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A SIMULATION STUDY ON SUPPLY CHAIN FINANCING STRATEGY OF MANUFACTURING FIRMS

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Abstract
This study considers a manufacturing supply chain comprising a single risk-neutral manufacturer and a single risk-averse retailer. Among them, the manufacturer can produce traditional or green products and has sufficient funds to produce traditional products but lacks green processing costs. When the manufacturer produces green products, it can solve its financial difficulties through bank loans or internal financing from the retailer. This study examines the manufacturing supply chain financing strategy under capital constraints and risk aversion and draws the following conclusions: the manufacturer's wholesale price is the largest and smallest under the bank loan financing and internal financing modes, respectively; the retailer's retail price is the largest and smallest under the bank loan financing and traditional product production modes, respectively. The green input levels between the two financing modes directly depend on the bank loan interest rate and risk aversion. The optimal decisions of the manufacturer and retailer are to sell green products and choose internal financing, while selling traditional products is the worst decision.
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Key Words: Green Manufacturing, Manufacturing Supply Chain, Financing Strategy, Capital Constraints, Risk Aversion

1. INTRODUCTION

With the rapid development of the social economy, the environment is also deteriorating, posing a serious threat to mankind. Therefore, there is an urgent need to protect the environment, reduce carbon emissions, and develop green technology [1, 2]. By the end of 2021, China has built a total of 2,783 green factories, 223 green industrial parks, and 296 green supply chain management enterprises, which will significantly improve the greening of the manufacturing sector, according to a white paper titled "China's Green Development in the New Era" released by the State Council of China. In this context, an increasing number of enterprises are actively improving the technical input of green products [3]. However, as the investment cost of green technology is very high, manufacturing enterprises may give up on the investment in green technology because of capital constraints, thus losing market competitiveness [4]. In real life, manufacturing enterprises with capital constraints can generally solve their financial difficulties through external or internal financing [5-7].

In the process of production and operation, enterprises will face not only the problem of capital constraints but also the uncertainty risk of market environmental [8-12]. Relevant experimental studies have established that enterprises will show behavioural preferences in the face of uncertain demand risks, such as risk aversion, stockout aversion, waste aversion, and fairness concern preferences [6, 13, 14]. These behavioural preferences have a serious impact on the decision-making behaviour of enterprises. Therefore, it is of great practical and theoretical significance to study the financing strategies of manufacturing supply chains with capital constraints and behavioural preferences.

Most existing studies are based on the situation in which the manufacturer or retailer has capital constraints, where they analyse the optimal financing strategy of the supply chain. Among them, bank loans and internal financing are two financing modes that are common in daily life and have been studied extensively. For the studies of bank loan financing, Kouvelis and Zhao investigate the optimal ordering and pricing decision of the supply chain when the capital-constrained retailer can lend to the bank and there is a bankruptcy cost [15]. Yan and Sun consider the optimal credit limit of commercial banks and the optimal ordering and pricing decisions of the supply chain when the retailer has a bankruptcy risk [16]. Xiao et al. study the coordination of a dual-channel supply chain in the context of the manufacturer lending to banks and providing commercial credit to the retailer [17]. In studies on internal financing, Xiao and Zhang consider the financing mode of capital-constrained manufacturer to raise funds from retailer through pre-sale activities and study the optimal pricing and quantity decisions in the supply chain [18]. Jin et al. study the effects of advance selling and deferred payment strategies on ordering decisions, bilateral performance, and supply chain performance [19]. Zhao and Huchzermeier consider the two financing modes of retailer providing advance payment discount and buyer-backed purchase order financing to reduce the financial pressure of supplier and analyse the retailer's preference for the two financing modes [20].

However, there are few financing problems related to capital constraints vis-à-vis the green supply chain in the existing literature. Wu et al. study enterprises' choices of bank financing and trade credit financing in a green supply chain composed of a single manufacturer and a single capital-constrained retailer [21]. Yang et al. further discuss a green supply chain composed of a single manufacturer and two capital-constrained retailers and analyse the impact of credit strategy on supply chain performance [22]. Other scholars have considered the impact of bank loan financing, equity financing, and mixed financing on the operation and financing decisions of low-carbon supply chains [23], the optimal production decision of both new and remanufactured products under the condition of maximizing the total profit when there are capital and carbon emission constraints [24], as well as the level of green input, ordering, and financing strategies of small manufacturers constrained by operating and green innovation funds [25].

The abovementioned studies all ignore the risk aversion preferences of enterprises. According to existing research, the risk aversion preference of enterprises is objective and will have an important impact on their ordering, pricing, green input level, and so on [26]. However, these studies do not consider the impact of risk aversion preferences on supply chain financing strategies, especially on manufacturing supply chain financing strategies. Therefore, this study introduces risk aversion into a manufacturing supply chain with capital constraints and constructs a two level supply chain model composed of a capital-constrained manufacturer and a risk-averse retailer. As the leading enterprise, the manufacturer can determine the green input level of the product, but it will face financial constraints when producing green products. In this case, it is necessary to solve its financial difficulties through bank loans or internal financing (at this time, it will lose the decision-making power of green input levels). Manufacturers can also choose to produce traditional products without facing financial constraints. Based on this background, this study examines green manufacturing supply chain financing strategies with capital constraints and risk aversion preferences.

2. MODEL DESCRIPTION AND ASSUMPTIONS

2.1 Model description

As shown in Fig. 1, the manufacturer in the first manufacturing supply chain only produces traditional products (Chain 1), while the manufacturer in the second and third manufacturing supply chains only produces green products. We assume that the manufacturer has sufficient funds to produce traditional products and that there are financial constraints when producing green products. At this point, the manufacturer can solve its financial constraints through bank loans or internal financing from the retailer. If the manufacturer chooses to lend to the bank, it has the decision right of the green input level, and the cycle interest rate of the loan is r (Chain 2). However, if the manufacturer chooses internal financing, the retailer will have the right to determine the level of green input but will need to bear all the green input costs [27] (Chain 3). Moreover, demand is well-known to be unpredictable and uncertain [28]. In this context, we study the manufacturing supply chain financing strategy of the retailer with risk aversion.

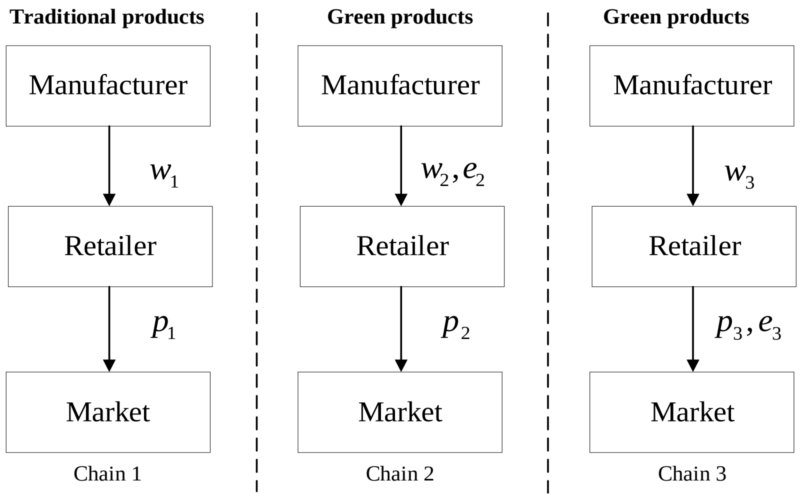

Figure 1: Manufacturing supply chain structure diagram.

2.2 Model assumptions

For convenience, we make the following assumptions in this paper:

(1) The demand for products is affected by the randomness of the retail price, green input level, and market demand, that is, $D = a - p + \theta e + \varepsilon$ [8, 29]. Here, the mean and variance of ε are 0 and δ^2, respectively; a is the scale of market demand; θ is the green preference of consumers; e is the level of green; and the green input cost is $C(e) = e^2$ [29].

(2) Considering that the retailer has risk aversion preferences for random demand, we use the mean-variance method to measure the uncertainty risk of demand. The retailer's utility function can be expressed as $U_R^g = E[\pi_R^g] - k\sqrt{Var(\pi_R^g)}$ [26]. The size of k can directly reflect the retailer's risk aversion, and π_R^g represents the retailer's profit.

(3) In the Stackelberg game, the manufacturer is the leader and retailer is the follower.

(4) $p_i > w_i > c_i, i \in \{1,2,3\}$.

All symbols used in this article and their meanings are presented in Table I.

Table I: Symbols and their meanings.

Symbols	Meaning	Symbols	Meanings
a	Market size	k	Risk aversion degree ($k > 0$)
r	Bank rate ($0 < r < 1$)	ε	Random variables of demand
c	Production cost of traditional products	δ	Mean square error of ε
θ	Consumers' green preference	π_M^g	Profit of the manufacturer
e	Green input level	U_R^g	The expected utility of the manufacturer
w_i	Wholesale price under the Chain i	π_R^g	Profit of the retailer
p_i	Retail price under the Chain i	$\{A, B, C\}$	{Chain 1, Chain 2, Chain 3}
$*$	Optimal value	$i \in \{1, 2, 3\}, g \in \{A, B, C\}$	

3. MODEL CONSTRUCTION

3.1 Production of traditional product model

When the manufacturer only produces traditional products, it does not need to bear the cost of green processing, so it has sufficient funds for the production of traditional products (Chain 1). The order of the manufacturing supply chain decision is as follows: the manufacturer decides the wholesale price in advance w_1, and the retailer then determines its retail price p_1 according to the manufacturer's decision. The manufacturer's profit function π_M^A, retailer's profit function π_M^A, and expected utility function U_R^A are:

$$\begin{cases} \pi_M^A = (w_1 - c)(a - p_1) \\ \pi_R^A = (p_1 - w_1)(a - p_1 + \varepsilon) \\ U_R^A = E[\pi_R^A] - k\sqrt{Var(\pi_R^A)} = (p_1 - w_1)(a - p_1) - k(p_1 - w_1)\delta \end{cases} \tag{1}$$

As the manufacturer is the leader under the Stackelberg game, we use backward induction to solve the problem. Because $\frac{\partial^2 U_R^A}{\partial^2 P_1^2} = -2 < 0$, so we make $\frac{\partial U_R^A}{\partial p_1} = a - 2p_1 + w_1 - k\delta = 0$, then we can obtain the retailer's optimal retail price expression as $p_1^* = \frac{1}{2}(a + w - k\delta)$. We then substitute p_1^* into π_M^A and similarly set $\frac{\partial \pi_M^A}{\partial w} = \frac{1}{2}(a + c - 2w + k\delta) = 0$ to determine the optimal wholesale price of the manufacturer w_1^*. At this time, the Nash equilibrium solution of the manufacturing supply chain is:

$$\begin{cases} w_1^* = \frac{1}{2}(a + c + k\delta) \\ p_1^* = \frac{1}{4}(3a + c - k\delta) \end{cases} \tag{2}$$

The optimal profit of the manufacturer and the optimal expected utility of the retailer are:

$$\begin{cases} \pi_M^{A*} = \frac{1}{8}(a - c + k\delta)^2 \\ U_R^{A*} = \frac{1}{16}(c - a + 3k\delta)^2 \end{cases} \tag{3}$$

3.2 Bank financing model

When the manufacturer produces green products and needs to bear the processing cost of green products, the manufacturer is underfunded, and it can choose to finance through bank loans. The decision order of the manufacturing supply chain is as follows: the manufacturer decides the wholesale price w_2 and green input level e_2 in advance and the retailer then determines its retail price p_2 according to the manufacturer's decision. The manufacturer's profit function, retailer's profit function, and the retailer's expected utility function are:

$$\begin{cases} \pi_M^B = (w_2 - c)(a - p_2 + \theta e_2) - (1 + r)e_2^2 \\ \pi_R^B = (p_2 - w_2)(a - p_2 + \theta e_2 + \varepsilon) \\ U_R^B = E[\pi_R^B] - k\sqrt{Var(\pi_R^B)} = (p_2 - w_2)(a - p_2 + \theta e_2) - k(p_2 - w_2)\delta \end{cases} \tag{4}$$

From Eq. (4), we can see that $\frac{\partial^2 U_R^B}{\partial^2 P_2^2} = -2 < 0$, so let $\frac{\partial U_R^B}{\partial p_2} = a - 2p_2 + w_2 - k\delta + \theta e_2 = 0$, and we can obtain the retailer's optimal retail price expression as $p_2^* = \frac{1}{2}(a + w_2 - k\delta + \theta e_2)$. We then introduce p_2^* into π_M^B and jointly solve $\frac{\partial \pi_M^B}{\partial w_2} = 0$ and $\frac{\partial \pi_M^B}{\partial e_2} = 0$ to determine the manufacturer's optimal wholesale price w_2^* and green input level e_2^*. At this time, the Nash equilibrium solution of the manufacturing supply chain is:

$$\begin{cases} w_2^* = \dfrac{4(a+k\delta)(1+r)+c(4+4r-\theta^2)}{8+8r-\theta^2} \\ e_2^* = \dfrac{(a-c+k\delta)\theta}{8+8r-\theta^2} \\ p_2^* = \dfrac{6a(1+r)+(c-k\delta)(2+2r-\theta^2)}{8+8r-\theta^2} \end{cases} \tag{5}$$

The optimal profit of the manufacturer π_M^{B*} and the optimal expected utility of the retailer U_R^{B*} are:

$$\begin{cases} \pi_M^{B*} = \dfrac{(1+r)(a-c+k\delta)^2}{8+8r-\theta^2} \\ U_R^{B*} = \dfrac{[2(a-c)(1+r)+k\delta(-6-6r+\theta^2)]^2}{(\theta^2-8-8r)^2} \end{cases} \tag{6}$$

3.3 Internal financing model

When the manufacturer only produces green products, the manufacturer will face financial constraints. If the manufacturer chooses to provide internal financing to the retailer, the retailer will obtain the decision-making right of green input level e_3 and must bear the processing cost of green products e_3^2 [27]. Meanwhile, it is assumed that the opportunity cost of the retailer's green processing cost is equal to the bank interest, that is, the opportunity cost is re_3^2. The decision order of the manufacturing supply chain is as follows: the manufacturer decides the wholesale price w_3 in advance and the retailer then determines its green input level e_3 and retail price p_3 according to the manufacturer's decision. The manufacturer's profit function π_M^C, the retailer 's profit function π_R^C, and the retailer 's expected utility function U_R^C are:

$$\begin{cases} \pi_M^C = (w_3-c)(a-p_3+\theta e_3) \\ \pi_R^C = (p_3-w_3)(a-p_3+\theta e_3+\varepsilon)-(1+r)e_3^2 \\ U_R^C = E[\pi_R^C] - k\sqrt{Var(\pi_R^C)} = (p_3-w_3)(a-p_3+\theta e_3)-k(p_3-w_3)\delta \end{cases} \tag{7}$$

By jointly solving $\frac{\partial U_R^C}{\partial p_3}=0$ and $\frac{\partial U_R^C}{\partial e_3}=0$, the expressions for the retailer 's optimal retail price and green input level are $p_3^* = \frac{2(1+r)(a+w-k\delta)-w\theta^2}{4+4r-\theta^2}$ and $e_3^* = \frac{(a-w-k\delta)\theta}{4+4r-\theta^2}$, respectively. Substituting p_3^* and e_3^* into π_M^C, we set $\frac{\partial \pi_M^C}{\partial w_3}=0$to determine the manufacturer's optimal wholesale price w_3^*. At this time, the Nash equilibrium solution of the manufacturing supply chain is:

$$\begin{cases} w_3^* = \dfrac{2a(1+r)+2c(1+r)+k\delta(2+2r-\theta^2)}{4(1+r)} \\ e_3^* = \dfrac{\theta[2(a-c)(1+r)-k\delta(6+6r-\theta^2)]}{4(1+r)(4+4r-\theta^2)} \\ p_3^* = \dfrac{(12a+4c)(1+r)^2-2k\delta(1+r)(2+2r-\theta^2)-\theta^2[2(a+c)(1+r)+k\delta(2+2r-\theta^2)]}{4(1+r)(4+4r-\theta^2)} \end{cases} \tag{8}$$

The optimal profit of the manufacturer π_M^{C*} and the optimal expected utility of the retailer U_R^{C*} are:

$$\begin{cases} \pi_M^{C*} = \dfrac{[2(a-c)(1+r)+k\delta(2+2r-\theta^2)]^2}{8(1+r)(4+4r-\theta^2)} \\ U_R^{C*} = \dfrac{[2(a-c)(1+r)-k\delta(6+6r-\theta^2)]^2}{16(1+r)(4+4r-\theta^2)} \end{cases} \tag{9}$$

4. SIMULATION ANALYSIS

The Nash equilibrium solution of the manufacturing supply chain under three different situations is obtained. To obtain more valuable conclusions, we use the method of numerical simulation to study how the change of the key coefficient will affect the decision-making, profit, and utility of participants, and discuss the financing strategy of participants and the sales strategy of product types. We consider the relevant parameter values as $a = 50$, $c = 2$, $\theta = 1$, and $\delta = 2$.

4.1 Sensitivity analysis

When the retailer's risk aversion value k is fixed, we take the bank loan interest rate $r = 0.1$, $r = 0.5$, and $r = 0.9$. We also fix the bank loan interest rate value r and consider the retailer's risk aversion degree $k = 0.5$, $k = 1$, and $k = 1.5$.

The following conclusions can be drawn from Table II: (1) If the manufacturer produces traditional products, the loan interest rate r will not affect the wholesale and retail price. (2) If the manufacturer produces green products and borrows from the bank, the loan interest rate r will reduce the wholesale price, retail price, and green input level. (3) If the manufacturer produces green products and conducts internal financing through the retailer, the loan interest rate r will increase the wholesale price but reduce the retail price and green input level. (4) If the manufacturer produces traditional products, the risk aversion k will reduce the retail price but increase the wholesale price. (5) If the manufacturer produces green products and borrows from the bank, the risk aversion k will increase the wholesale price and green input levels but reduce the retail price. (6) If the manufacturer produces green products and conducts internal financing through the retailer, the risk aversion k will increase the wholesale price but reduce the retail price and green input levels.

Table II: Impact of k and r on wholesale price, retail price and green input level.

k	r	w_1^*	w_2^*	w_3^*	p_1^*	p_2^*	p_3^*	e_2^*	e_3^*
0.5	0.1	26.50	29.64	26.27	37.75	42.46	40.98	6.28	6.68
	0.5	26.50	28.73	26.33	37.75	41.09	39.93	4.455	4.53
	0.9	26.50	28.23	26.35	37.75	40.34	39.40	3.451	3.43
1.0	0.1	27.00	30.21	26.55	37.50	42.31	40.43	6.41	6.31
	0.5	27.00	29.27	26.67	37.50	40.91	39.47	4.55	4.27
	0.9	27.00	28.76	26.74	37.50	40.14	38.98	3.52	3.22
1.5	0.1	27.50	30.77	26.82	37.25	42.15	39.88	6.54	5.94
	0.5	27.50	29.82	27.00	37.25	40.71	39.00	4.64	4.00
	0.9	27.50	29.30	27.11	37.25	39.94	38.56	3.59	3.01

Table III: Impact of k and r on manufacturer's profit and retailer's expected utility.

k	r	π_M^{A*}	π_M^{B*}	π_M^{C*}	U_R^{A*}	U_R^{B*}	U_R^{C*}
0.5	0.1	300.13	338.60	381.23	126.56	164.34	167.11
	0.5	300.13	327.41	355.27	126.56	152.86	154.13
	0.9	300.13	321.26	341.90	126.56	146.72	147.45
1.0	0.1	312.50	352.56	389.84	110.25	146.47	148.92
	0.5	312.50	340.91	365.07	110.25	135.41	136.55
	0.9	312.50	334.51	352.31	110.25	129.51	130.16
1.5	0.1	325.13	366.81	398.55	95.06	129.61	131.78
	0.5	325.13	354.68	375.00	95.06	119.01	120.00
	0.9	325.13	348.02	362.89	95.06	113.38	113.94

The following conclusions can be drawn from Table III: (1) If the manufacturer produces traditional products, the loan interest rate r will not affect the manufacturer's profit and the retailer's expected utility. (2) If the manufacturer produces green products, the loan interest rate r will always reduce the manufacturer's profit and the retailer's expected utility. (3) If the manufacturer produces green products, the risk aversion k will always reduce the retailer's expected utility but increase the manufacturer's profit.

4.2 Comparative analysis

From Figs. 2 and 3, we can see that, first, the wholesale price is highest when the manufacturer produces green products and lends to the bank, followed by the production of traditional products and internal financing through the retailer, that is, $w_3^* < w_1^* < w_2^*$. Second, the retail price is highest when the manufacturer produces green products and lends to the bank, followed by internal financing and the production of traditional products, that is, $p_1^* < p_3^* < p_2^*$. Third, when the retailer has a high degree of risk aversion, the manufacturer has greater green input levels when choosing bank loans, that is, $e_2^* > e_3^*$. When the retailer's risk aversion is low, the manufacturer has greater green input levels when choosing internal financing, that is, $e_2^* < e_3^*$. When the retailer's risk aversion is moderate, the size of the green input levels between the two financing modes is related to the loan interest rate and the risk aversion degree.

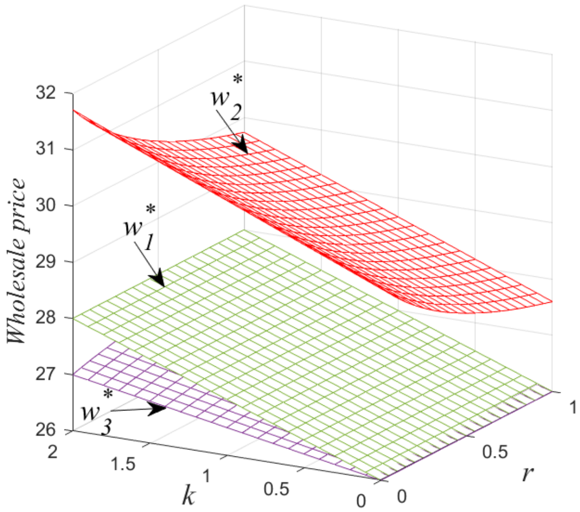

Figure 2: Impact of k and r on wholesale price under the three models.

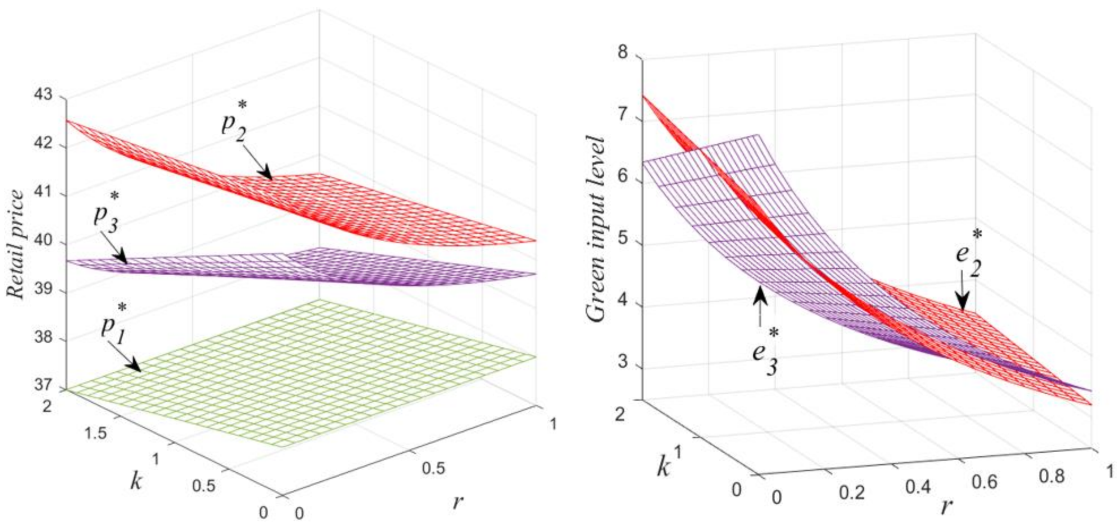

Figure 3: Impact of k and r on retail price and green input levels under the three models.

It can be found from Figs. 4 and 5 that the manufacturer (retailer) obtains the largest profit (expected utility) when producing green products and choosing internal financing, followed by choosing bank loans and producing traditional products, that is, $\pi_M^{A*} < \pi_M^{B*} < \pi_M^{C*}$ ($U_R^{A*} < U_R^{B*} < U_R^{C*}$).

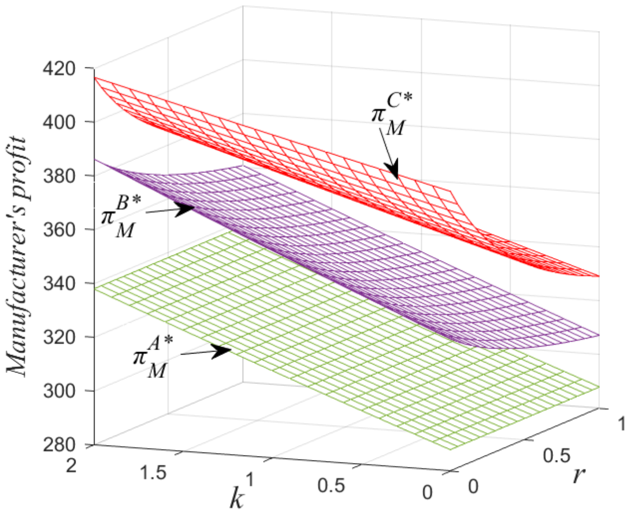

Figure 4: Impact of *r* and *k* on the manufacturer's profit under the three models.

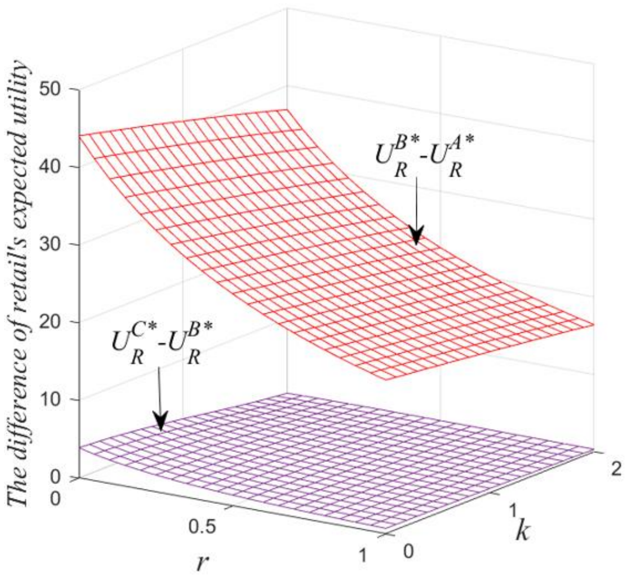

Figure 5: Effects of *r* and *k* on the difference of retailer's expected utility under the three models.

5. CONCLUSION

We focus on a manufacturing supply chain consisting of a single risk-neutral manufacturer and a single risk-averse retailer, where the manufacturer can produce traditional or green products, while the retailer can choose to sell traditional or green products. The manufacturer has sufficient funds to produce traditional products, but it lacks green input costs when producing green products. To solve the financial constraints, the manufacturer can choose to lend to the bank when it has the right to decide the green input levels or internal financing from the retailer when it loses the right to decide the green input levels. Under the manufacturer-led Stackelberg game framework, we study the financing strategy and product type selections of the manufacturing supply chain. The following conclusions can be drawn from the analysis of the full text:

(1) The wholesale price is largest when the manufacturer produces green products and borrows from the bank, followed by the production of traditional products, whereas the wholesale price is smallest when the retailer bears the green input cost. As the manufacturer bears the highest cost when choosing bank loans, the wholesale price is also the highest. However, when the retailer bears the green input cost, the manufacturer bears the lowest cost; therefore, the wholesale price is also the lowest. In summary, the manufacturer's wholesale price is closely related to its production costs.

(2) When the manufacturer produces green products and borrows from banks, the retailer has the highest retail price, while the retail price is the lowest when producing traditional products. This is because the retail price is related to the wholesale price, and the price of green products is generally higher than that of traditional products.

(3) When the retailer's risk aversion is high, the green input levels in the internal financing model are smaller than those in the bank loan financing model. When the retailer's risk aversion is low, the input levels in the internal financing model will be greater. When the retailer's risk aversion is moderate, the input levels between the two financing modes depend on the degree of risk aversion and loan interest rate. This is because the retailer will bear all the green input costs in internal financing, and if the retailer's risk aversion to the market reaches a certain level, it will adopt a more conservative green input to reduce the risk of uncertainty, and vice versa. When the retailer's degree of risk aversion is moderate, the green input levels are affected by not only the risk aversion but also the bank lending rate.

(4) In the case of the manufacturer, the optimal decision is to produce green products and abandon the decision of green input levels in exchange for internal financing support from the retailer, whereas producing traditional products is the manufacturer's worst decision.

(5) For the retailer, its optimal decision is to sell green products and bear all the green input costs, and the retailer has the least benefit from selling traditional products.

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