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Pricing and Financing Strategies for a Green Supply Chain With a Risk-Averse Supplier

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ABSTRACT This study investigated a green supply chain comprising a single supplier with financial constraints and a single retailer, while also considering the supplier's degree of risk aversion. A supplier-retailer Stackelberg game model was established under different financing situations, namely, bank financing and retailer's advance payment, and optimal decisions were derived for both the supplier and the retailer. The analysis examined the influence of the degree of the supplier's risk aversion, pricing and financing strategies on optimal decisions. The results show that high supplier risk aversion is not conducive to the supply chain green development. When the supplier has less initial capital, the strategy of advance payment provided by the retailer will be prioritized within the supplier's financial constraints. When the supplier's initial capital is more, he should use the initial capital for production. The study's consideration of the supply chain green level as an endogenous variable, as well as of the supplier's risk aversion, contributes to its novelty.

INDEX TERMS Green supply chain, capital constraint, risk aversion, pricing strategy, financing strategy.

I. INTRODUCTION

The promulgation of relevant laws and regulations has enhanced the environmental consciousness of citizens, and green products are being demanded by an increasing number of customers. Improving the green level of products is an essential strategic decision in the sustainable development of the supply chain. Navinchandra officially came up with the concept of green product design, and defined it as increasing the compatibility between products and environment without affecting product quality and performance [1]. Green products can raise enterprise competitiveness while improving the environment ([2], [3]). Improving the product green level is not only a crucial way for businesses to expand market demand and enhance competitiveness, but also a principal element to be considered in improving supply chain competitiveness ([4], [5]).

The design and production of green products necessitate more green investment. Suppliers play key roles in increasing the green level of products to protect the environment and expand market demand [6]. Large enterprises with sufficient capital have started to produce green products. Coca-Cola sponsored the World Without Waste initiative, whereby it began utilizing more recyclable packaging to lessen the generation of waste in packaging [7]. A well-know multinational corporation Haier took energy management and environmental management as a guarantee, increased green production inputs, and produced a number of green products like energy-saving refrigerators.

In practice, most of China's manufacturing suppliers are micro, small and medium enterprises (MSMEs). It is hard for these suppliers to obtain financing support, especially this long-standing global problem is more prominent under economic slowdown and liquidity squeeze pressures. MSMEs in China account for 60% of China's GDP, contribute exceed 50% to tax revenue, and solve 80% of the employment problem. However, for them, only 15% of the total loan amount will be obtained from financial institutions. There is a large discrepancy between the economic contribution of MSMEs and the loan support by financial institutions.

Supply chain finance provides an important financial methods of settling the financing concerns of MSMEs. The central bank of China has introduced relevant policies to support selected banks to expand the market of, and issue loans

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to MSMEs. Trade credit and other internal supply chain financing methods also have a very important impact on promoting the integration of supply chain financial market resources. Essentially, the time nodes of delivery and payment are staggered to inject new vitality into the flow of supply chain capital and alleviate enterprises' capital constraints. The large-scale penetration and development of supply chain financing has effectively alleviated the financing pressure of MSMEs, and changed the financial environment in which decisions were made on both sides of the supply chain. For the sake of speeding up the implementation of green development and ecological civilization construction at the middle and micro level, the green supply chain financial service project arises at the historic moment. As a result, many enterprises have made strategic adjustments. In terms of international practice, a number of companies have vigorously carried out and implemented green supply chain financing programs, such as Puma, BNP Paribas and the International Finance Corporation. In practice in China, under the guidance of the strategy of Industrial Bank CO.,LTD (CIB) Green Finance Group, CIB Research has undertaken a number of green finance related research projects from international organizations, state ministries, local governments, association organizations and financial institutions in recent years which promotes green development and business landing for China's green finance.

The increase of green product demand and the changing financial environment bring opportunities for suppliers, but also create new challenges. The complexity and uncertainty of their decision-making environment increase, and the capital constraint becomes an important factor in decision-making with operational risk. However, scholars usually assume that decision makers are risk-neutral with regard to the current research on green supply chain. In fact, suppliers not only pay attention to their own profits, but also consider the risk factors and their consequences. When emergencies occur, suppliers will face more uncertain risks in the green supply chain system on account of financial constraints, such as the change of products for green demand, the higher capital cost, the increase of demand uncertainty and so on. Therefore, it is not too close to the reality to regard profit maximization without considering risk factors as the only goal of enterprise management. When suppliers faced with financial constraints and various risks brought by the green supply chain, how to make optimal decisions will be an important research topic. One of the major objectives of this study is to research the influence of the degree of supplier's risk aversion on optimal choices under financial constraints.

This research studies the green supply chain from the perspectives of supplier's financial constraint and risk aversion which not only intersects research in the fields of operations and finance, but also incorporates important variables risk-averse of behavioral economics into the research model. Different from the current literature, it investigates the pricing and financing strategies in the green supply chain. Simultaneously, it also analyzes the impact of suppliers' risk attitudes on the best decision-making and financing strategy choices of the entire supply chain. The valuable conclusions are as follows. First, the degree of risk aversion of suppliers has an impact on their unit wholesale price, green level and unit retail price. Second, in the case of shortage of suppliers' funds, both bank financing and advance payment provided by retailers can effectively solve the shortage of suppliers' funds. Third, when the supplier's initial capital is less, advance payment strategy provided by retailer will be prioritized within the supplier's financial constraints. When the supplier has more initial capital, the retailer will not provide advance payment financing. At this point, the supplier should choose to arrange production with the initial capital.

The rest of this paper is structured as follows. Section 2 reviews the relevant literature. Section 3 describes the problem and associated symbols. Section 4 establishes mathematical models and derives the equilibrium solutions under different financing situations; it analyzes the effect of the degree of supplier's risk aversion on optimal choices and compares financing strategies. In Section 5, numerical analyses are outlined and results are discussed. Finally, Section 6 gives the conclusion.

II. LITERATURE REVIEW

This section examines related work from the perspectives of green supply chain, financing and risk aversion.

A. GREEN SUPPLY CHAIN MANAGEMENT

From the first perspective, the idea of the green supply chain (GSC) was primarily developed by the Manufacturing Research Institute of Michigan State University. It is developed based on the research of green manufacturing theory and supply chain management technology, penetrating running through each main body of the supply chain, in order to achieve the purpose of protecting the environment and improving the utilization rate of resources. Green supply chain management (GSCM) as an enabler of a more environmentally friendly supply chain emerged as a discipline after the 1990s [8]. GSCM has been in existence for many years, and receives extensive attention from academics and practitioners on account of environmental deterioration and the increased awareness of environmental protection.

Green supply chain research mainly focuses on supply chain operational decisions and coordination contracts. Ma made the pricing decision for a green supply chain composed of two suppliers and a single retailer, and found that the Stackelberg model is beneficial to the supplier and the Bertrand model is beneficial to the retailer in decentralized decision-making; further, suppliers participating in green investment benefit from green manufacturing [9]. Li considered the production of green products by suppliers, and studied the pricing and green strategy under centralized and decentralized decision-making [10]. Under government incentives for R&D investment projects, Nielsen believe that the greening rate is the largest and the environmental improvement degree is higher [11]. Rahmani studied the

demand interruption management for the production and sale of green products, and showed that products produced by centralized decision-making under demand interruption had a higher green level than decentralized decision-making products [12]. When the market size increased or the green cost decreased, whether it is centralized or decentralized, the optimal price for its decision will increase. Song took the sensitivity of consumers to green products into account, coordinated the interest distribution among the various entities in the green supply chain through a revenue sharing mechanism, which improved the performance of the entire supply chain [13]. Ma compared four game models of the green dual-channel supply chain they verified that online sales had become the main distribution channel for green products, and under the revenue sharing mechanism, both economic benefits and environmental goals would be improved [14]. Saha believes that the appropriate combination of supply chain coordination mechanisms and subsidy policies can promote green and sustainable development [15]. From the perspective of manufacturers, Nielsen proposes a sequential profit-sharing mechanism under the constraint of wholesalers, which will enable manufacturers to produce products at the highest green level to move towards sustainable development [16]. Xin explored the harmonization problem of green production with uncertain demand, illustrating the validity of contract with uncertain demand [17].

Environmental regulations and consumers' continuous pursuit of green products are the driving force behind suppliers' green production [13]. While MSMEs increase green product input, they also increase the possibility of capital constraints. The success of the green transformation of the supply chain is directly related to R&D funds, so the correct choice of financing methods has turned into the key factor to be considered in all links of the green supply chain [18]. Dash researched the impact of carbon emission reduction in green production on corporate operations and financing decisions and found that, when suppliers invest in emission reduction, a win-win situation can be achieved in terms of output and emission reduction [19]. Nielsen researched the optimal pricing and investment strategies in green-oriented competitive supply chains composed of manufacturers and exclusive retailers [20]. Yang deeply analyzed the performance fluctuations of green credit decision-making on each link of the supply chain [21]. To sum up, few studies have considered the situation of retailer-led and suppliers' financial constraints. However, in reality, compared with retailers, suppliers are more likely to face a shortage of funds because of the increased cost of producing green products. During the green production period of the supply chain, suppliers' financing needs are often more urgent. Therefore, this paper considers that the increase of green investment by suppliers is constrained by funds, and then studied its financing strategy.

B. SUPPLY CHAIN FINANCE

From the second aspect, in the early days of the 21st century, the concept of supply chain finance was mentioned [22]. Its study was mainly initiated by two concepts: external financing and internal financing. The former is a form of financing in which companies with limited funds obtain capital through external financing institutions (such as banks), and the financing capital ultimately come from financial institutions outside supply chain nodes. When supply chain members are financially constrained, they need to obtain operating capital from external financing institutions to support the operation. Yan studied retailer and manufacturer financing strategies under financial constraints from the perspective of external financing institutions, proving that partial credit guarantee contracts can improve supply chain performance [23]. Shi studied the purchasing and financing strategies of seasonal products for retailers with financial constraints, indicating that, the decision to increase product orders through bank financing is determined by the size of the initial capital and its threshold [24]. Jin believed that credit insurance could effectively relieve the capital constraint of the retailer and realize pareto improvement of the whole supply chain [25]. Bi found that the manufacturer guarantee can be seen as a combination of bank financing and trade credit strategies, and that the financing decisions of retailers depend on the wholesale prices of manufacturers [26]. Lu evaluated the best order quantity and reasonable interest rate of a retailer when it uses credit guarantees provided by a third party or supplier to obtain bank financing [27].

Internal supply chain financing is a type of capital circulation among supply chain enterprises. The financing capital ultimately comes from internal supply chain enterprises rather than external financial institutions. An optimal ordering strategy in advance and delayed payment is one of the operational decisions studied in internal finance([28]–[30]). Chen studied the supplier and retailer's pricing and ordering decision-making with financial constraints, and supply chain performance, showing that buyback-guaranteed financing can enhance supply chain value, and enable members to achieve multiple wins [31]. Alex showed that trade credit as a means of internal financing is an effective mechanism to share risk between the supplier and retailer [32]. Xiao believed that when retailers have financial constraints, buy back contract, revenue sharing contract and quantity discount contract will have an impact on supply chain coordination, and proposed an improved revenue sharing contract [33].

The above studies assumed that the initial capital was almost zero, however, the amount of initial capital does influence decision-making in practice. Zhou analyzed the effect of capital constraints on the retailer's ordering strategy, and showed that it depends on the initial capital level and external financing interest rate [34]. Huang studied the equilibrium strategies under buyback guarantee financing, credit guarantee financing and trade credit, and found that the initial working capital of the retailer influenced the wholesale price decision [35]. Therefore, this paper considers the supplier's own funds and studies the impact of different scope of suppliers' own funds on the financing strategies of both suppliers and retailers.

C. RISK AVERSION IN THE SUPPLY CHAIN

The third perspective integrates risk aversion into supply chain management. Note that the above studies assume that the risk of each participant is neutral. However, the risk attitude of supply chain members impact their decisions, particularly when supply chain members face high uncertainty([36], [37]). Li found in their study that With the increase of retailers' risk aversion, retail prices would decrease, while suppliers' initial inventory would increase [10]. Choi showed that the retailer's risk aversion behavior plays a key role in the optimal decision-making of each subject of the supply chain [38]. Luo proved that the risk-averse retailer in buyback contracts would reduce the order quantity, leading to the reduction of supply chain performance [39]. Xie analyzed the effect of decision-makers' risk attitude on different supply chain coordination contracts, and found that risk parameters played a key role in contract design [40]. Considering that each subject had the phenomenon of risk aversion, Raza studied its impact on the performance of supply chain coordination [41]. Liu considered risk-neutral suppliers and risk-averse retailers, studied their option pricing, ordering and production issues, and coordinated supply chains in supplier-led and retailer-led supply chains [42]. When the supplier or retailer is financially constrained, the risk aversion is a more important decision-making factor. There have been several researches on the supply chain with the risk attitude under capital constraints. Yan found that the balance of supply chain financing was largely affected by the risk aversion of the borrower and guarantor [43]. Li considered a financially constrained retailer and a risk-averse supplier, and found that there existed a range of trade credit strategies that are superior to a partial credit guarantee strategy [44]. Based on this, in the optimization decision of green supply chain, few scholars consider the impact of capital constraint on suppliers' risk attitude. Therefore, this paper focuses on the impact of risk attitude for suppliers on participants' decision-making under financial constraints.

Motivated by the relevant research and practice, this study investigates green supply chain pricing and financing strategies and the influence of the degree of supplier's risk aversion on best decisions. Several contributions are made. First, the study considers a two-echelon green supply chain with a retailer and a capital-constrained supplier, treating the green level as an endogenous decision variable. Second, the influence of suppliers' risk aversion is considered, on this basis, this study examines the influence of this aspect on the best decision and financing strategy selection. Third, This research studies the changes of optimal financing strategies under different initial funds of suppliers.

III. PROBLEM DESCRIPTION

In this research, the pricing and financing decisions of a green supply chain, composed of a single supplier and a single retailer, are studied, and the supplier's initial capital and risk aversion factors are considered. The supplier increases investment in green production, but he is financially constrained; financial support for production is obtained through bank financing and the retailer's advance payment. Bank financing implies that the supplier obtains capital from the bank at a financing interest rate of r_b, after which the supplier returns to the bank with the principal and profit. Advance payment provided by the retailer represents the retailer provision of financial support $cD - B$ to the supplier; the supplier delivers products that are worth $(cD - B)(1 + r_r)$; the quantity of the remaining part of the product is $D - \frac{(cD-B)(1+r_r)}{w}$; and the retailer purchases the remaining products at the unit wholesale price w. r_r is the wholesale price discount rate, which can also be expressed as the interest rate of prepayment financing. The financial mechanism of the supply chain is shown in Fig.1.

TABLE 1. The Notations and Descriptions.

Notation	Description
D	The market demand
k	The supplier's risk averse coefficient
ε	The market demand fluctuation variable, $\varepsilon \sim (0, \sigma^2)$
c	The production unit cost
γ	Consumer sensitivity to green level improvement, $\gamma < 1$
w	The unit wholesale price of products
p	The unit retail price of products
e	Cost factor for enhancing green level
θ	Green level of product decided by the supplier
α	The basic market demand
$\tilde{\alpha}$	The maximum market potential
B	The supplier's initial capital
r_b	The financing interest rate from bank
r_r	The discount rate of the wholesale price
π_s, π_r	The supplier and retailer's profits
U_s	The utility of supplier

The supplier is risk averse. The objective function consists of expected revenue and mean square deviation, that is, $U(\pi_s) = E(\pi_s) - k\sqrt{var(\pi_s)}$, $var(\pi_s) = E[\pi_s - E(\pi_s)]^2$, in which k is the supplier's risk-aversion coefficient ($k > 0$); a larger k indicates a larger degree of risk aversion. The retailer is risk neutral and has sufficient capital to support the activity.

The supplier first determines the unit wholesale price w and the green level θ, according to which the retailer decides the unit retail price p. The basic market demand is α; the maximum market potential is $\tilde{\alpha}$, which is a random variable and $\tilde{\alpha} = \alpha + \varepsilon$; ε is the market demand fluctuation variable; and $\varepsilon \sim (0, \sigma^2)$. The market demand is D, and $D = \tilde{\alpha} - p + \gamma\theta$. γ is consumers' sensitivity to product green degree.

The symbols and related definitions are revealed in Table 1.

This paper conducts in-depth research based on the following three assumptions:

Hypothesis 1: the supplier's own capital is B and satisfies $0 < B < cD$.

Hypothesis 2: in order to ensure the rigor and rationality of this paper, we assume $\gamma < 1$, which is to satisfy the solution of Hesse matrix.

Hypothesis 3: we assume that the information between the supplier and the retailer is symmetrical and both parties pursue profit maximization.

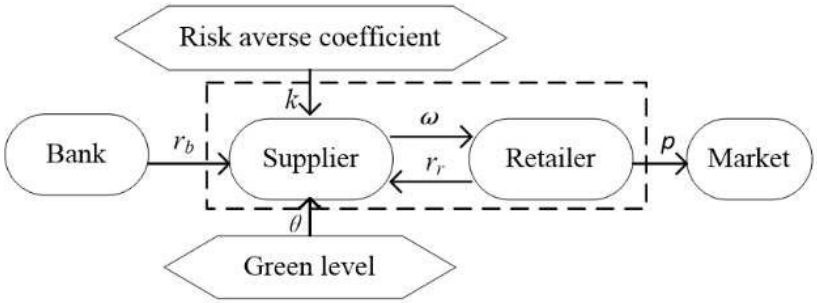


FIGURE 1. The supply chain financing mechanism.

IV. DESCRIPTION OF MODELS

A. THE BASIC MODEL

This section establishes a well-capitalized decentralized decision-making model. In a supply chain with well-capitalized, the supplier first determines the unit wholesale price w and the green level θ, according to which the retailer decides the unit retail price p. According to [45] and [10], the total cost for enhancing the green level of the supplier is $e\frac{\theta^2}{2}$; this section assumes the cost factor to improve the green level of the product $e = 1$ for simplification, which does not affect the results. The profit function of both parties can be written as follows:

$$\begin{aligned}\pi_s &= (w-c)D - \frac{\theta^2}{2} \\ &= (w-c)(\alpha+\varepsilon-p+\gamma\theta) - \frac{\theta^2}{2} \qquad (1)\\ \pi_r &= (p-w)D = (p-w)(\alpha+\varepsilon-p+\gamma\theta) \qquad (2)\end{aligned}$$

The expected revenue and variance of the supplier are as follows:

$$\begin{aligned}E(\pi_s) &= (w-c)(\alpha-p+\gamma\theta) - \frac{\theta^2}{2}\\ var(\pi_s) &= E[\pi_s - E(\pi_s)]^2 = (w-c)^2\sigma^2\end{aligned}$$

Therefore, the objective functions of both parties can be expressed as:

$$\begin{aligned}U(\pi_s) &= (w-c)(\alpha-p+\gamma\theta) - \frac{\theta^2}{2} - k(w-c)\sigma \qquad (3)\\ E(\pi_r) &= (p-w)D = (p-w)(\alpha-p+\gamma\theta) \qquad (4)\end{aligned}$$

The Hesse matrix of $U(\pi_s)$ is $\begin{bmatrix} -1 & \frac{\gamma}{2} \\ \frac{\gamma}{2} & -1 \end{bmatrix}$, and $4-\gamma^2 > 0$ shows that the Hessian matrix is a negative definite matrix. That is to say, $U(\pi_s)$ is the union concave function of w and θ.

Proposition 1: The objective function of the supplier with sufficient capital $U(\pi_s)$ is the union concave function of the unit wholesale price and the green level (w, θ). There is a unique equilibrium solution to maximize the utility function. The optimal solutions of supplier and retailer are expressed as follows:

$$w^s = \frac{2(\alpha+c) - c\gamma^2 - 4k\sigma}{4-\gamma^2}$$

$$\theta^s = \frac{(\alpha-c-2k\sigma)\gamma}{4-\gamma^2}$$

$$p^s = \frac{3\alpha+c-2k\sigma-(c+k\sigma)\gamma^2}{4-\gamma^2}$$

Thus, the market demand and the profits of both parties are as follows:

$$E(D^s) = \frac{\alpha-c+2k\sigma-\gamma^2 k\sigma}{4-\gamma^2}$$

$$E(\pi_s^s) = \frac{(\alpha-c+2k\sigma)(\alpha-c-2k\sigma)}{2(4-\gamma^2)^2}$$

$$E(\pi_r^s) = \frac{(\alpha-c+2k\sigma-\gamma^2 k\sigma)^2}{(4-\gamma^2)^2}$$

Proposition 1 shows that when the wholesale price of green products is very low with the improvement of green degree, the quality of green products will be improved. But costs and wholesale prices will rise accordingly. The improvement of the quality of green products continuously meets the green demand of consumers, thus simulating the rise of demand level, leading to the rise of profits and utility. When the wholesale price reaches a certain level, with the improvement of green color, the room for the improvement of green product quality is getting smaller and smaller. But costs and wholesale prices have increased accordingly. Consumers can no longer afford high prices, and the satisfaction with the quality of green products is getting smaller and smaller, which leads to a decline in demand, resulting in lower profits and lower utility.

Corollary 1: The unit wholesale price w^s, unit retail price p^s, and green level θ^s are decreasing as the supplier's risk-aversion coefficient increases.

Proof of Corollary 1: $\frac{\partial w^s}{\partial k} < 0$; $\frac{\partial \theta^s}{\partial k} < 0$; $\frac{\partial p^s}{\partial k} < 0$; $\frac{\partial E(D^s)}{\partial k} > 0$.

Corollary 1 suggests that the green level and wholesale price of products will decrease as the risk-aversion increases. That is, the supplier with a higher degree of risk aversion sets a lower unit wholesale price to ensure the product sales quantity. The retailer decreases the unit retail price as the unit wholesale price decreases, leading to an increase in market demand.

TABLE 2. The Optimal Decisions and Profits of Supplier and Retailer.

	Sufficient capital $A = \alpha - c$	Capital constraint but no financing $A = \alpha - c$
w	$w^s = \frac{2(\alpha+c)-c\gamma^2-4k\sigma}{4-\gamma^2}$	$w^0 = \alpha - \frac{(2-\gamma^2)B+c\gamma^2k\sigma}{c}$
θ	$\theta^s = \frac{(A-2k\sigma)\gamma}{4-\gamma^2}$	$\theta^0 = \gamma(\frac{B}{c} - k\sigma)$
p	$p^s = \frac{3\alpha+c-2k\sigma-(c+k\sigma)\gamma^2}{4-\gamma^2}$	$p^0 = \alpha - \frac{(1-\gamma^2)B+c\gamma^2k\sigma}{c}$
D	$D^s = \frac{A+2k\sigma-\gamma^2k\sigma}{4-\gamma^2}$	$D^s = \frac{B}{c}$
π_s	$\pi_s^s = \frac{A^2-4k^2\sigma^2}{2(4-\gamma^2)^2}$	$\pi_s^0 = \frac{2ABc-4B^2+\gamma^2(B^2-c^2k^2\sigma^2)}{2c^2}$
π_r	$\pi_r^s = (\frac{A+2k\sigma-\gamma^2k\sigma}{4-\gamma^2})^2$	$\pi_r^0 = (\frac{B}{c})^2$

1) THE DECISION MODEL WITH THE SUPPLIER's CAPITAL CONSTRAINT

The capital required by the supplier for production is at least $B^0 \equiv cE(D^s) = \frac{c(\alpha-c+2\ k\sigma-\gamma^2k\sigma)}{4-\gamma^2}$. The supplier's capital constraint refers to his initial capital $B < B^0$ in production. The optimal decisions and profits of both parties are shown in Table 2, when the supplier uses his initial capital to produce without financing.

It is clear that the supplier with capital constraints decreases the green level ($\theta^0 < \theta^s$) and increases the unit wholesale price ($w^0 > w^s$), which leads to the enhancement of the retailer's unit retail price ($p^0 > p^s$) and the reduction of market demand ($D^0 < D^s$). The supplier's capital constraint is not beneficial to the supplier, retailer, and consumer, and is not conducive to the enhancement of the product's environmental protection property. Therefore, the supplier tends to obtain financial support from others to improve this situation. The study assumes that he can gain financial support through bank financing and advance payments from retailers.

2) BANK FINANCING

Under bank financing, the profit functions of the supplier and retailer are expressed as follows:

$$\begin{aligned}\pi_s^b &= (w-c)D - \frac{\theta^2}{2} - (cD-B)r_b \\ &= [(w-c(1+r_b)](\alpha+\varepsilon-p+\gamma\theta) - \frac{\theta^2}{2} + Br_b \quad (5)\\ \pi_r^b &= (p-w)D = (p-w)(\alpha+\varepsilon-p+\gamma\theta) \quad (6)\end{aligned}$$

The expected revenue and variance of the supplier are as follows:

$$\begin{aligned}E(\pi_s^b) &= [(w-c(1+r_b)](\alpha-p+\gamma\theta) - \frac{\theta^2}{2} + Br_b \\ var(\pi_s^b) &= E[\pi_s^b - E(\pi_s^b)]^2 = [w-c(1+r_b)]^2\sigma^2\end{aligned}$$

Therefore, the supplier's and retailer's objective functions are expressed as:

$$\begin{aligned}U(\pi_s^b) = [(w-c(1+r_b)](\alpha-p+\gamma\theta) \\ - \frac{\theta^2}{2} + Br_b - k[(w-c(1+r_b)]\sigma \quad (7)\end{aligned}$$

$$\begin{aligned}E(\pi_r^b) &= (p-w)D \\ &= (p-w)(\alpha-p+\gamma\theta) \quad (8)\end{aligned}$$

The decisions of the supplier and retailer are obtained by means of backward induction. It can be obtained from equation (8) that the retailer's objective function is the concave function of the unit retail price p of the product, and its optimal solution is as follows:

$$p^b = \frac{\alpha+w+\gamma\theta}{2} \quad (9)$$

By substituting equation (9) into equation (7), the supplier's objective function can be obtained:

$$\begin{aligned}U(\pi_s^b) = [(w-c(1+r_b)](\frac{\alpha+w+\gamma\theta}{2}) \\ - \frac{\theta^2}{2} + Br_b - k[(w-c(1+r_b)]\sigma \quad (10)\end{aligned}$$

Proposition 2: Under bank financing, the supplier's objective function $U(\pi_s^b)$ is the union concave function of the unit wholesale price and green level (w, θ). There is a unique equilibrium solution to maximize the utility function. The optimal decisions of supplier and retailer are respectively as follows:

$$\begin{aligned}w^b &= \frac{2\alpha+2c(1+r_b)-c(1+r_b)\gamma^2-4k\sigma}{4-\gamma^2} \\ \theta^b &= \frac{[\alpha-c(1+r_b)-2k\sigma]\gamma}{4-\gamma^2} \\ p^b &= \frac{3\alpha+c(1+r_b)-2k\sigma-[c(1+r_b)+k\sigma]\gamma^2}{4-\gamma^2}\end{aligned}$$

Thus, the profit functions of market demand and suppliers and retailer's profits are shown as:

$$\begin{aligned}&E(D^b) \\ &= \frac{\alpha-c(1+r_b)+2k\sigma-\gamma^2k\sigma}{4-\gamma^2} \\ &E(\pi_s^b) \\ &= \frac{[4[\alpha-c(1+r_b)]+8k\sigma][\alpha-c(1+r_b)-2k\sigma]}{2(4-\gamma^2)^2} \\ &\quad + \frac{[-\alpha\gamma^2+c\gamma^2(1+r_b)-2\gamma^2k\sigma][\alpha-c(1+r_b)-2k\sigma]}{2(4-\gamma^2)^2} \\ &E(\pi_r^b) \\ &= [\frac{\alpha-c(1+r_b)+2k\sigma-\gamma^2k\sigma}{4-\gamma^2}]^2\end{aligned}$$

Corollary 2: The supplier obtains bank financing; his own profit increases as his initial capital increases, and the retailer's profit is not related to the supplier's initial capital. The supplier's profit decreases as the interest rate increases when $0 \le B < \frac{c[\alpha-c(1+r_b)]}{4-\gamma^2}$, and the supplier's profit increases as the interest rate increases when $\frac{c[\alpha-c(1+r_b)]}{4-\gamma^2} \le B < \frac{c(\alpha-c)+(2-\gamma^2)k\sigma}{4-\gamma^2}$. The retailer's profit decreases as the interest rate increases.

Proof of Corollary 2: $\frac{\partial \pi_s^b}{\partial B} > 0$; $\frac{\partial \pi_s^b}{\partial r_b} < 0$ when $0 \le B < \frac{c[\alpha - c(1+r_b)]}{4-\gamma^2}$, $\frac{\partial \pi_s^b}{\partial r_b} > 0$ when $\frac{c[\alpha - c(1+r_b)]}{4-\gamma^2} \le B < \frac{c[(\alpha-c)+(2-\gamma^2)k\sigma]}{4-\gamma^2}$; $\frac{\partial \pi_r^b}{\partial B} = 0$; $\frac{\partial \pi_r^b}{\partial r_b} < 0$.

Corollary 2 shows that the supplier's financing amount decreases and his profit increases as the initial capital increases, but the supplier's profit is not impacted by the supplier's initial capital. Lower bank interest rates are beneficial to both the supplier and retailer, with the supplier's reduced initial capital. Higher bank rates are good for suppliers, but not for retailers with higher initial capital, as suppliers pass on capital costs to retailers by charging higher wholesale unit prices.

Corollary 3: The influence of risk aversion of the supplier coefficient on the unit wholesale price w^b, unit retail price p^b, green level θ^b, and market demand D^b is consistent with the situation when the supplier has sufficient capital. The unit wholesale price, green level, unit retail price, and market demand are found to have the following order $w^b > w^s$, $\theta^b < \theta^s$, $p^b > p^s$ and $D^b < D^s$.

It is found that the unit wholesale price and unit retail price under bank financing is higher than that with sufficient supplier capital; however, the supplier's green level and market demand under bank financing is lower than that with sufficient supplier capital. That is, when the supplier is financially constrained and obtains financial support from the bank, he will increase the unit wholesale price of the product and reduce its green level, which makes retailers have to increase the unit retail price. Therefore, the market demand is further reduced.

3) THE RETAILER's ADVANCE PAYMENT

The profit functions of the supplier (11) and retailer (12) are as follows under the retailer's advance payment:

$$\begin{aligned}\pi_s^a &= [w - c(1+r_r)]D - \frac{\theta^2}{2} + Br_r \\ &= [(w - c(1+r_r)](\alpha + \varepsilon - p + \gamma\theta) - \frac{\theta^2}{2} + Br_r \qquad (11)\\ \pi_r^a &= (p-w)D + (cD - B)r_r \\ &= (p - w + cr_r)(\alpha + \varepsilon - p + \gamma\theta) - Br_r \qquad (12)\end{aligned}$$

The expected revenue and variance of the supplier are as follows:

$$\begin{aligned}E(\pi_s^a) &= [(w - c(1+r_r)](\alpha - p + \gamma\theta) - \frac{\theta^2}{2} + Br_r \\ var(\pi_s^a) &= E[\pi_s^a - E(\pi_s^a)]^2 = [w - c(1+r_r)]^2\sigma^2\end{aligned}$$

Therefore, the supplier's (13) and retailer's (14) objective functions are as follows:

$$\begin{aligned}U(\pi_s^a) &= [(w - c(1+r_r)](\alpha - p + \gamma\theta) \\ &\quad - \frac{\theta^2}{2} + Br_r - k[(w - c(1+r_r)]\sigma \qquad (13)\\ E(\pi_r^a) &= (p-w)D + (cD - B)r_r \\ &= (p - w + cr_r)(\alpha - p + \gamma\theta) - Br_r \qquad (14)\end{aligned}$$

The decisions of supplier and retailer are obtained by backward induction. It can be deduced from equation (14) that the retailer's objective function is a concave function of the unit retail price p of the product; its optimal solution is as follows:

$$p^a = \frac{\alpha + w + \gamma\theta - cr_r}{2} \qquad (15)$$

The objective function of the supplier is obtained by substituting equation (15) into equation (13):

$$\begin{aligned}U(\pi_s^a) &= [(w - c(1+r_r)](\frac{\alpha + w + \gamma\theta + cr_r}{2}) \\ &\quad - \frac{\theta^2}{2} + Br_r - k[(w - c(1+r_r)]\sigma \qquad (16)\end{aligned}$$

Proposition 3: The objective function of the supplier under retailer's advance payment $U(\pi_s^a)$ is the union concave function of the unit wholesale price and the green level (w, θ). There is a unique equilibrium solution to maximize the utility function. The optimal decisions of supplier and retailer, respectively, are as follows:

$$\begin{aligned}w^a &= \frac{2\alpha + 2c(1+2r_r) - c\gamma^2(1+r_r) - 4k\sigma}{4-\gamma^2} \\ \theta^a &= \frac{(\alpha - c - 2k\sigma)\gamma}{4-\gamma^2} \\ p^a &= \frac{3\alpha + c - 2k\sigma - (c + k\sigma)\gamma^2}{4-\gamma^2}\end{aligned}$$

Thus, the market demand and the supplier and retailer's profits are as follows:

$$\begin{aligned}E(D^a) &= \frac{\alpha - c + 2k\sigma - \gamma^2 k\sigma}{4-\gamma^2} \\ E(\pi_s^a) &= \frac{[4(\alpha - c) + 8k\sigma](\alpha - c - 2k\sigma)}{2(4-\gamma^2)^2} \\ &\quad + \frac{[-(\alpha - c)\gamma^2 - 2\gamma^2 k\sigma](\alpha - c - 2k\sigma)}{2(4-\gamma^2)^2} + Br_r \\ E(\pi_r^a) &= \frac{(\alpha - c + 2k\sigma - \gamma^2 k\sigma)^2}{(4-\gamma^2)^2} - Br_r\end{aligned}$$

Corollary 4: Under retailer's advance payment, the supplier's profit increases as the initial capital and wholesale price discount rate increases; however, the retailer's profit decreases with the crease of supplier's initial capital and wholesale price discount rate.

Proof of Corollary 4: $\frac{\partial \pi_s^a}{\partial B} > 0$; $\frac{\partial \pi_s^a}{\partial r_r} > 0$; $\frac{\partial \pi_r^a}{\partial B} < 0$; $\frac{\partial \pi_r^a}{\partial r_r} < 0$.

It is proved that with the increase of initial capital, the financing amount of the supplier decreases and the profit increases, while the profit of the retailer decreases. With the crease of wholesale price discount rate, the profit of the supplier increases, while the profit of the retailer decreases. Higher wholesale discount rates benefit retailers, which is not intuitive. Transfer the full capital cost of production from the supplier to the retailer by raising unit wholesale prices; the retailer only receives interest on the product $D^a - \frac{B}{c}$.

Corollary 5: Under the retailer's advance payment, the influence of risk aversion of the supplier coefficient on

the unit wholesale price w^a, green level θ^a, unit retail price p^a, and market demand D^a is consistent with the scenario when the supplier has sufficient capital. The unit wholesale price, green level, unit retail price, profit of both members, and market demand are found to have the following order $w^a > w^s$, $\theta^a = \theta^s$, $p^a = p^s$, $D^a = D^s$, $E(\pi_s^a) > E(\pi_s^s)$ and $E(\pi_r^a) < E(\pi_r^s)$.

It is found that the unit wholesale price of the retailer with prepayment is higher than that of the supplier with sufficient funds, and the supplier's green level, unit retail price, and market demand under the retailer's advance payment is equivalent to that of sufficient supplier sufficient capital. The supplier's profit is higher than under a scenario of sufficient supplier capital, but the retailer's profit is lower than under sufficient supplier capital.

That is, when the supplier is financially constrained and obtains financial support from the retailer, the green level, unit retail price, and market demand are consistent with the values of a scenario of sufficient capital. Nevertheless, the supplier will raise the unit wholesale price to take the interest on the retailer's advance payments. When the supplier's degree of risk aversion remains unchanged, the profit of the whole supply chain can reach the same level as under the situation of sufficient capital, which simultaneously alleviates the supplier's financial constraints. However, advance payment comes with a cost for the retailer compared to when the supplier is not financially constrained. The supplier prefers the retailer's advance payment, although he needs to pay a certain amount of interest.

B. THE SELECTION FOR FINANCING STRATEGY

1) THE SELECTION FOR THE SUPPLIER

This study assumes that the bank interest rate is equal to discount rate on the wholesale price, for simplified comparison with the financing strategy ($r_b = r_r = r_0$). Marking $B^b \equiv cE(D^b)$, the supplier encounters the dilemma where he has sufficient capital because of reduced market demand under bank financing, although he is financially constrained when $B^b < B < B^0$. Therefore, when $0 < B < B^b$, the study obtains $\pi_s^a > \pi_s^b$ and $\pi_s^a > \pi_s^0$; the supplier can choose either bank financing or retailer's advance payment, but the latter is more advantageous. When $B^b < B < B^0$, the study obtains $\pi_s^a > \pi_s^0$, and the supplier should choose retailer's advance payment. In the latter case, the supplier charges a higher unit wholesale price for all products, but only needs to return interest on the proportion of products with retailer's advance payment, and the market demand is not changed. Thus, prepayment financing is more beneficial to the supplier, because he can obtain more profit than in the scenario where he has sufficient capital.

2) THE SELECTION FOR THE RETAILER

For the retailer, the study marks that

$$h = \frac{cr_0(3-\gamma^2) - (\alpha - c)(2-\gamma^2)}{\sigma(2-\gamma^2)^2},$$

$$B^1 = \frac{c[2(\alpha - c) + (4-2\gamma^2)k\sigma - cr_0]}{(4-\gamma^2)^2},$$

$$B^2 = \frac{c\sqrt{c^2(4-\gamma^2)^2 r_0^2 + 4[\alpha - c + (2-\gamma^2)k\sigma]^2} - c^2 r_0(4-\gamma^2)}{2(4-\gamma^2)}.$$

If $k < h$, when $0 < B < B^b$, the study obtains $\pi_r^a > \pi_r^b > \pi_r^0$; when $B^b < B < B^2$, the study obtains $\pi_r^0 < \pi_r^a$; when $B^2 < B < B^0$, the study obtains $\pi_r^0 > \pi_r^a$.

If $k > h$, when $0 < B < B^1$, the study obtains $\pi_r^a > \pi_r^b > \pi_r^0$; when $B^1 < B < B^b$, the study obtains $\pi_r^b > \pi_r^a$ and $\pi_r^b > \pi_r^0$; when $B^b < B < B^0$, the study obtains $\pi_r^a < \pi_r^0$.

The prepayment financing strategy provided by the retailer is better than the bank financing strategy when the degree of suppliers' risk aversion is less and the risk-aversion coefficient satisfies $k < h$. However, when the supplier has more initial capital ($B^2 < B < B^0$), the retailer will not provide prepayment financing, and the supplier can only arrange production with the initial capital. When the degree of suppliers' risk aversion is greater and the risk-aversion coefficient satisfies $k > h$, the retailer would prefer to provide advance payment only in the case when the supplier has less initial capital ($0 < B < B^1$).

V. NUMERICAL ANALYSIS AND DISCUSSION OF RESULTS

From the results obtained above, the study identified three decision variables, namely, the unit wholesale price, green level, and unit retail price. This section numerically presents the validity of the decision variables and analyzes the choice of the financing strategy.

A. IMPACT OF THE SUPPLIER's RISK-AVERSION COEFFICIENT

In this section, the following four situations are studied: (1) the supplier with sufficient funds; (2) the supplier with limited funds but no financing; (3) bank financing; and (4) advance payment provided by the retailer. The study investigates the influence of risk-aversion of the supplier coefficient on the unit wholesale price w, green level θ, and unit retail price p. The relevant propositions in this paper have described the decision-making and parameters. However, in view of the complexity of parameters and models, we have designed an arithmetic analysis for in-depth analysis, and further management insights have been obtained. In this paper, we refer to the study of Bai [46] and Wang [47]. Under the premise of satisfying the Hesse matrix of this paper, we assume that the parameters of this paper are $c = 20$, $\alpha = 50$, $\varepsilon \sim (0, 10^2)$, $\gamma = 0.5$, $B = 20$, $k \in [0, 2]$, $r_b = r_r = r_0 = 0.2$.

Fig.2 shows that wholesale prices show a gradual downward trend as suppliers' risk aversion increases. Compared with the wholesale price when the supplier carries on financing under the financial constraint, this is because the financing increases the cost of the supplier, which will have an enlarged effect on the degree of disgust of the supplier, which makes the wholesale price of the supplier further reduced.

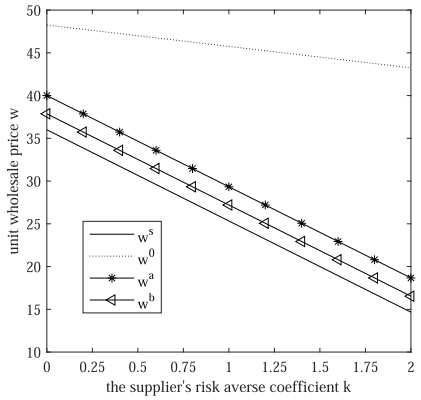


FIGURE 2. The relation between k and w.

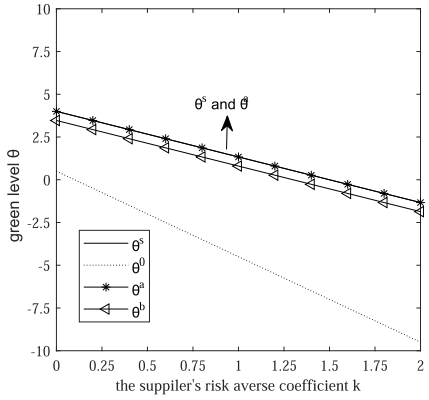


FIGURE 3. The relation between k and θ.

When suppliers have sufficient funds, the capital invested in the production of green products is entirely borne by themselves, which increases the degree of risk aversion. Suppliers tend to lower wholesale prices to sell products to retailers to realize the transfer of risk.

Fig.3 indicates that the green degree of the product decreases as the supplier's risk coefficient increases. That is to say, the higher the supplier's risk aversion, the lower the greenness of the product. It is worth noting that the supplier's green level in the case of prepayment financing is the same as the case of the supplier's sufficient funds. This is due to the fact that prepayment financing, as a means of internal financing, solves the problem of shortage of funds, and does not cause the loss of profits, but only changes the profit distribution between the two sides.

Fig.4 suggests that the unit retail price has the same trend as the unit wholesale price, which decreases with the increase of supplier risk aversion coefficient. On the other hand, the retailer reduces the unit retail price on account of the purchase cost reduction. Under the retailer's advance payment, the unit retail price is equivalent to that with sufficient supplier capital. It's obvious that, similar to the green level, the decision of the supplier is affected by the bank interest rate rather than the wholesale price discount rate.

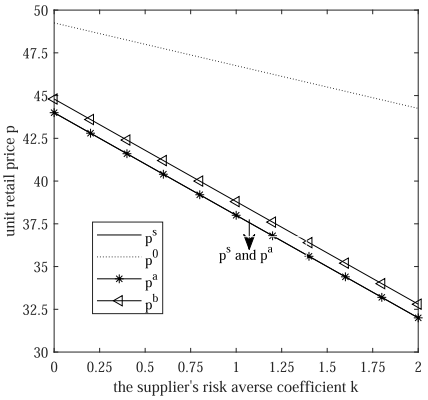
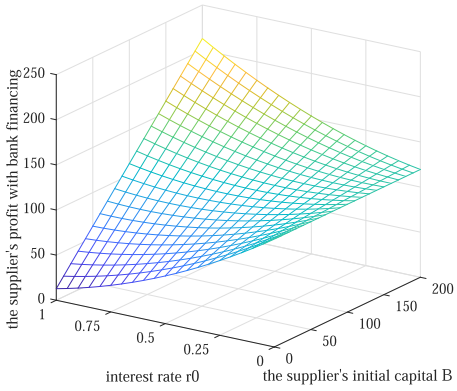


FIGURE 4. The relation between k and p.



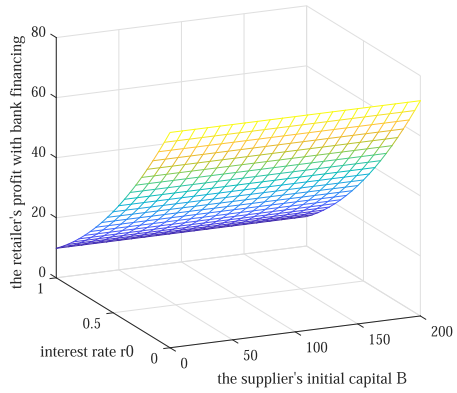


FIGURE 5. The supplier and retailer's profits vs r_0 and B under bank financing.

B. IMPACT OF INTEREST RATE AND THE SUPPLIER'S INITIAL CAPITAL

This section analyzes how the interest rate and supplier's initial capital affect the supplier and retailer's profit in different financing strategies. The values for the corresponding parameters are $c = 20$, $\alpha = 50$, $\varepsilon \sim (0, 10^2)$, $\gamma = 0.5$, $k = 0.1$, $B \in [0, 200]$, $r_0 \in [0, 1]$.

Fig.5 indicates that, under bank financing, the profit of suppliers increases as his initial capital increases. His profit increases as the interest rate increases when the initial capital

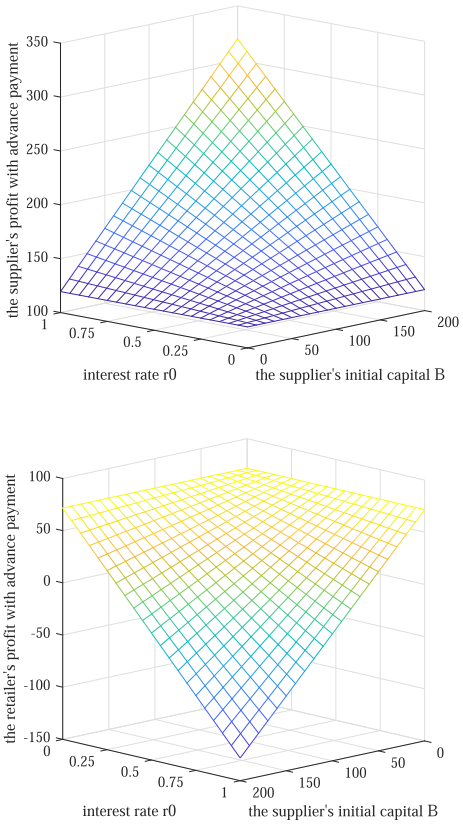


FIGURE 6. The supplier and retailer's profits vs r_0 and B under retailer's advance payment.

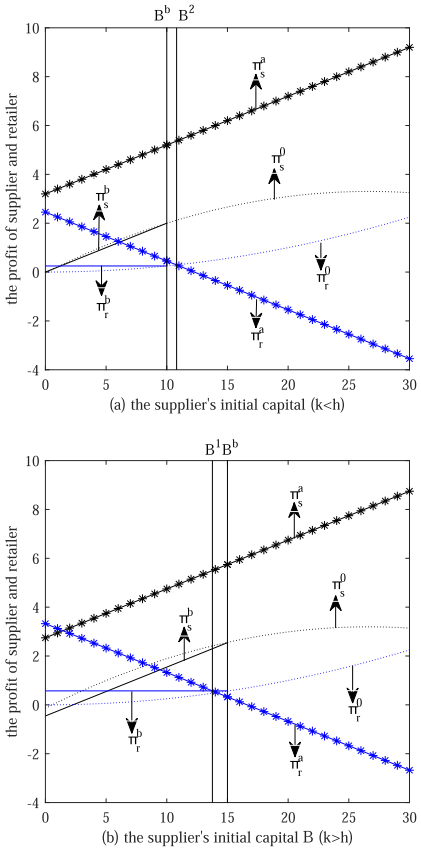


FIGURE 7. The supplier and retailer's profits vs the supplier's initial capital in different situations.

is more. However, when has less initial capital, it decreases as the interest rate increases. The profit of the retailer has nothing to do with the initial capital of the supplier, but decreases as the interest rate increases. The lower the bank interest rate, the better it will be for all subjects. Higher bank rates are good for suppliers, but it is bad for retailers when suppliers have more initial capital.

It can be clearly seen from Fig.6, under retailer's advance payment, the supplier's profit increases as his initial capital and wholesale price discount rate increases. However, the retailer's profit decreases as the supplier's initial capital and wholesale price discount rate increases.

C. THE FINANCING STRATEGY CHOICE

This section further outlines choices of the retailers and suppliers for financing strategy under three circumstances: (1) the supplier is financially constrained but no financing; (2) bank financing; and (3) retailer's advance payment.

Fig.7 shows that if $k < h$, then $B_b = 10$, $B_2 = 10.81$, $B_0 = 31.33$. When$0 < B < B^b$, $\pi_s^a > \pi_s^b > \pi_s^0$, $\pi_r^a > \pi_r^b > \pi_r^0$; when$B^b < B < B^2$, $\pi_r^0 < \pi_r^a$; when $B^2 < B < B^0$, $\pi_r^0 > \pi_r^a$. If $k > h$, $B_1 = 13.76$, $B_b = 15.13$, $B_0 = 36.47$. When $0 < B < B^1$, $\pi_s^a > \pi_s^b$ and $\pi_s^a > \pi_s^0$, $\pi_r^a > \pi_r^b > \pi_r^0$; when $B^1 < B < B^b$, $\pi_s^a > \pi_s^b$ and $\pi_s^a > \pi_s^0$, $\pi_r^b > \pi_r^a$ and $\pi_r^b > \pi_r^0$; when $B^b < B < B^0$, $\pi_r^a < \pi_r^0$. Therefore, if $k < h$, when the initial capital of the supplier meets $0 < B < B^b$, prepayment financing is the best choice for suppliers and retailers. From the supply chain perspective, the internal financing provided by retailers effectively solves the problem of shortage of suppliers' funds, reduces the marginal utility of the supply chain, and promotes the strategic cooperation of both sides. Therefore, both sides prefer internal supply chain financing (prepayment financing). When the initial capital meets $B^b < B < B^2$, $\pi_r^0 > \pi_r^b$, it indicates that the retailer's profit is lower when the supplier makes trade credit from the bank Compared to financing. This shows that the marginal profit brought by the R&D investment of green products from bank loans is gradually lower than the marginal cost and the bank credit interest rate. As a result, suppliers will reduce the level of green research and development, and eventually retailers' profits will decline as a result. Therefore, when the initial capital meets $B^b < B < B^2$, it is more beneficial for retailers when suppliers use their own funds for research and development. However, it is more profitable than internal financing. Therefore, it is the best strategy for retailers to provide prepayment financing.

If $k > h$, when $0 < B < B^1$, in the case of prepayment financing, the profits of both parties are better than the other two decisions. However, when $B^1 < B < B^b$, the optimal decisions of suppliers and retailers are different, suppliers tend to advance financing, retailers tend to bank loans. The reason for this result is that suppliers with too high degree

of risk aversion want to transfer to retailers in the form of advance payment, and retailers are not willing to bear this part of the risk. Therefore, for retailers, not providing advance payment is the best option. Compared with bank financing, the profits of suppliers are improved, so suppliers often adopt the way of bank financing to carry out green production.

Fig.7 shows that the best choice for suppliers is prepayment financing provided by the retailer regardless of the degree of supplier's risk aversion. This can not only improve the profit distribution between the two parties, but also realize the transfer of risk in the form of advance payment. However, for retailers, the degree of suppliers' risk aversion has an impact on the financing methods they provide. When the degree of suppliers' risk aversion of is getting higher and higher, retailers are more inclined not to provide financing to reduce risk.

VI. CONCLUSION

Based on green production and financial constraints of the supplier, the green supply chain comprising a single supplier and a single retailer is studied, and the supplier's financial constraints and degree of risk aversion are considered. The objective of this research is to clarify how to effectively price and balance the financing strategy in the green supply chain, and to analyze the influence of the degree of supplier's risk aversion on the best decisions and on both member's choices for the strategy.

The supplier's risk-aversion attitude has an influence on the unit wholesale price, green level, and unit retail price. A risk-averse supplier ought to charge lower unit wholesale prices and reduces the green level of product. The retailer should lower the unit retail price to attract more consumers and increase market demand in the face of the risk-averse supplier. The high risk aversion of suppliers is disadvantageous to the improvement of the green level of the supply chain.

When the supplier is financially constrained, bank financing and the retailer's advance payment can both effectively solve the supplier's financial constraint. When the supplier's initial capital is less, the advance payment is the optimal choice for both parties. On the contrary, the supplier faces a dilemma as he has sufficient capital because of the reduction of market demand under bank financing, although he is financially constrained. However, under prepayment financing, the retailer's profit will be lower than the retailer's that when the supplier is financially constrained but has no financing; the retailer will not provide advance financing, and the supplier should choose to arrange production with initial capital.

Further research may be extended in the following direction. In practice, all participants may be risk-averse; therefore, the combination of these risk preferences could be considered. Furthermore, this study assumed that the bank interest rate and discount rate from the wholesale price are exogenous, which can be treated as endogenous decision variables to enrich this research.

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