right] = \frac{(w_1^{ur*} - c)[(a - c)(8I - \theta^2) + 4Ib(a + c + bc - 2k_{m2}\sigma) - bc\theta^2]}{2(8I - \theta^2)};
\]

\[
E\left[\pi_{r}^{ur*}\right] = \frac{(p_1^{ur*} - w_1^{ur*})[(a - c)(8I - \theta^2) + 4Ib(a + c + bc - 2k_{m2}\sigma) - bc\theta^2]}{2(8I - \theta^2)} + \frac{(p_2^{ur*} - w_2^{ur*})[I(8I - \theta^2)(2(a - c) + b(a + c)] - 4I^2b^2(a + bc) + 8I^2k_{m2}\sigma(4 - 3b^2)}{4I(2 - b^2) - \theta^2}(8I - \theta^2);
\]

\[
U\left(\pi_{m2}^{ur*}\right) = \frac{4I(a + c + bw_1^{ur*}) - 8I(k_{m2}\sigma + c)(d_2^{ur*} - k_{m2}\sigma) - I(e^{ur*})^2(8I - \theta^2)}{8I - \theta^2}.
\]

See Appendix A for proof. The following solution process is similar, so it is omitted.
\[
E \left[ \pi_{ur}^* \right] = \frac{(p_{1ur}^* - w_{1ur}^*) \left[ 4I(1 + r_r) \{ b(a + c + bc - 2k_{m2}\sigma) + 2(a - c) - (a - c + bc)\theta^2 \} \right]}{4[8I(1 + r_r) - \theta^2]}, \\
+ \frac{(p_{2ur}^* - w_{2ur}^* + r_r e_c) \left[ a + bw_{1ur}^* + cr_r + \theta e_{ur}^* - w_{2ur}^* \right] + 2r_r \left[ I(e_{ur}^*)^2 - B \right]}{2}, \\
U_{(\pi_{m2}^{ub})} = \frac{[w_{2ur}^* - c(1 + r_r)] (a + bw_{1ur}^* + cr_r + \theta e_{ur}^* - w_{2ur}^* - 2k_{m2}\sigma) - 2 \left[ I(e_{ur}^*)^2 (1 + r_r) - r_r B \right]}{2}.
\]

4.1.3. External financing from the bank under risk-averse M2 (ub)

We consider the financing from banks when M2 is risk-averse and capital-constrained. The expected profits for M1 and R are:

\[
E[\pi_{m1}^{ub}] = (w_1 - c)(a - p_1 + b_p2) \\
E[\pi_{r}^{ub}] = (p_1 - w_1)(a - p_1 + b_p2) + (p_2 - w_2)(a - p_2 + b_p1 + \theta e).
\]

The expected profit of M2 is:

\[
E[\pi_{m2}^{ub}] = (w_2 - c)(a - p_2 + b_p1 + \theta e) - Ie^2 - r_b L.
\]

The utility function of M2 is:

\[
U_{(\pi_{m2}^{ub})} = E[\pi_{m2}^{ub}] - k_{m2}\sqrt{Var(\pi_{m2}^{ub})} = (w_2 - c)(a - p_2 + b_p1 + \theta e) - Ie^2 - r_b L - k_{m2}[w_2 - c(1 + r_b)]\sigma.
\]

Similarly, using the reverse induction method to solve the problem, the optimal decisions supply chain can be obtained as follows:

\[
w_{1ur}^{ub*} = \frac{(1 + r_b) \left[ 4I[(a + c)(2 + b) - b(bc + 2k_{m2}\sigma) + bcr_b - bcd\theta^2] - (a + c)\theta^2 \right]}{2[4I(1 + r_b)(2 - b^2) - \theta^2]}, \\
d_{2ur}^{ub*} = \frac{a + bw_{1ur}^{ub*} + \theta e_{ub}^* - w_{2ur}^{ub*}}{2}, \\
e_{ub}^* = \frac{(a + bw_{1ur}^{ub*} - 2k_{m2}\sigma)\theta - (1 + r_b)e\theta}{8I(1 + r_b) - \theta^2}, \\
p_{1ur}^{ub*} = \frac{a(1 + b) + w_{1ur}^{ub*} (1 - b^2) + b\theta e_{ub}^*}{2(1 - b^2)}, \\
p_{2ur}^{ub*} = \frac{a(1 + b) + w_{2ur}^{ub*} (1 - b^2) + \theta e_{ub}^*}{2(1 - b^2)}, \\
d_{1ur}^{ub*} = \frac{(a - c) \left[ 8I(1 + r_b) - \theta^2 \right] + b(1 + r_b) \left[ 4I(a + c(1 + r_b + b - 2k_{m2}\sigma) - c\theta^2 \right]}{4[8I(1 + r_b) - \theta^2]}, \\
E[\pi_{m1}^{ub*}] = \frac{\{(a - c) \left[ 8I(1 + r_b) - \theta^2 \right] + 4Ib(1 + r_b) \left[ a + c(1 + r_b + b - \theta^2) - 2k_{m2}\sigma \right] \}^2}{8[8I(1 + r_b) - \theta^2][4I(1 + r_b)(2 - b^2) - \theta^2]}, \\
E[\pi_{r}^{ub*}] = \frac{\{(p_{1ur}^{ub*} - w_{1ur}^{ub*}) \left( (a - c) \left[ 8I(1 + r_b) - \theta^2 \right] + b(1 + r_b) \left[ 4I(a + c(1 + r_b + b - 2k_{m2}\sigma) - c\theta^2 \right] \}^2}{4[8I(1 + r_b) - \theta^2]} \\
+ \frac{(p_{2ur}^{ub*} - w_{2ur}^{ub*}) \left( a + bw_{1ur}^{ub*} - w_{2ur}^{ub*} + \theta e_{ub}^* \right)}{2}, \\
U_{(\pi_{m2}^{ub})} = \frac{[w_{2ur}^{ub*} - c(1 + r_b)] (a + bw_{1ur}^{ub*} - w_{2ur}^{ub*} + \theta e_{ub}^* - 2k_{m2}\sigma) - 2 \left[ I(e_{ub}^*)^2 (1 + r_b) - r_r B \right]}{2}.
\]

**Corollary 1.** \(\frac{\partial p_{1ur}^{A*}}{\partial k_{m2}} < 0; \frac{\partial w_{1ur}^{A*}}{\partial k_{m2}} < 0; \frac{\partial e_{ur}^{A*}}{\partial k_{m2}} < 0; \frac{\partial p_{1ur}^{A*}}{\partial k_{m2}} > 0; \frac{\partial d_{1ur}^{A*}}{\partial k_{m2}} > 0; \frac{\partial E[\pi_{m1}^{A*}]}{\partial k_{m2}} < 0; \frac{\partial E[\pi_{r}^{A*}]}{\partial k_{m2}} > 0; \frac{\partial U_{(\pi_{m2}^{A*})}}{\partial k_{m2}} < 0\) \((A = un, ur, ub, i = 1, 2), \text{See Appendix B for proof.}\)
It can be seen from Corollary 1 that no matter if M2 has sufficient funds or capital constraint, whether internal or external financing of the supply chain is adopted, the impacts of risk aversion on the decisions of the supply chain are opposite except the demand and the retailer’s expected profit.

First of all, when the degree of risk aversion of M2 is relatively large, it means that there is a large difference between the expected market demand of M2 and the actual demand, that is to say, the increase in the degree of risk aversion of M2 is equivalent to the decrease in its expected demand, so M2 will reduce investment in green technology, which will lead to a reduction in the greenness of products; at the same time, in order to promote its sales, M2 will reduce the wholesale price, thereby reducing the sales price, but we find that the wholesale price of M2 falls faster than its demand grows, so the target utility of M2 decreases as its risk aversion increases.

For the risk-neutral M1, due to product competition, the reduction of M2’s wholesale price and sales price will inevitably lead to “vicious price competition”, which will lead to the reduction of M1’s wholesale price, sales price, and the demand, mainly because the increase in the demand of M2 products squeezed the original market share of M1 products. Therefore, the expected profit of M1 decreased with the increase of the degree of risk aversion of M2.

Combining the decision changes of M1 and M2, for risk-neutral R, the decline in the wholesale price of M1’s product reduces its cost, and the decline in cost exceeds the decline in sales price and demand. However, the growth rate of M2’s demand far exceeds the decline rate of the sales price. Therefore, R’s expected profit increases with the increase of M2’s risk aversion, and R is more willing to cooperate with risk-averse M2.

Combined with the above analysis, it can be seen that the impact of changes in the degree of risk aversion of M2 will not change with the changes in its financing model. However, we find that M2’s concerns about the transition of future market uncertainties and risks will increase its market share, but it is not conducive to its long-term development. Excessive price cuts may make it “debt high” and face insolvency. At the same time, it will have an adverse impact on competitors in the same industry, causing market “shocks” and increasing market uncertainty and risks. Therefore, M2 should maintain moderate risk concerns, seize the opportunity under the general trend of green economic development, increase investment in green products, and improve its own competitive advantage.

4.2. The models under risk-averse M2 and R

In this section, this paper will consider the decision-making of the supply chain under the three models of \(tn, tr, tb\) when M1 is risk-neutral and M2 and R are both risk-averse.

4.2.1. The model of risk-averse M2 and R without capital constraints (tn)

We consider the optimal decision-making of the supply chain when M2 and R are both risk-averse and M2 has no capital constraints. According to the previous description can be obtained.

The expected profit of M1 is:

\[
E[\pi_{m1}^{tn}] = (w_1 - c)(a - p_1 + b_p_2).
\]

The expected profit and variance of R are:

\[
E[\pi_r^{tn}] = (p_1 - w_1)(a - p_1 + b_p_2) + (p_2 - w_2)(a - p_2 + b_p_1 + \theta e)
\]
\[
Var(\pi_r^{tn}) = E[\pi_r^{tn} - E[\pi_r^{tn}]]^2 = [(p_1 - w_1) + (p_2 - w_2)]^2 \sigma^2.
\]

The utility function of R is:

\[
U(\pi_r^{tn}) = E[\pi_r^{tn}] - k_r \sqrt{Var(\pi_r^{tn})}
\]
\[
= (p_1 - w_1)(a - p_1 + b_p_2) + (p_2 - w_2)(a - p_2 + b_p_1 + \theta e) - k_r[(p_1 - w_1) + (p_2 - w_2)]\sigma.
\]

The expected profit and variance of M2 are:
The utility function of M2 is:

\[ U(\pi_{m2}^{tn}) = \sqrt{\text{Var}(\pi_{m2}^{tn})} = (w_2 - c)(a - p_2 + b + \theta e) - Ie^2 - k_{m2}(w_2 - c)\sigma. \]

Similarly, using the reverse induction method to solve the problem, the optimal decisions of the supply chain can be obtained as follows:

\[
\begin{align*}
\pi_{m1}^{tn} &= \left(4Ib + 8I - \theta^2\right)(a + c) + 4I[k_\sigma(2 + b) - b(bc - 2k_{m2}\sigma)] - (bc + k_\sigma)\theta^2; \\
\pi_{m2}^{tn} &= 4I\left[a + c + k_\sigma + b\pi_{m1}^{tn} - 2k_{m2}\sigma\right] - c\theta^2; \\
p_1^{tn} &= \frac{(a - k_\sigma)(1 + b) + \pi_{m1}^{tn}(1 - b^2) + \theta e_{m1}^{tn}}{8I - \theta^2}; \\
p_2^{tn} &= \frac{(a - k_\sigma)(1 + b) + \pi_{m1}^{tn}(1 - b^2) + \theta e_{m1}^{tn}}{2(1 - b^2)}; \\
d_1^{tn} &= \frac{(8I - \theta^2)(a - c) + 4I[k_\sigma(2 + b) + b(bc - 2k_{m2}\sigma)] + 4Ib(a + c) - (bc + k_\sigma)\theta^2}{4(8I - \theta^2)}; \\
d_2^{tn} &= \frac{a + \pi_{m1}^{tn} + \theta e_{m1}^{tn} + k_\sigma - \pi_{m2}^{tn}}{2}.
\end{align*}
\]

4.2.2. Internal financing from the retailer under risk-averse M2 and R (tr)

When M2 and R are both risk-averse and M2 is capital-constrained, the optimal decision-making of the supply chain is considered, we can get.

The expected profit of M1 is:

\[ E[\pi_{m1}^{tr}] = (w_1 - c)(a - p_1 + b + p_2). \]

The expected profit and variance of risk aversion R are:

\[ E[\pi_{r}^{tr}] = (p_1 - w_1)(a - p_1 + b + p_2) + (p_2 - w_2)(a - p_2 + b + p_1 + \theta e) + r_L. \]

\[ \text{Var}(\pi_{r}^{tr}) = E[\pi_{r}^{tr} - E[\pi_{r}^{tr}]]^2 = [(p_1 - w_1) + (p_2 - w_2)]^2\sigma^2. \]

The utility function of R is:

\[ U(\pi_r^{tr}) = \sqrt{\text{Var}(\pi_r^{tr})} = (p_1 - w_1)(a - p_1 + b + p_2) + (p_2 - w_2)(a - p_2 + b + p_1 + \theta e) + r_L - k_r[(p_1 - w_1) + (p_2 - w_2) + r_L]\sigma. \]

The expected profit and variance of M2 are:
The expected profit of M1 is:

\[
\pi_{m1} = \frac{4I(1 + r_r) \left[ (2 + b)(a + c + k_r) - b(b^2 + 2k_{m2}^2) \right] - (a + c + bc + k_r\sigma)\theta^2}{2[4I(1 + r_r)(2 - b^2) - \theta^2]};
\]

\[
w_1^{tr*} = \frac{(1 + r_r)\left[ 4I(a + c + 2cr_r + k_r\sigma + bw_1^{tr*} - 2k_{m2}^2\sigma) - cd^2 \right]}{8I(1 + r_r) - \theta^2};
\]

\[
p_1^{tr*} = \frac{(1 + b)(a - k_r\sigma + w_1^{tr*}(1 - b^2) + \theta e^{t_r*})}{2(1 - b^2)};
\]

\[
d_1^{tr*} = \frac{4I(1 + r_r)[b(a + c) + 2(a - c) + 2k_r\sigma(1 + b) + b^2c - 2bk_{m2}^2] - (a + c + bc + k_r\sigma)\theta^2}{4[8I(1 + r_r) - \theta^2]};
\]

\[
U(\pi_{m1}) = \frac{\{ (1 + r_r)\left[ 4I(a + c + 2cr_r + k_r\sigma + bw_1^{tr*} - 2k_{m2}^2\sigma) - cd^2 \right] - (1 + r_r)c[8I(1 + r_r) - \theta^2] \}}{8I(1 + r_r) - \theta^2};
\]

\[
U(\pi_{m1}^{tr*}) = \frac{(p_1^{tr*} - w_1^{tr*}) \left[ (d_1^{tr*} - k_r\sigma) \right] + (p_2^{tr*} - w_2^{tr*}) \left[ (d_2^{tr*} - k_r\sigma) + r_r \left( cd_2^{tr*} + I(e^{t_r*})^2 - Br_r \right) \right]}{8I(1 + r_r) - \theta^2}.
\]

4.2.3. External financing from the bank under risk-averse R and M2 (tb)

This paper considers the optimal decision of the supply chain when M2 and R are both risk-averse and M2 has capital constraints, and M2 provides financing to financial institutions such as external banks in the supply chain, and we can get.

The expected profit of M1 is:

\[
E[\pi_{m1}^{tb}] = (w_1 - c)(a - p_1 + bp_2).
\]

The expected profit and variance of risk aversion R are:

\[
E[\pi_r^{tb}] = (p_1 - w_1)(a - p_1 + bp_2) + (p_2 - w_2)(a - p_2 + bp_1 + \theta e);
\]

\[
V_r = E[\pi_r^{tb} - E[\pi_r^{tb}]^2 = [(p_1 - w_1) + (p_2 - w_2)]^2 \sigma^2.
\]

The utility function of R is:

\[
U(\pi_r^{tb}) = E[\pi_r^{tb}] - k_r \sqrt{Var(\pi_r^{tb})} = (p_1 - w_1)(a - p_1 + bp_2) + (p_2 - w_2)(a - p_2 + bp_1 + \theta e) - k_r[(p_1 - w_1) + (p_2 - w_2)]\sigma.
\]
The expected profit and variance of $M_2$ are:

\[
E[\pi_{m_2}^{tb}] = (w_2 - c)[a - p_2 + b p_1 + \theta e] - I e^2 - r_b L
\]

\[
Var(\pi_{m_2}^{tb}) = E[\pi_{m_2}^{tb} - E[\pi_{m_2}^{tb}]]^2 = [w_2 - c(1 + r_b)]^2 \sigma^2.
\]

The utility function of $M_2$ is:

\[
U(\pi_{m_2}^{tb}) = E[\pi_{m_2}^{tb}] - k m_2 \sqrt{Var(\pi_{m_2}^{tb})} = (w_2 - c)(a - p_2 + b p_1 + \theta e) - I e^2 - r_b L - k m_2[w_2 - c(1 + r_b)] \sigma.
\]

Similarly, using the reverse induction method to solve the problem, the optimal decisions and demands of the supply chain can be obtained as follows:

\[
w_1^{tb} = \frac{4I(1 + r_b)[(2 + b)(a + c + k r) - bc(b - r_b) - 2bk m_2 \sigma] - [a + c + c(b + 1 + r_b) + k r] \theta^2}{2[4I(1 + r_b)(2 - b^2) - \theta^2]};
\]

\[
w_2^{tb} = \frac{(1 + r_b)[4I(a + c + k r + c r_b + b w_1^{rb} - 2k m_2 \sigma) - c \theta^2]}{8I(1 + r_b) - \theta^2}; \quad \epsilon = \frac{c}{8I(1 + r_b) - \theta^2};
\]

\[
p_1^{tb} = \frac{(1 + b)(a - k r) + w_1^{rb}(1 - b^2) + b \epsilon \theta}{2(1 - b^2)}; \quad p_2^{tb} = \frac{(1 + b)(a - k r) + (w_2^{rb} - c r_b)(1 - b^2) + \theta \epsilon \theta}{2(1 - b^2)};
\]

\[
d_1^{tb} = \frac{4I(1 + r_b)[2(a - c) + b(a + c) + bc(b + r_b) + k r(2 + b) - 2bk m_2 \sigma] - [a + c + c(b + 1 + r_b) + k r] \theta^2}{8I(1 + r_b) - \theta^2};
\]

\[
d_2^{tb} = \frac{a - w_2^{rb} + b w_1^{rb} + c r_b + k r \epsilon \theta}{2};
\]

\[
U(\pi_{m_1}^{tb}) = \frac{(p_1^{tb} - w_1^{tb})(d_1^{tb} - k r) + (p_2^{tb} - w_2^{tb})(d_2^{tb} - k r)\sigma}{8I(1 + r_b)(2 - b^2) - \theta^2};
\]

\[
E[\pi_{m_1}^{tb}] = \frac{4I(1 + r_b)[2(a - c) + b(a + c) + bc(b + r_b) + k r(2 + b) - 2bk m_2 \sigma] - [a + c + c(b + 1 + r_b) + k r] \theta^2}{8I(1 + r_b)(2 - b^2) - \theta^2};
\]

\[
\left\{\begin{array}{l}
(1 + r_b)[4I(a + c + k r + c r_b + b w_1^{rb} - 2k m_2 \sigma) - c \theta^2] - (1 + r_b)c \left[8I(1 + r_b) - \theta^2\right]\end{array}\right\}
\]

\[
U(\pi_{m_2}^{tb}) = \frac{8I(1 + r_b) - \theta^2}{8I(1 + r_b) - \theta^2}.
\]

**Corollary 2.** If $M_2$ adopts internal or external financing in the supply chain when it has sufficient funds or is constrained by funds, or whether $M_2$ has risk aversion behavior alone or with $R$ at the same time, the risk aversion degree of $M_2$ has an impact on the decision-making of all parties in the supply chain is consistent. This shows that the impact of changes in the degree of risk aversion of $M_2$ does not change with the changes in the behavior of supply chain partners.

**Corollary 3.** If $M_2$ has sufficient funds or there are capital constraints, the internal or external financing of the supply chain is adopted, and the risk aversion degree of $R$ has the same impact on the decision-making of the supply chain. That is, the degree of risk aversion of $R$ is negatively correlated with the sales price of the two products and positively correlated with the wholesale price and demand of the two products, the greenness of $M_2$, the expected profit of $M_1$, and the target utility of $M_2$. **See Appendix C for proof.**
Table 3. Impacts of retailer financing interest rate $r_r$ on supply chain decisions ($k_x = 0.2; r_r = [0, 0.2]$).

<table>
<thead>
<tr>
<th>$r_r$</th>
<th>$p_1^{w*}$</th>
<th>$p_2^{w*}$</th>
<th>$w_1^{r*}$</th>
<th>$w_2^{r*}$</th>
<th>$w_3^{r*}$</th>
<th>$d_1^{r*}$</th>
<th>$d_2^{r*}$</th>
<th>$E[\pi^{m_1*}]$</th>
<th>$E[\pi^{m_2*}]$</th>
<th>$U(\pi^{m_1*})$</th>
<th>$U(\pi^{m_2*})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>142.19</td>
<td>144.01</td>
<td>78.81</td>
<td>76.88</td>
<td>16.72</td>
<td>35.44</td>
<td>35.44</td>
<td>2051.6</td>
<td>4269.1</td>
<td>2096.8</td>
<td>2096.8</td>
</tr>
<tr>
<td>0.04</td>
<td>142.04</td>
<td>143.69</td>
<td>78.74</td>
<td>77.09</td>
<td>16.03</td>
<td>35.35</td>
<td>35.35</td>
<td>2048.7</td>
<td>4251.7</td>
<td>2098.4</td>
<td>2098.4</td>
</tr>
<tr>
<td>0.08</td>
<td>141.91</td>
<td>143.39</td>
<td>78.69</td>
<td>77.32</td>
<td>15.40</td>
<td>35.26</td>
<td>35.26</td>
<td>2046.0</td>
<td>4234.7</td>
<td>2100.5</td>
<td>2100.5</td>
</tr>
<tr>
<td>0.12</td>
<td>141.79</td>
<td>143.12</td>
<td>78.63</td>
<td>77.56</td>
<td>14.81</td>
<td>35.18</td>
<td>35.18</td>
<td>2043.5</td>
<td>4218.0</td>
<td>2103.1</td>
<td>2103.1</td>
</tr>
<tr>
<td>0.16</td>
<td>141.67</td>
<td>142.86</td>
<td>78.58</td>
<td>77.81</td>
<td>14.27</td>
<td>35.11</td>
<td>35.11</td>
<td>2041.2</td>
<td>4201.7</td>
<td>2106.0</td>
<td>2106.0</td>
</tr>
<tr>
<td>0.20</td>
<td>141.56</td>
<td>142.63</td>
<td>78.54</td>
<td>78.08</td>
<td>13.77</td>
<td>35.04</td>
<td>35.04</td>
<td>2039.0</td>
<td>4185.8</td>
<td>2109.3</td>
<td>2109.3</td>
</tr>
</tbody>
</table>

From the analysis of the model itself, the risk-averse behavior of $R$ will make it lower its expectation of market demand, thereby reducing the sales price of the product to increase the sales volume and avoid unsalable products. The lower sales price will increase the expectations of $M_1$ and $M_2$ for demand, thereby increasing the wholesale price of the product. For $M_2$, it will increase investment in green technology according to expectations, and the green degree of $M_2$ products will increase accordingly. Although $M_1$ and $M_2$ are in a competitive relationship, the wholesale prices of $M_1$ and $M_2$ have achieved steady growth in line with demand. Therefore, the expected profit of $M_1$ and the target utility of $M_2$ increase with the degree of risk aversion of $R$.

Based on the above analysis, it can be seen that $R$’s risk aversion is beneficial to supply chain members and is conducive to maintaining the market competition. But it will have a negative effect on the sales of its own products, and an excessive reduction in the sales price will cause $R$ to suffer huge losses. Therefore, $R$ should not be too pessimistic and negative when making anticipative judgments on the market, while maintaining an appropriate degree of risk aversion. It should strengthen cooperation with upstream companies in the supply chain to deal with market uncertainty together. For $M_1$ and $M_2$, they are more willing to cooperate with risk-averse $R$ because $R$ brings them great rewards.

5. Numerical analysis

According to Sun et al. [59], the analysis is carried out through assignment simulation because the related calculation results are complex and difficult to compare. At the same time, for the sake of comparison, it is assumed that the rates of retailer financing and bank financing are equal. According to Zhou et al. [60], the relevant parameters are set under satisfying all the conditions and assumptions as follows: $a = 100, b = 0.5, c = 10, B = 200, \sigma = 10, k_x = [0, 1]([x = m n 2, r], r_i = [0, 0.2](i = r, b)$.

Corollary 4. According to Table 3, whether $M_2$ is risk-averse by itself or with $R$ at the same time, when $M_2$ finances from $R$, the financing interest rate is positively correlated with $M_2$’s wholesale price and utility but is positively correlated with the sales price and demand of two products, but the wholesale price of $M_1$ is negatively correlated with the expected profit, the greenness of $M_2$, the retailer’s expected profit, and the utility.

First of all, the increase in financing interest rate will inevitably lead to the increase in $M_2$’s cost, which will lead to chain reactions such as an increase in the wholesale price of products, greenness, and a decline in demand. At the same time, $R$ takes price reduction measures to prevent unsalable sales, so the sales price falls.
Table 4. Impacts of bank financing interest rate $r_b$ on supply chain decisions ($k_x = 0.2; r_b = [0, 0.2]$).

<table>
<thead>
<tr>
<th>$r_b$</th>
<th>$p_{1b}^{ur}$</th>
<th>$p_{2b}^{ur}$</th>
<th>$w_{1b}^{ur}$</th>
<th>$w_{2b}^{ur}$</th>
<th>$e^{ur}$</th>
<th>$d_{1b}^{ur}$</th>
<th>$d_{2b}^{ur}$</th>
<th>$E[\pi_{m1}^{ur}]$</th>
<th>$E[\pi_{r}^{ur}]$</th>
<th>$U(\pi_{m1}^{ur})$</th>
<th>$U(\pi_{r}^{ur})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>142.19</td>
<td>144.01</td>
<td>78.808</td>
<td>76.88</td>
<td>16.72</td>
<td>29.817</td>
<td>35.44</td>
<td>2051.6</td>
<td>4269.1</td>
<td>2096.8</td>
<td></td>
</tr>
<tr>
<td>0.04</td>
<td>142.06</td>
<td>143.78</td>
<td>78.799</td>
<td>76.90</td>
<td>15.98</td>
<td>29.825</td>
<td>35.25</td>
<td>2051.9</td>
<td>4244.2</td>
<td>2086.0</td>
<td></td>
</tr>
<tr>
<td>0.08</td>
<td>41.95</td>
<td>143.57</td>
<td>78.795</td>
<td>76.93</td>
<td>15.31</td>
<td>29.834</td>
<td>35.06</td>
<td>2052.4</td>
<td>4220.7</td>
<td>2075.8</td>
<td></td>
</tr>
<tr>
<td>0.12</td>
<td>141.84</td>
<td>143.38</td>
<td>78.796</td>
<td>76.97</td>
<td>14.68</td>
<td>29.844</td>
<td>34.88</td>
<td>2053.2</td>
<td>4198.3</td>
<td>2066.1</td>
<td></td>
</tr>
<tr>
<td>0.16</td>
<td>141.75</td>
<td>143.21</td>
<td>78.801</td>
<td>77.03</td>
<td>14.10</td>
<td>29.856</td>
<td>34.71</td>
<td>2054.1</td>
<td>4176.9</td>
<td>2056.9</td>
<td></td>
</tr>
<tr>
<td>0.20</td>
<td>141.67</td>
<td>143.07</td>
<td>78.810</td>
<td>77.09</td>
<td>13.56</td>
<td>29.868</td>
<td>34.55</td>
<td>2055.2</td>
<td>4156.5</td>
<td>2048.2</td>
<td></td>
</tr>
</tbody>
</table>

At the same time, the wholesale price of M2 rises faster than their demand declines, so the target utility of M2 increases with the increase in the financing interest rate. For M1, due to product competition, it can only take price reduction measures to cope with the competition, so its sales price is also reduced accordingly, but its demand does not increase accordingly, because the increase in the demand for M2’s products squeezes M1’s products market, so the expected profit of M1 is negatively related to the financing interest rate. Combining the decision analysis of M1 and M2, it can be seen that the expected profit and target utility of R are also negatively related to the financing interest rate.

Corollary 5. According to Table 4, whether M2 is risk-averse by itself or with R at the same time, when M2 finances from the bank, the financing interest rate is positively correlated with M2’s wholesale price, M1’s demand, and expected profit, and M1’s wholesale price is first rising after falling, but it is negatively correlated with the sales price of the two products, the greenness of M2, the demand and target utility, and the expected profit and target utility of R.

Similarly, the impacts of financing interest rate on M2’s decision are the same as those of M2’s financing mode from the retailer. However, the impacts on M1 are different. In order to compete with M2, M1 reduces the wholesale price at the beginning of the period to promote the sales. In the later stage, under the decrease in demand because of the increase of M2’s cost, R bought the products from M1, so the wholesale price of its products increased, but its sales price does not increase for reducing the inventory, which leads to the decrease in the sales price of M1 to a certain extent, so the expected profit of M1 rises with the increase of the financing interest rate. Combining the analysis of M1 and M2, it can be seen that the expected profit and target utility of R are also negatively related to the financing interest rate.

Combining Corollaries 4 and 5, it can be seen that whether M2 is risk-averse by itself or with R at the same time, the effects of M2’s financing from the retailer or bank are completely different when M2 has capital constraints. The impacts don’t change with the changes of risk aversion in the supply chain. According to financing methods, M2 is more willing to finance from the retailer, but the rate should not be set too high when R provides financial assistance to M2, otherwise it will be unfavorable to itself, so the rate should be set based on “win–win” negotiation.

Corollary 6. According to Table 5, there are regular changes in the vertical comparison as follows ($j = u, t; i = 1, 2$):
GREEN FINANCING STRATEGIES UNDER RISK AVERSION AND MANUFACTURER COMPETITION

1943

Table 5. Decision comparison of the supply chain ($r_1 = 0.2; k_r = 0.2; k_{m2} = 0 : 0.2 : 1$).

<table>
<thead>
<tr>
<th>$k_{m2}$</th>
<th>$p_{1u}^{*}$</th>
<th>$p_{1l}^{*}$</th>
<th>$p_{1u}^{th}$</th>
<th>$p_{1l}^{th}$</th>
<th>$p_{2u}^{*}$</th>
<th>$p_{2l}^{*}$</th>
<th>$p_{2u}^{th}$</th>
<th>$p_{2l}^{th}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>142.59</td>
<td>141.95</td>
<td>142.05</td>
<td>141.39</td>
<td>140.72</td>
<td>140.83</td>
<td>145.35</td>
<td>143.92</td>
</tr>
<tr>
<td>0.2</td>
<td>142.19</td>
<td>141.56</td>
<td>141.67</td>
<td>140.98</td>
<td>140.34</td>
<td>140.44</td>
<td>144.01</td>
<td>142.63</td>
</tr>
<tr>
<td>0.4</td>
<td>141.79</td>
<td>141.28</td>
<td>141.28</td>
<td>140.58</td>
<td>139.96</td>
<td>140.06</td>
<td>142.67</td>
<td>141.33</td>
</tr>
<tr>
<td>0.6</td>
<td>141.38</td>
<td>140.80</td>
<td>140.90</td>
<td>140.90</td>
<td>139.58</td>
<td>139.68</td>
<td>141.33</td>
<td>140.04</td>
</tr>
<tr>
<td>0.8</td>
<td>140.98</td>
<td>140.42</td>
<td>140.52</td>
<td>139.77</td>
<td>139.19</td>
<td>139.30</td>
<td>139.99</td>
<td>138.75</td>
</tr>
<tr>
<td>1</td>
<td>140.58</td>
<td>140.03</td>
<td>140.13</td>
<td>139.37</td>
<td>138.81</td>
<td>138.91</td>
<td>138.65</td>
<td>137.46</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$k_{m2}$</th>
<th>$w_{1}^{un}$</th>
<th>$w_{1}^{ur}$</th>
<th>$w_{1}^{ub}$</th>
<th>$w_{1}^{tr}$</th>
<th>$w_{1}^{tb}$</th>
<th>$w_{2}^{un}$</th>
<th>$w_{2}^{ur}$</th>
<th>$w_{2}^{ub}$</th>
<th>$w_{2}^{tr}$</th>
<th>$w_{2}^{tb}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>79.42</td>
<td>79.15</td>
<td>79.43</td>
<td>80.88</td>
<td>80.60</td>
<td>80.89</td>
<td>79.18</td>
<td>80.35</td>
<td>79.36</td>
<td>80.64</td>
</tr>
<tr>
<td>0.2</td>
<td>79.81</td>
<td>78.54</td>
<td>78.82</td>
<td>80.27</td>
<td>79.99</td>
<td>80.28</td>
<td>76.88</td>
<td>78.08</td>
<td>77.09</td>
<td>78.34</td>
</tr>
<tr>
<td>0.4</td>
<td>79.19</td>
<td>77.93</td>
<td>78.20</td>
<td>79.65</td>
<td>79.39</td>
<td>79.66</td>
<td>74.58</td>
<td>75.81</td>
<td>74.82</td>
<td>76.04</td>
</tr>
<tr>
<td>0.6</td>
<td>77.58</td>
<td>77.32</td>
<td>77.59</td>
<td>79.04</td>
<td>78.78</td>
<td>79.05</td>
<td>72.29</td>
<td>73.54</td>
<td>72.55</td>
<td>73.74</td>
</tr>
<tr>
<td>0.8</td>
<td>76.96</td>
<td>76.72</td>
<td>76.99</td>
<td>78.42</td>
<td>78.17</td>
<td>78.44</td>
<td>69.99</td>
<td>71.27</td>
<td>70.28</td>
<td>71.45</td>
</tr>
<tr>
<td>1</td>
<td>76.35</td>
<td>76.11</td>
<td>76.38</td>
<td>77.81</td>
<td>77.56</td>
<td>77.84</td>
<td>67.69</td>
<td>69.00</td>
<td>68.01</td>
<td>69.15</td>
</tr>
</tbody>
</table>

(1) $p_{1u}^{jr} > p_{1l}^{jr} > p_{1u}^{tr}$. The sales price of both products is the highest in the $jn$ model and the lowest in the $jr$ model. Combining Corollaries 4 and 5, whether $M2$ is financing from the retailer or bank, the financing interest rate will lead to a decrease in the sales prices of the two products, and the sales prices of the two products when financing from the bank are higher than those when financing from the retailer.

(2) $w_{1}^{tb} > w_{1}^{tn} > w_{1}^{tr} ; w_{2}^{tb} > w_{2}^{tn} > w_{2}^{tr}$. The wholesale price of product 1 is the highest in the $jb$ model and the lowest in the $jr$ model, while the wholesale price of product 2 is the highest in the $jr$ model and the lowest in the $jn$ model. Similarly, for the wholesale price of $M1$, when $M2$ finances from the bank, the financing interest rate raises the wholesale price of $M1$, and when $M2$ finances from the retailer, the financing interest rate decreases the wholesale price of $M1$. For the wholesale price of $M2$, whether $M2$ finances from the retailer or bank, the financing interest rate will increase the wholesale price of $M2$, and the wholesale price of $M2$ is higher when financing from the retailer than those when financing from the bank.
(3) $e^{nP} > e^{jP} > e^{bP}$. Product 2 has the highest greenness in the jn model and the lowest in the jb model. Similarly, whether M2 finances from the retailer or bank, the financing interest rate will reduce the greenness of M2, and the greenness of M2 under financing from the retailer is higher than that under financing from the bank.

(4) $d_{21}^{bP} > d_{12}^{n} > d_{12}^{jP} > d_{22}^{jP}$. Product 1 has the highest demand in the jb model and the lowest in the jr model, while product 2 has the highest demand in the jr model and the lowest in the jb model. Similarly, the demand for product 1 decreases when M2 finances from the retailer, but increases when M2 finances from the bank. In the same way, no matter whether M2 finances from banks or retailers, the financing interest rate will reduce its demand, and M2’s product demand is higher when M2 finances from the retailer than when M2 finances from the bank.

(5) $E[p_{m1}^{bP}] > E[p_{n1}^{jP}] > E[p_{r1}^{jP}]$. The expected profit of M1 is the highest in the jb model and the lowest in the jr model. Similarly, the bank financing interest rate has a positive effect on M1’s expected profit, while the retailer’s financing interest rate has a negative effect on M1’s expected profit.

(6) $E[p_{m1}^{n}] > E[p_{n1}^{r}] > E[p_{r1}^{r}] ; U_m^{n} > U_m^{r} > U_m^{r}$. When M2 has risk aversion alone, the expected profit of R is the highest in the un model and the lowest in the ub model; when both M2 and R have risk aversion, the target utility of R is the highest in the tn model and the lowest in the tb model. Similarly, the financing interest rate reduces the expected profit and target utility of R, and the expected profit and target utility of R are higher when M2 finances from the retailer than those if it finances from the bank.

(7) $U_m^{n} > U_m^{r} > U_m^{r}$. The target utility of M2 is the highest in the jr model and the lowest in the jb model. Similarly, the retailer financing interest rate has a positive effect on M2’s target utility, while the bank financing interest rate has a negative effect on M2’s target utility.

**Corollary 7.** In the horizontal comparison, each decision of the supply chain presents the following rules ($z = n, r, b; i = 1, 2$): $p_i^{uzP} > p_i^{uzP} ; w_i^{uz} < w_i^{uz} ; e_i^{uzP} < e_i^{uzP} ; d_i^{uz} < d_i^{uz} ; \pi_i^{uzP} < \pi_i^{uzP} ; U_m^{uz} < U_m^{uz}$.

Similarly, the sales prices of the two products are affected by the risk aversion behavior of M2 and will decrease to a certain extent. When both M2 and R are risk-averse, the sales prices of the two products are affected by the risk aversion behavior of R and further decrease. Therefore, the sales price of the two products under risk-averse M2 is higher than when M2 and R are both risk-averse. R’s risk aversion increases the wholesale price and demand of the two products, M1’s expected profit, M2’s product greenness, and target utility when M2 and R are risk-averse. Therefore, the wholesale price and demand of the two products, M1’s expected profit, M2’s product greenness, and target utility when M2 and R are both risk-averse.

**Corollary 8.** It can be seen from Figure 2, we will find that R’s risk-averse behavior makes its own target utility diminish. Combined with the effects of R’s risk-averse behavior on the sales price and demand of the two products, it can be concluded that its target utility decreases with the increase of its risk aversion. This shows that although R’s risk-averse behavior can bring benefits to partners and consumers, excessive risk concerns are extremely detrimental to its own development.

**Corollary 9.** It can be seen from Figure 3 that when the financing interest rates are equal, the expected profits of M1, the target utility of M2, and R are all positively correlated with the risk aversion behavior of R, but negatively correlated with the risk aversion behavior of M2. When the degree of risk aversion of M2 and R is the same, M2 is more inclined to the retailer financing model, that is to say, the choice of M2’s financing method is not affected by the behavior of its own and its partners, and its choice is only affected by the maximization of utility.

From the above discussion, it can be seen that different financing methods have different impacts on the overall supply chain. However, both external and internal financing methods can solve the problem of enterprise capital shortage, thereby improving the competitiveness and sustainable development of the supply chain. For example, Yonghui Supermarket collaborated with Guangfa Bank to establish external financing channel.
Figure 2. The effects of $k_r$ on $U_{(\pi^*_A)}$ ($A = tn, tr, tb$).

Figure 3. The effects of $k_{m2}, k_r$ on $E[\pi^*_m]$, $U_{(\pi^*_m)}$, $U_{(\pi^*_r)}$ ($A = tn, tr, tb$). (a) $E[\pi^*_m]$. (b) $U_{(\pi^*_m)}$. (c) $U_{(\pi^*_r)}$. 
Through the evaluation, it provided different credit loans to 245 suppliers, which to some extent solved the problem of capital shortage. The collaboration not only reduced the bank’s risk but also improved Yonghui’s production and operation capabilities. At the same time, Yonghui Supermarket also built self financing channel by commercial factoring business and provided credit loan services to customers. As a leader in the Chinese automotive industry, FOTON began cooperating with Industrial Bank in 2010 to provide external financing services to dealers. In 2018, FOTON jointly built the Foton All Link system with Ping An Group to provide financing services to customers. In 2016, FOTON established its own factoring company to solve the problem of capital shortage for upstream and downstream enterprises, while also expanding its own financing scale and improving the stability of its supply chain. Therefore, supply chain financing has a very important application in reality, especially for small and medium-sized enterprises, which relatively easily solves the problem of financing difficulties.

6. Conclusion

The paper explores the financing strategies of a green competitive supply chain consisting of a retailer (R), a common manufacturer (M1), and a capital-constrained green manufacturer (M2). At the same time, it also analyzes the impacts of financing interest rate and risk aversion on the competitive green supply chain. The main conclusions are obtained as follows:

Firstly, the influences of risk aversion on the decisions of the supply chain will not change according to the changes of the different financing methods under any circumstances. At the same time, the greater degree of M2’s risk aversion is not only conducive to its own development but also adversely affects the entire supply chain. The greater degree of R’s risk aversion is beneficial to supply chain members but not conducive to its own development. Therefore, M2 and R, should maintain a rational attitude towards market uncertainty risks and should not be overly concerned, otherwise it will bring unnecessary losses to the supply chain or itself, and supply chain companies should strengthen cooperation to deal with the market uncertainty risk.

Finally, the paper has certain limitations. We consider the supply chain financing interest rate as an exogenous variable. In future research work, we will consider how the financing interest rate affects the supply chain decision when it is an endogenous variable. At the same time, this paper will further expand research on cost uncertainty and information asymmetry of supply chain members, and explore the impacts of cost uncertainty and information asymmetry on green supply chain financing and decision-making.

Appendix A.

First, the expected profit of the retailer is calculated by the Hessian matrix for the sales price of the two products, and we can get: \( H_{(p_1^{un}, p_2^{un})} = 4(1 - b^2) > 0 \). It can be seen that the expected profit of the retailer is a concave function of the sales price of the two products, and there is an optimal solution. Therefore, let \( \frac{\partial E[\pi^{un}_r]}{\partial p_1^{un}} = 0 \), \( \frac{\partial E[\pi^{un}_r]}{\partial p_2^{un}} = 0 \), solving the parallel system of equations gives:

\[
p_1^{un} = \frac{a(1 + b) + (1 - b^2)w_1 + be\theta}{2(1 - b^2)}, \quad p_2^{un} = \frac{a(1 + b) + (1 - b^2)w_2 + e\theta}{2(1 - b^2)}.
\]

Bringing \( p_1^{un} \) and \( p_2^{un} \) into the expected profit function and objective function of M1 and M2, we get:

\[
E[\pi^{un}_{m1}] = \frac{(w_1 - c)(a - w_1 + bw_2)}{2}, \quad U(\pi^{un}_{m2}) = \frac{(w_2 - c)(a + bw_1 + w_2 + \theta e - 2k\sigma) - 2Ie^2}{2}.
\]

M2 objective function calculates the Hessian matrix for its wholesale price and greenness, and we can get: \( H_{(w_2^{un}, e^{un})} = 8I - \theta^2 > 0 \). It can be seen that the objective function of M2 is the concave function of its wholesale...
price and greenness, and there is an optimal solution. Therefore, let \( \frac{\partial U_{(x, y, z)}}{\partial w_2} = 0 \), \( \frac{\partial U_{(x, y, z)}}{\partial w_3} = 0 \), and solving the parallel equations, it can be obtained:

\[
\begin{align*}
\quad w_2 &= \frac{4I(a + c + bw_1 - 2k\sigma) - c\theta^2}{8I - \theta^2}; \\
\quad e &= \frac{a - c + bw_1 - 2k\sigma}{8I - \theta^2}.
\end{align*}
\]

Bringing 1 and 2 into the expected profit function of M1, we get:

\[
E[\pi_{m1}] = \frac{(w_1 - c)[(8I - \theta^2)(a - w_1) + 4Ib(a + c + bw_1 - 2k\sigma) - bc\theta^2]}{2(8I - \theta^2)}.
\]

M1 objective function calculates the Hessian matrix for its wholesale price, and we can get: \( H_{(w_1)} = 4Ib^2 + r^2 - 8I < 0 \). It can be seen that the objective function of M2 is the concave function of its product wholesale price, and there is an optimal solution. Therefore, let \( \frac{\partial E[\pi_{m1}]}{\partial w_2} = 0 \), it can be obtained that:

\[
\begin{align*}
\quad w_1 &= \frac{(a + c)(8I - 4Ib^2 - r^2) - 4Ib(bc + 2kz) - bc\sigma^2}{2(8I - 4Ib^2 - r^2)}.
\end{align*}
\]

Bringing \( w_1 \) into \( w_2 \) and \( e \), we get:

\[
\begin{align*}
\quad w_2 &= \frac{4I(a + c + bw_1^*) - 8Ikz - cr^2}{8I - r^2}; \\
\quad e &= \frac{(a - c + bw_1^* - 2kz)r}{8I - r^2}.
\end{align*}
\]

Substituting \( w_1^*, w_2^*, e^* \) into \( p_1^*, p_2^* \), we get:

\[
\begin{align*}
\quad p_1^* &= \frac{a(1 + b) + w_1^*(1 - b^2) + b\theta e^*}{2(1 - b^2)}, \\
\quad p_2^* &= \frac{a(1 + b) + w_2^*(1 - b^2) + \theta e^*}{2(1 - b^2)}.
\end{align*}
\]

Bring \( w_1^*, w_2^*, e^*, p_1^*, p_2^* \) into \( E[\pi_{m1}], U(\pi_{m2}) \), we can get:

\[
\begin{align*}
E[\pi_{m1}] &= \frac{(w_1^* - c)[(a - c)(8I - \theta^2) + 4Ib(a + c + bc - 2k_m2\sigma) - bc\theta^2]}{2(8I - \theta^2)}; \\
E[\pi_{m2}] &= \frac{(p_2^* - w_1^*)[(a - c)(8I - \theta^2) + 4Ib(a + c + bc - 2k_m2\sigma) - bc\theta^2]}{2(8I - \theta^2)} \\
&\quad + \frac{(p_2^* - w_2^*)[I(8I - \theta^2)[2(a - c) + (a + c)] - 4I^2b^2(a + bc) + 8I^2k_m2\sigma(4 - 3b^2)]}{[4I(2 - b^2) - \theta^2][8I - \theta^2]} \\
&\quad - \frac{4I^2k_m2\sigma(3 - b^2) + 1b^2c(12I - \theta^2) + k_m2\sigma\theta^4]}{[4I(2 - b^2) - \theta^2][8I - \theta^2]}; \\
U(\pi_{m2}^*) &= \frac{[4I(a + c + bw_1^*) - 8I(k_m2\sigma + c)](d_{m2}^* - k_m2\sigma) - I(e^{m*})^2(8I - \theta^2)}{8I - \theta^2}.
\end{align*}
\]

**Appendix B.**

**Corollary 1.** \( \frac{\partial \pi_{m2}^*}{\partial k_m2} < 0; \frac{\partial \pi_{m2}^*}{\partial k_m2} < 0; \frac{\partial \pi_{m2}^*}{\partial k_m2} < 0; \frac{\partial \pi_{m2}^*}{\partial k_m2} > 0; \frac{\partial U[\pi_{m2}^*]}{\partial k_m2} < 0; \frac{\partial U[\pi_{m2}^*]}{\partial k_m2} > 0; \frac{\partial U[\pi_{m2}^*]}{\partial k_m2} < 0 \) \((A = u_n, u_r, u_b; i = 1, 2)\).

**Proof.** The first-order partial derivative of each variable to the risk aversion coefficient of M2 can be obtained:
un model

\[
\begin{align*}
\frac{\partial p_{1u}^{\text{un}}}{\partial k_{m2}} &= -b\sigma \left[ 16I^2(1-b^2)(1-b^2) + r^2(6I-\theta^2) \right] < 0; \\
\frac{\partial p_{2u}^{\text{un}}}{\partial k_{m2}} &= -\sigma \left[ 2I(4-b^2) - \theta^2 \right] [4I(1-b^2) + \theta^2] < 0; \\
\frac{\partial w_{1u}^{\text{un}}}{\partial k_{m2}} &= -4Ib\sigma < 0; \\
\frac{\partial w_{2u}^{\text{un}}}{\partial k_{m2}} &= -8I\sigma \left[ 2I(4-b^2) - \theta^2 \right] < 0; \\
\frac{\partial u_{1u}^{\text{un}}}{\partial k_{m2}} &= -2\sigma \theta \left[ 2I(4-b^2) - \theta^2 \right] < 0; \\
\frac{\partial d_{1u}^{\text{un}}}{\partial k_{m2}} &= -2Ib\sigma < 0; \\
\frac{\partial d_{2u}^{\text{un}}}{\partial k_{m2}} &= \frac{\sigma \left[ 4I(8I-6I^2-3\theta^2 + b^2\theta^2) + \theta^4 \right]}{(8I-\theta^2)[4I(2-b^2) - \theta^2]} > 0; \\
\frac{\partial p_{1u}^{\text{un}}}{\partial k_{m2}} &= -2Ib\sigma \left[ (a-c)(8I-\theta^2) + 4Ib(a+c+bc-2k\sigma) - bc\theta^2 \right] < 0; \\
\frac{\partial p_{2u}^{\text{un}}}{\partial k_{m2}} &= -8I\sigma \left[ 2I(4-b^2) - \theta^2 \right] [4I(1-b^2) + \theta^2] < 0; \\
\frac{\partial w_{1u}^{\text{un}}}{\partial k_{m2}} &= -4Ib\sigma(1+r_r) < 0; \\
\frac{\partial w_{2u}^{\text{un}}}{\partial k_{m2}} &= \frac{\sigma [4I(8I - 6I^2 - 3\theta^2 + b^2\theta^2) + \theta^4]}{(8I-\theta^2)[4I(2-b^2) - \theta^2]} > 0; \\
\frac{\partial u_{1u}^{\text{un}}}{\partial k_{m2}} &= -2Ib\sigma (1+r_r) \left[ (8I(1+r_r) - \theta^2) (a-c) + 4Ib(1+r_r)(a+c+bc-2k\sigma) - bc\theta^2 \right] < 0; \\
\frac{\partial u_{2u}^{\text{un}}}{\partial k_{m2}} &= -4I(1+r_r)[a+b^2+2k\sigma(4-b^2)+b^2c(3)] \left[ (8I(1+r_r) - \theta^2) (a-c) + b(a+c) \right] < 0. \\
\end{align*}
\]

ur model

\[
\begin{align*}
\frac{\partial p_{1u}^{\text{ur}}}{\partial k_{m2}} &= -b\sigma \left[ 16I^2(1-b^2)(1+b_r)^2 + 6I\theta^2(1+b_r) - \theta^4 \right] < 0; \\
\frac{\partial p_{2u}^{\text{ur}}}{\partial k_{m2}} &= -\sigma \left[ 2I(1+r_r)(4-b^2) - \theta^2 \right] [4I(1+r_r)(1-b^2) + \theta^2] < 0; \\
\frac{\partial w_{1u}^{\text{ur}}}{\partial k_{m2}} &= -4Ib\sigma < 0; \\
\frac{\partial w_{2u}^{\text{ur}}}{\partial k_{m2}} &= -8I\sigma \left[ 2I(4-b^2) - \theta^2 \right] < 0; \\
\frac{\partial u_{1u}^{\text{ur}}}{\partial k_{m2}} &= -2\sigma \theta \left[ 2I(4-b^2) - \theta^2 \right] < 0; \\
\frac{\partial d_{1u}^{\text{ur}}}{\partial k_{m2}} &= -2Ib\sigma < 0; \\
\frac{\partial d_{2u}^{\text{ur}}}{\partial k_{m2}} &= \frac{\sigma \left[ 4I(8I-6I^2-b^2\theta^2) + \theta^4 \right]}{(8I-\theta^2)[4I(2-b^2) - \theta^2]} > 0; \\
\frac{\partial p_{1u}^{\text{ur}}}{\partial k_{m2}} &= -2Ib\sigma \left[ (a-c)(8I-\theta^2) + 4Ib(1+r_r)(a+c+bc-2k\sigma) - bc\theta^2 \right] < 0; \\
\frac{\partial p_{2u}^{\text{ur}}}{\partial k_{m2}} &= -8I\sigma \left[ 2I(4-b^2) - \theta^2 \right] [4I(1-b^2) + \theta^2] < 0; \\
\frac{\partial w_{1u}^{\text{ur}}}{\partial k_{m2}} &= -4Ib\sigma(1+r_r) < 0; \\
\frac{\partial w_{2u}^{\text{ur}}}{\partial k_{m2}} &= \frac{\sigma [4I(8I - 6I^2 - 3\theta^2 + b^2\theta^2) + \theta^4]}{(8I-\theta^2)[4I(2-b^2) - \theta^2]} > 0; \\
\frac{\partial u_{1u}^{\text{ur}}}{\partial k_{m2}} &= -2Ib\sigma (1+r_r) \left[ (8I(1+r_r) - \theta^2) (a-c) + 4Ib(1+r_r)(a+c+bc-2k\sigma) - bc\theta^2 \right] < 0; \\
\frac{\partial u_{2u}^{\text{ur}}}{\partial k_{m2}} &= -4I(1+r_r)(a+b^2+2k\sigma(4-b^2)+b^2c(3)) \left[ (8I(1+r_r) - \theta^2) (a-c) + b(a+c) \right] < 0. \\
\end{align*}
\]

ub model

\[
\begin{align*}
\frac{\partial p_{1u}^{\text{ub}}}{\partial k_{m2}} &= -b\sigma \left[ 2I(1+r_b)(8I(1+r_b)(1-b^2) - 3\theta^2) - \theta^4 \right] < 0; \\
\frac{\partial p_{2u}^{\text{ub}}}{\partial k_{m2}} &= -\sigma \left[ 2I(1+r_b)(4-b^2) - \theta^2 \right] [4I(1+r_b)(1-b^2) + \theta^2] < 0; \\
\frac{\partial w_{1u}^{\text{ub}}}{\partial k_{m2}} &= -4Ib(1+r_b) < 0; \\
\frac{\partial w_{2u}^{\text{ub}}}{\partial k_{m2}} &= -8I\sigma(1+r_b) \left[ 2I(1+r_b)(4-b^2) - \theta^2 \right] < 0; \\
\end{align*}
\]
\[
\frac{\partial e_{ub}^*}{\partial k_{m2}} = -\frac{2n\sigma}{8I(1 + r_b) - \theta^2} \left[ 2I(1 + r_b)(4 - b^2) - \theta^2 \right] < 0; \quad \frac{\partial d_{1}^{ub^*}}{\partial k_{m2}} = \frac{-2b\sigma(1 + r_b)}{8I(1 + r_b) - \theta^2} < 0;
\]
\[
\frac{\partial d_{2}^{ub^*}}{\partial k_{m2}} = \sigma \left[ 4I(1 + r_b)(4 - 3b^2) - \theta^2(3 - b^2) + \theta^4 \right] > 0;
\]
\[
\frac{\partial \pi_{ub}^*}{\partial k_{m2}} = -\frac{2b\sigma(1 + r_b)}{8I(1 + r_b) - \theta^2} \left[ 8I(1 + r_b)(2 - b^2) - \theta^2 \right] (a - c) + 4Ib(1 + r_b) + ac(1 + r_b) + bc(1 - 2k\sigma) - b\theta^2(1 + r_b) \right] < 0;
\]
\[
\frac{\partial \pi_{1m}^*}{\partial k_{m2}} = -\frac{2b\sigma(1 + r_b)}{8I(1 + r_b) - \theta^2} \left[ 8I(1 + r_b)(2 - b^2) - \theta^2 \right] (a - c) + 4Ib(1 + r_b) + ac(1 + r_b) + bc(1 - 2k\sigma) - b\theta^2(1 + r_b) \right] < 0;
\]
\[
\frac{\partial E[\pi_{1m}^*]}{\partial k_{m2}} > 0.
\]

**Appendix C.**

**Corollary 2.** \( \frac{\partial p_{F}^*}{\partial k_{m2}} < 0; \quad \frac{\partial e_{F}^*}{\partial k_{m2}} < 0; \quad \frac{\partial d_{F}^*}{\partial k_{m2}} > 0; \quad \frac{\partial E[\pi_{F}^*]}{\partial k_{m2}} > 0; \quad \frac{\partial U(F)}{\partial k_{m2}} > 0; \quad \frac{\partial U(F)^*}{\partial k_{m2}} < 0 \)

\((F = tn, tr, tb; i = 1, 2).\)

**Proof.** The first-order partial derivative of each variable to the risk aversion coefficient of M2 can be obtained:

**tn model**

\[
\frac{\partial p_{tn}^*}{\partial k_{m2}} = -\frac{b\sigma}{2I(2 - b^2)(8I - \theta^2)} \left[ 16I^2(1 - b^2) + (6I - \theta^2)\theta^2 \right] < 0; \quad \frac{\partial d_{1}^{tn^*}}{\partial k_{m2}} = -\frac{-\sigma}{2I(2 - b^2)(8I - \theta^2)} \left[ 16I^2(1 - b^2) + \theta^2 \right] + \theta^4 \left[ 4I(1 + r_b) - \theta^2 \right] \left[ 4I(2 - b^2) - \theta^2 \right] < 0;
\]
\[
\frac{\partial w_{2}^{tn^*}}{\partial k_{m2}} = -\frac{8I\sigma}{2I(2 - b^2)(8I - \theta^2)} \left[ 16I^2(1 - b^2) + (6I - \theta^2)\theta^2 \right] < 0; \quad \frac{\partial d_{1}^{tn^*}}{\partial k_{m2}} = 4(8I - \theta^2) < 0;
\]
\[
\frac{\partial e_{tn}^*}{\partial k_{m2}} = -\frac{\partial d_{2}^{tn^*}}{\partial k_{m2}} = -\frac{\partial \pi_{tn}^*}{\partial k_{m2}} = \frac{\partial U_{1m}^*}{\partial k_{m2}} = \frac{-2b\sigma}{(8I - \theta^2)(1 + r_b) - \theta^2} \left[ 4I(2 - b^2) - \theta^2 \right] \left[ 8I(1 + r_b) - \theta^2 \right] \left[ 8I(1 + r_b)(2 - b^2) - \theta^2 \right] (a - c) + 4Ib(1 + r_b) + ac(1 + r_b) + bc(2 - k\sigma) - b\theta^2(1 + r_b) \right] \left[ (2a - c) + b(c + k\sigma) + 2\sigma^2(2k\sigma - k_r) \right] \left[ (4 - b^2) + b(2c + k\sigma - b(2k\sigma + bc) \right] \right] < 0;\n\]
\[
\frac{\partial U_{1m}^*}{\partial k_{m2}} = \frac{-2b\sigma}{(8I - \theta^2)(1 + r_b) - \theta^2} \left[ 4I(2 - b^2) - \theta^2 \right] \left[ 8I(1 + r_b) - \theta^2 \right] \left[ 8I(1 + r_b)(2 - b^2) - \theta^2 \right] (a - c) + 4Ib(1 + r_b) + ac(1 + r_b) + bc(2 - k\sigma) - b\theta^2(1 + r_b) \right] \left[ (2a - c) + b(c + k\sigma) + 2\sigma^2(2k\sigma - k_r) \right] \left[ (4 - b^2) + b(2c + k\sigma - b(2k\sigma + bc) \right] \right] < 0;\n\]

**tr model**

\[
\frac{\partial p_{tr}^*}{\partial k_{m2}} = \frac{-\sigma}{8I(1 + r_b) - \theta^2} \left[ 4I(1 + r_b)(4 - b^2) + \theta^2(1 + r_b) - \theta^4 \right] \left[ 16I^2(1 + r_b)^2 + 32r + 6\theta^2(1 + r_b) - \theta^4 \right] < 0; \quad \frac{\partial d_{1}^{tr^*}}{\partial k_{m2}} = \frac{-2b\sigma(1 + r_b)}{8I(1 + r_b) - \theta^2} \left[ 4I(1 + r_b)(2 - b^2) - \theta^2 \right] < 0;
\]
\[
\frac{\partial p_{2}^{tr^*}}{\partial k_{m2}} = \frac{-\sigma}{8I(1 + r_b) - \theta^2} \left[ 4I(1 + r_b)(4 - b^2) + \theta^2(1 + r_b) - \theta^4 \right] \left[ 16I^2(1 + r_b)^2 + 32r + 6\theta^2(1 + r_b) - \theta^4 \right] < 0; \quad \frac{\partial d_{2}^{tr^*}}{\partial k_{m2}} = \frac{-2b\sigma(1 + r_b)}{8I(1 + r_b) - \theta^2} \left[ 4I(1 + r_b)(2 - b^2) - \theta^2 \right] < 0;
\]
\[
\frac{\partial w^*_{t_2}}{\partial k_{m_2}} = -8I\sigma(1 + r_c)[2(1 + r_c)(4 - b_2^2) - \theta^2] \\
\frac{\partial t^*_{m_2}}{\partial k_{m_2}} = -2I\sigma(1 + r_c)[2(1 + r_c)(4 - b_2^2) - \theta^2] < 0;
\]

**Corollary 3.**

\[
\frac{\partial w^*_{t_2}}{\partial k_{m_2}} = [8I(1 + r_c) - \theta^2][4I(1 + r_c)(2 - b_2^2) - \theta^2] < 0;
\]

\[
\frac{\partial t^*_{m_2}}{\partial k_{m_2}} = \sigma[4I(1 + r_c)(4 - 3b_2^2) - (3 - b_2^2)\theta^2] + \theta^4 > 0;
\]

\[
\frac{\partial t^*_{m_1}}{\partial k_{m_2}} = \frac{[8I(1 + r_c) - \theta^2][2(a - c) + b(a + c + bc) + k_r\sigma + 2k_r\sigma - 2bk_{m_2}\sigma] - (bc + k_r\sigma)\theta^2}{[8I(1 + r_c) - \theta^2][4I(1 + r_c)(2 - b_2^2) - \theta^2]} < 0;
\]

\[
\frac{\partial t^*_{m_2}}{\partial k_{m_2}} = \frac{[8I(1 + r_c) - \theta^2][2(a - c) + b(a + c)] + 4I(1 + r_c)}{[8I(1 + r_c) - \theta^2][4I(1 + r_c)(2 - b_2^2) - \theta^2]} < 0.
\]

**tb model**

\[
\frac{\partial p^*_{m_1}}{\partial k_{m_2}} = \frac{-8I\sigma(1 + r_b)[2I(1 + r_b)[8I(1 + r_b)(1 - b_2^2) + 3\theta^2] - \theta^2]}{[8I(1 + r_b) - \theta^2][4I(1 + r_b)(2 - b_2^2) - \theta^2]} < 0;
\]

\[
\frac{\partial t^*_{m_1}}{\partial k_{m_2}} = -2I\sigma(1 + r_b)[2I(1 + r_b)[8I(1 + r_b)(1 - b_2^2) + 3\theta^2] - \theta^2] < 0;
\]

\[
\frac{\partial t^*_{m_2}}{\partial k_{m_2}} = \frac{-8I\sigma(1 + r_b)[2I(1 + r_b)(4 - b_2^2) - \theta^2]}{[8I(1 + r_b) - \theta^2][4I(1 + r_b)(2 - b_2^2) - \theta^2]} < 0;
\]

\[
\frac{\partial t^*_{m_1}}{\partial k_{m_2}} = \frac{8I(1 + r_b) - \theta^2][4I(1 + r_b)(2 - b_2^2) - \theta^2]}{[8I(1 + r_b) - \theta^2][4I(1 + r_b)(2 - b_2^2) - \theta^2]} < 0;
\]

\[
\frac{\partial t^*_{m_2}}{\partial k_{m_2}} = \frac{\sigma[4I(1 + r_b)[2I(1 + r_b)(4 - 2b_2^2) - (3 - b_2^2)\theta^2] - \theta^4]}{[8I(1 + r_b) - \theta^2][4I(1 + r_b)(2 - b_2^2) - \theta^2]} > 0;
\]

\[
\frac{\partial \pi^*}{\partial k_r} > 0; \frac{\partial \pi^*_{F^*}}{\partial k_r} > 0; \frac{\partial \pi^*_{E^*_{F^*}}}{\partial k_r} > 0; \frac{\partial \pi^*_{E^*_{F^*}}}{\partial k_r} > 0 \quad (F = tn, tr, tb; i = 1, 2).
\]

**Proof.** Take the first-order partial derivative of each variable to the retailer’s risk aversion coefficient, we can get:

**APPENDIX D.**

**Corollary 3.**
tn model
\[ \frac{\partial p_1^{tn}}{\partial k_r} = -\sigma \left\{ 8I(3b + 2) - 4I(4b^2 + 11b + 4) \theta^2 - 2b^3 (4I - \theta^2) + \theta^4(2b^2 + 4b + 1) \right\} < 0; \]
\[ \frac{\partial p_2^{tn}}{\partial k_r} = -\sigma \left\{ 4I \left[ (2b^2 + 1 + 9b + 9) \theta^2 + 4I(6b + 4b^2 (2b^2 + 2b - 1)) \right] + \theta^4(3b + 4) \right\} < 0; \]
\[ \frac{\partial u_1^{tn}}{\partial k_r} = \frac{\sigma (4I(2 + b) - \theta^2)}{2I(2 - b^2) - \theta^2} > 0; \]
\[ \frac{\partial u_2^{tn}}{\partial k_r} = \frac{\sigma 2I(4 + 2b + b^2) - (2 + b) \theta^2}{(8I - \theta^2)(4I(2 - b^2) - \theta^2) > 0; \]
\[ \frac{\partial u_3^{tn}}{\partial k_r} = \frac{\sigma 2I(4 + 2b + b^2)}{(8I - \theta^2)(4I(2 - b^2) - \theta^2) > 0; \]
\[ \frac{\partial u_4^{tn}}{\partial k_r} = -\frac{8Ik_m^2 \sigma (4 - b^2) - \kappa \theta^2 (2 + b)}{2(8I - \theta^2)(4I(2 - b^2) - \theta^2)^2 > 0. \]

tr model
\[ \frac{\partial p_1^{tr}}{\partial k_r} = -\sigma \left\{ 4I(1 + r_r) \left[ 8I(3b + 2) - 4I(4b^2 + 11b + 4) \theta^2 \right] - (4b^2 + 11b + 4 - 2b^2) \theta^2 \right\} < 0; \]
\[ \frac{\partial p_2^{tr}}{\partial k_r} = -\sigma \left\{ 4I(4I + r_r) (4 + 6b + b^2 - 2b^3 - b^4) - (10 - 9b - b^2 - b^3) \theta^2 \right\} < 0; \]
\[ \frac{\partial u_1^{tr}}{\partial k_r} = \frac{\sigma (4I(1 + r_r) (2 + b) - \theta^2) (8I(1 + r_r) - \theta^2)(4I(1 + r_r) (2 - b^2) - \theta^2)}{4I(1 + r_r) - \theta^2} > 0; \]
\[ \frac{\partial u_2^{tr}}{\partial k_r} = \frac{\sigma 2I(1 + r_r) (1 + b^2) - (2 + b) \theta^2}{(4I(1 + r_r) - \theta^2)(8I(1 + r_r) - \theta^2) > 0; \]
\[ \frac{\partial u_3^{tr}}{\partial k_r} = \frac{\sigma (4I(1 + r_r) (2 + b) - \theta^2)}{4I(1 + r_r) - \theta^2} > 0; \]
\[ \frac{\partial u_4^{tr}}{\partial k_r} = \frac{\sigma (4I(1 + r_r) (1 + b^2) - (2 + b) \theta^2)}{4I(1 + r_r) - \theta^2} > 0; \]
\[ \frac{\partial u_5^{tr}}{\partial k_r} = \frac{\sigma 2I(1 + r_r) (1 + b^2) - (2 + b) \theta^2}{(4I(1 + r_r) - \theta^2)(8I(1 + r_r) - \theta^2) > 0; \]
\[ \frac{\partial u_6^{tr}}{\partial k_r} = \frac{\sigma 2I(1 + r_r) (1 + b^2) - (2 + b) \theta^2}{(4I(1 + r_r) - \theta^2)(8I(1 + r_r) - \theta^2) > 0. \]

tb model
\[ \frac{\partial p_1^{tb}}{\partial k_r} = -\sigma \left\{ 4I(1 + r_b) \left[ 8I(3b + 2) - 4I(4b^2 + 11b + 4) \theta^2 \right] - (4b^2 + 11b + 4 - 2b^2) \theta^2 \right\} < 0; \]
\[ \frac{\partial p^{th}_{2}}{\partial k_r} = -\sigma \left[ 4I(1 + r_b)(4 + 6b + b^2 - 2b^3 - b^4) - (10 - 9b - b^2 - b^3)\theta^2 \right] < 0; \]
\[ \frac{\partial w^{th}_{1}}{\partial k_r} = \frac{\sigma [4I(1 + r_b)(2 + b) - \theta^2] [4I(1 + r_b)(2 - b^2) - \theta^2]}{2[4I(1 + r_b)(2 - b^2) - \theta^2]} > 0; \]
\[ \frac{\partial w^{th}_{1}}{\partial k_r} = \frac{2I \gamma(1 + r) [4I(1 + r)(2 - b^2) - (2 + b)n^2]}{[8I(1 + r) - n^2] [4I(1 + r)(2 - b^2) - n^2]} > 0; \]
\[ \frac{\partial w^{th}_{1}}{\partial k_r} = \frac{\theta \gamma_1(1 + r) [4I(1 + r_b)(1 - b^2) - (2 + b)\theta^2]}{2[8I(1 + r_b) - \theta^2] [4I(1 + r_b)(2 - b^2) - \theta^2]} > 0; \]
\[ \frac{\partial w^{th}_{1}}{\partial k_r} = \frac{\sigma [4I(1 + r_b)(2 + b) - \theta^2]}{4[8I(1 + r_b) - \theta^2]} > 0; \]
\[ \frac{\partial w^{th}_{1}}{\partial k_r} = \frac{\sigma [4I(1 + r_b)(2 + b) - \theta^2] [8I(1 + r_b) - \theta^2] [2(a - c) + b(a + c)]}{4[8I(1 + r_b) - \theta^2] [4I(1 + r_b)(2 - b^2) - \theta^2]} > 0; \]
\[ \frac{\partial w^{th}_{1}}{\partial k_r} = \frac{[\theta \gamma_1(1 + r_b)(1 - b^2) - (2 + b)\theta^2] [2c r_b + 4k_{m2} \sigma - 2k_r \sigma - 2 \theta^2 c(1 + r_b) \theta^2]}{4c r_b + 4k_{m2} \sigma - 2k_r \sigma - 2 \theta^2 c(1 + r_b) \theta^2} > 0; \]
\[ \frac{\partial U^{th}_{1}}{\partial k_r} > 0. \]

Acknowledgements

This research was supported by Key Project of Humanities and Social Sciences of Anhui (Grant no. 2023AH051574), Project of Doctor scientific research (Grant no. 2023QD11), Anhui Planning Office of Philosophy and Social Science (Grant no. AHSKQ2020D49), National College Students’ innovation and entrepreneurship training program (202210071024).

Data availability statement

The data used to support the findings of this study are open and available from the corresponding author upon request.

References


---

**Please help to maintain this journal in open access!**

This journal is currently published in open access under the Subscribe to Open model (S2O). We are thankful to our subscribers and supporters for making it possible to publish this journal in open access in the current year, free of charge for authors and readers.

Check with your library that it subscribes to the journal, or consider making a personal donation to the S2O programme by contacting subscribers@edpsciences.org.

More information, including a list of supporters and financial transparency reports, is available at [https://edpsciences.org/en/subscribe-to-open-s2o](https://edpsciences.org/en/subscribe-to-open-s2o).