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Research Article

Pricing and Coordination Strategy in a Green Supply Chain with a Risk-Averse Retailer

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This paper addresses the pricing and coordination strategy in a green supply chain in which a manufacturer produces a green product and sells it to a risk-averse retailer. The product's demand is a random variable influenced by the green level and the retail price. The problem is modeled in three different structures, a centralized and two decentralized models, in which the upstream manufacturer and the downstream retailer act as the channel leader, respectively. This paper presents the optimal decisions for all supply chain members, analyzes the effects of green degree and risk-averse coefficient on the supply chain members' decision-making and their profits, and performs the numerical analysis. The results show that the green degree and the whole supply chain's expected profits are highest in the centralized scenario, followed by the retailer-led scenario, and lowest under the manufacturer-led scenario; the green degree and the manufacturer's expected profit increase with the risk-averse coefficient, no matter who dominates the channel; however, the risk-averse coefficient's effects on the retailer's expected utility and the retail price depends on who dominates the channel and on the greening investment parameter.

1. Introduction

With rapid economic development, the environment has deteriorated markedly [1]. Governments and environmental protection agencies have issued a series of laws and regulations to encourage enterprises to resolve the problems of environmental deterioration and resource exhaustion [2]. The report of the Nineteenth National Congress of the Communist Party of China put forward that "we should adhere to environmental friendliness, cooperate in dealing with climate change, and protect the earth's homeland on which human beings depend." The International Organization for Standardization issued an international certification standard for the ISO14000 system on environmental management to regulate the activities, products, and environmental services of enterprises and organizations worldwide [3].

Increasingly stringent legal requirements and growing public awareness of environmental protection have prompted leading global businesses to collaborate with their partners to establish sustainable supply chains [4]. For example, the overall goal of Hewlett Packard is to realize a 10% reduction in greenhouse gas emissions related to suppliers by 2025, as compared to 2015 (http://www.sohu.com/a/276053081_818836). Another practical example of green supply chain coordination is also found in the computer business. Lenovo helps its partners commit to green business activities from operations and recycling (https://www.lenovo.com/us/en/social_responsibility/environment/). The significance of green supply chains and increasing attention on sustainable supply chain coordination has made it essential for both practical managers and academicians to consider green supply chain coordination in their management decisions and research.

Green supply chain coordination has received a great deal of attention and has been attributed with many achievements. Most recent research on supply chain coordination assumes that participants are risk neutral [5, 6], but in reality, supply chain members have different risk attitudes [7, 8]. Scholars have shown that not all decision

makers are risk neutral [9], but previous studies have not taken risk-averse decision makers into account. Because an enterprise's attitude to risk affects their final profits [10], there is a tremendous need to consider risk aversion in green supply chain models. In this paper, we examine how the risk-averse coefficient affects decision-making. Several questions are of interest:

(1) How do the supply chain members set the wholesale price, the retail price, and the green degree in three kinds of supply chain structures, and how do they compare in these three scenarios?

(2) How are the profits of the supply chain members in the three scenarios?

(3) How does the risk aversion coefficient affect the supply chain members' decisions and their profits?

(4) Is the two-part tariff contract effective in improving members' profits?

To answer these questions, we consider a scenario in which the manufacturer produces one brand of environmental green product and sells it through a risk-averse retailer. The manufacturer affords the research cost of the green product. We construct three models under these scenarios: the integrated scenario and two other scenarios, one with the manufacturer as a leader and the other with the retailer as a leader. Then, we obtain and compare the optimal price and green degree and the expected profits of supply chain members, allowing us to present a coordination contract. Lastly, this paper presents a numerical example to verify the results obtained in the theoretical models.

Our study finds that the green degree and the supply chain system's profit are the highest in the centralized scenario. When the greening investment parameter of the green product is lower than a certain multiple of the sensitivity coefficient of consumers to green products, the retail price is positively correlated with the risk-averse coefficient. The manufacturer's profit and the green degree increase with the risk-averse coefficient. The retailer's profit under the retailer-led condition decreases with the risk-averse coefficient; if the risk-averse coefficient is lower than a certain threshold, the retailer's profit under the manufacture-led condition increases with the risk-averse coefficient.

This paper contributes to the literature by examining green supply chain coordination considering the retailer's risk aversion. The proposed collaboration model posits a win-win solution for both members. To the best of the authors' knowledge, no green supply chain studies have taken risk aversion into consideration, as in the current paper. This paper also contributes to practice by advising managers how to price and distribute green products according to the retailer's risk aversion.

We organize the paper as follows: the Section 2 reviews the related literature; Section 3 presents the three models; Section 4 introduces green supply chain coordination; and numerical examples are given in Section 5. Section 6 summarizes our conclusions and managerial insights.

2. Literature Review

Two streams of the related literature are considered: research on green supply chain coordination and research on risk aversion.

2.1. Coordination of Green Supply Chain. Green supply chain coordination has received a great deal of attention and has enjoyed many achievements in recent years. Zhang and Liu showed that a revenue-sharing contract can coordinate the green supply chain following the Stackelberg game [11]. Basiri and Heydari studied the issue of green supply chain coordination with a model selling a traditional product and a substitutable green product [12]. Biswas et al. explored coordination of a sustainable supply chain and assumed that demand is determined by greening effort [13]. Heydari et al. analyzed a two-stage reverse supply chain in which the retailer pays rewards for returning obsolete products and the manufacturer refurbishes qualified returned products in a remanufacturing process [14]. They showed that the retailer cannot receive benefits until the remanufacturing process is complete. Taleizadeh et al. studied a two-tier green supply chain and showed that the profits of green supply chain members are higher in a cooperative scenario than in a noncooperative scenario [15]. Song and Gao established a green supply chain game model with two kinds of revenue-sharing contracts [16]. Taleizadeh et al. presented three contracts, including wholesale price, cost sharing, and a buyback contract, to coordinate a two-echelon green supply chain [15]. Hong and Guo studied three cooperation contracts, including two-part tariff, cost sharing, and a price-only contract, and investigated their environmental performance [17]. Rahmani and Yavari examined the pricing and greening issues in a dual-channel green supply chain when the market demand is disrupted [18]. All the aforementioned papers researching green supply chain coordination tended to consider the members as risk neutral. In contrast to these studies, we consider a situation in which the retailer is risk averse. More importantly, we capture the reality that supply chain members have different risk attitudes. As a result, risk-averse behavior should be considered. Such characteristics are of practical relevance.

2.2. Supply Chain Decisions with Risk Aversion. Recently, the business environment has become more complex and highly uncertain due to rapid economic growth and frequent environmental changes. In a volatile environment, supply chain members pay more attention to risk in decision-making processes. Choi and Choi et al. studied a single-supplier single-retailer supply chain with risk characteristics affected by return policy [19, 20]. Xiao and Choi considered a dynamic theoretic game model in which all players are risk averse and analyzed the effects of the retailer's risk sensitivity on the wholesale prices [21]. Xu et al. studied a risk-averse manufacturer's dual-channel pricing strategy and proposed a profit-sharing contract coordination mechanism [22]. Liu et al. [23] and Kim and Park [24] studied how risk attitude affects traditional supply chain members on price and profit

under different channel structures. Li et al. analyzed how the risk-averse coefficient affects decisions in a traditional supply chain with uncertain demand [25]. Liu et al. focused on the effect of risk aversion on the optimal decisions of a dual-channel supply chain in a scenario of complete and asymmetric information [23]. While all these papers do consider risk aversion, they do not take the product's greenness into account. By contrast, our work considers risk aversion in green supply chain models. These characteristics have significant effects on managerial decisions and insights.

2.3. Research Gap. The literature on the green supply chain has paid little attention to the risk aversion of the supply chain's members. Conversely, the literature that considers risk aversion is mainly concerned with traditional supply chains.

The work that most closely approximates to ours is the study by Li et al. [25], but there are two differences between the papers. First, the background of the problem. Li et al. [25] consider similar supply chain structures but do not consider the greenness of the product. We consider pricing and cooperation in the scenario of a green supply chain. Second, the methods for measuring risk aversion. Li et al. [25] use the Value at Risk method to assess the risk-averse behavior, while we evaluate the retailer's risk-averse behavior using the utility function approach.

Table 1 summarizes the aforementioned literature on green supply chain models and risk aversion. In Table 1, it can be readily observed that our paper contributes to this stream of research in two ways. First, we incorporate the risk preferences of the green supply chain members into the model. Second, we design an incentive mechanism to realize green supply chain coordination.

3. Models

We study a two-layer green supply chain consisting of one upstream manufacturer and one downstream retailer. We shall refer to the manufacturer as "she" and the retailer as "he" in the following. In order to support a more sustainable environment and enhance the competitiveness on the market, the manufacturer produces a low-carbon product. To build our models, we first make these assumptions:

Assumption 1. The demand is determined jointly by the retail price and the green degree. According to Li et al. [25], we have demand D as follows:

$$D = a - bp + k\theta + \varepsilon, \tag{1}$$

where a is total market potential, b is consumer demand price sensitivity, p is the green product's price charged by the retailer, k is consumer sensitivity, θ is the low-carbon product's green degree, ε is random noise, and $\varepsilon \sim N(0, \sigma^2)$.

Assumption 2. The production of the green product will not bring additional cost to the manufacturer except research cost $C(\theta) = (1/2)\eta\theta^2$, where η is the unit cost coefficient of the green degree according to Swami and Shah [27]. Model parameters and decision variables are listed in Table 2.

Subscripts M, R, and SC denote the manufacturer, the retailer, and the whole supply chain, respectively. Subscripts c and d denote the integrated and decentralized scenarios, respectively. Superscripts M and R denote the manufacturer-led and the retailer-led scenarios, respectively.

Firstly, we give optimal decisions of the green supply chain members under three different scenarios including the integrated, the manufacturer-led, and the retailer-led. Secondly, we compare the optimal solution and present the sensitivity analysis. Thirdly, we propose a simple contract to coordinate the sustainable supply chain, and lastly, we present a numerical example.

3.1. Integrated Scenario. In the integrated scenario we assume there is a central decision maker whose aim is to maximize the whole supply chain's profits. We can find the optimal solution of the whole supply chain by modeling such a decision model. The profits of the manufacturer and the retailer, denoted by π_M and π_R, are listed as follows:

$$\pi_M = (w - c)D - \frac{1}{2}\eta\theta^2 = (w - c)(a - bp + k\theta + \varepsilon) - \frac{1}{2}\eta\theta^2, \tag{2}$$

$$\begin{aligned} \pi_R &= (p - w), \\ D &= (p - w)(a - bp + k\theta + \varepsilon). \end{aligned} \tag{3}$$

We assume that the manufacturer is risk neutral and the retailer is risk-averse since the manufacturer can diversify her assets across multiple firms, while the retailer's income is tied to the manufacturer. This assumption is common in the literature [7, 25, 28].

The manufacturer is risk neutral, so the expected utility $U(\cdot)$ equals the expected profit $E(\cdot)$:

$$E(\pi_M) = (w - c)(a - bp + k\theta) - \frac{1}{2}\eta\theta^2, \tag{4}$$

$$E(\pi_R) = (p - w)(a - bp + k\theta), \tag{5}$$

$$U(\pi_M) = E(\pi_M). \tag{6}$$

The retailer is risk averse. Based on mean variance theory, the expected utility is

$$\begin{aligned} U(\pi_R) = E(\pi_R) - r\mathrm{Var}(\pi_R) &= (p - w)(a - bp + k\theta) \\ &\quad - r(p - w)^2\sigma^2. \end{aligned} \tag{7}$$

Thus, the supply chain's overall utility is

$$\begin{aligned} U(\pi_{SC}) = U(\pi_M) + U(\pi_R) &= (p - c)(a - bp + k\theta) \\ &\quad - \frac{1}{2}\eta\theta^2 - r(p - w)^2\sigma^2. \end{aligned} \tag{8}$$

Theorem 1. *Under the integrated scenario, the optimal decisions are*

Table 1: Comparison of previous papers with the current study.

Reference	Supply chain		Coordinated contract				Decision variables			Risk reference
	Green	Nongreen	Two-part tariff	Revenue sharing	Cost sharing	Risk sharing	Retail price	Green degree	Wholesale price	
Li et al [25]		✓				✓	✓			✓
Li et al [26]	✓		✓				✓	✓	✓	
Basiri and Heydari [12]	✓						✓	✓		
Zhou et al. [7]		✓								✓
Song and Gao [16]	✓			✓			✓	✓	✓	
Taleizadeh et al. [15]	✓				✓		✓		✓	
Heydari et al. [14]	✓						✓	✓		
Rahmani and Yavari [18]	✓						✓	✓	✓	
Hong and Guo [17]	✓		✓				✓	✓	✓	
This paper	✓		✓				✓	✓	✓	✓

Table 2: Model parameters and decision variables.

Model parameter	
D	The demand in the direct channel
a	The total market potential demand
b	Consumer demand's price sensitivity
k	Consumer sensitivity to the green degree
η	Unit cost coefficient of the green degree
C	Research cost of the green product
ε	Random noise of the demand
σ	Standard deviation of normal distribution
r	Risk-averse coefficient
Decision variables	
w	Wholesale price of the green product
θ	The product's green degree
p	Retail price of the green product

$$p_c^* = \frac{(a+bc)\eta - k^2 c}{2b\eta - k^2}, \tag{9}$$

$$\theta_c^* = \frac{k(a-bc)}{2b\eta - k^2}. \tag{10}$$

The proof of Theorem 1 appears in the Appendix.

Thus, the whole green supply chain system's expected profits are

$$E\left(\pi_{SC,c}^*\right) = E\left(\pi_{M,c}^*\right) + E\left(\pi_{R,c}^*\right) = \frac{\eta(a-bc)^2}{2\left(2b\eta - k^2\right)}. \tag{11}$$

3.2. The Manufacturer as Leader. In this section, the upstream manufacturer and the downstream retailer are considered as independent individuals making decisions for profit maximization. We consider a model with the manufacturer as channel leader and the retailer as follower. First, the manufacturer decides the green degree and the wholesale price. Second, the follower determines the retail price.

Theorem 2. *Under the manufacturer-led scenario, the optimal decisions are*

$$w_d^{M^*} = \frac{2\eta(a+bc)\left(b+r\sigma^2\right) - ck^2\left(b+2r\sigma^2\right)}{4b\eta\left(b+r\sigma^2\right) - k^2\left(b+2r\sigma^2\right)}, \tag{12}$$

$$\theta_d^{M^*} = \frac{k(a-bc)\left(b+2r\sigma^2\right)}{4b\eta\left(b+r\sigma^2\right) - k^2\left(b+2r\sigma^2\right)}, \tag{13}$$

$$p_d^{M^*} = \frac{2ab\eta + \left(b+2r\sigma^2\right)\left[\eta(a+bc) - ck^2\right]}{4b\eta\left(b+r\sigma^2\right) - k^2\left(b+2r\sigma^2\right)}. \tag{14}$$

The proof of Theorem 2 appears in the Appendix.

Taking formulas (12)–(14) into (4) and (5), we get the green members' expected profits as follows:

$$E\left(\pi_{M,d}^{M^*}\right) = \frac{\eta\left(b+2r\sigma^2\right)(a-bc)^2}{2\left[4b\eta\left(b+r\sigma^2\right) - k^2\left(b+2r\sigma^2\right)\right]}, \tag{15}$$

$$E\left(\pi_{R,d}^{M^*}\right) = \frac{\eta^2 b^2\left(b+2r\sigma^2\right)(a-bc)^2}{\left[4b\eta\left(b+r\sigma^2\right) - k^2\left(b+2r\sigma^2\right)\right]^2}. \tag{16}$$

Then, we have the whole supply chain's expected profits:

$$\begin{aligned} E\left(\pi_{SC,d}^{M^*}\right) &= E\left(\pi_{M,d}^{M^*}\right) + E\left(\pi_{R,d}^{M^*}\right) \\ &= \frac{\eta\left(b+2r\sigma^2\right)(a-bc)^2\left[2b\eta\left(3b+2r\sigma^2\right) - k^2\left(b+2r\sigma^2\right)\right]}{2\left[4b\eta\left(b+r\sigma^2\right) - k^2\left(b+2r\sigma^2\right)\right]^2}. \end{aligned} \tag{17}$$

3.3. The Retailer as Leader. In this section, we consider a Stackelberg model with the retailer as a leader and the manufacturer as a follower. First, the retailer decides the retail price. Then, as follower the manufacturer determines the green degree and her price. The method is similar to that of the manufacturer as leader.

Theorem 3. *Under the retailer-led scenario, the optimal decisions are*

$$w_{\mathrm{d}}^{\mathrm{R}^*} = \frac{\eta b^2\left[\eta(a+3bc)-2k^2c\right]+2\left(2b\eta-k^2\right)\left[\eta(a+bc)-k^2c\right]r\sigma^2}{2\left(2b\eta-k^2\right)\left[\eta b^2+r\sigma^2\left(2b\eta-k^2\right)\right]}, \tag{18}$$

$$\theta_{\mathrm{d}}^{\mathrm{R}^*} = \frac{k(a-bc)\left[\eta b^2+2r\sigma^2\left(2b\eta-k^2\right)\right]}{2\left(2b\eta-k^2\right)\left[\eta b^2+r\sigma^2\left(2b\eta-k^2\right)\right]}, \tag{19}$$

$$p_{\mathrm{d}}^{\mathrm{R}^*} = \frac{\eta b\left[b\eta(3a+bc)-k^2(a+bc)\right]+2\left(2b\eta-k^2\right)\left[\eta(a+bc)-k^2c\right]r\sigma^2}{2\left(2b\eta-k^2\right)\left[\eta b^2+r\sigma^2\left(2b\eta-k^2\right)\right]}. \tag{20}$$

The proof of Theorem 3 appears in the Appendix.

Taking formulas (18)–(20) into (4) and (5), we get the green supply chain members' expected profits as follows:

$$E\left(\pi_{\mathrm{M,d}}^{\mathrm{R}^*}\right) = \frac{\eta(a-bc)^2\left[\eta b^2+2r\sigma^2\left(2b\eta-k^2\right)\right]^2}{8\left(2b\eta-k^2\right)\left[\eta b^2+r\sigma^2\left(2b\eta-k^2\right)\right]^2}, \tag{21}$$

$$E\left(\pi_{\mathrm{R,d}}^{\mathrm{R}^*}\right) = \frac{b^2\eta^2(a-bc)^2\left[\eta b^2+2r\sigma^2\left(2b\eta-k^2\right)\right]}{4\left(2b\eta-k^2\right)\left[\eta b^2+r\sigma^2\left(2b\eta-k^2\right)\right]^2}, \tag{22}$$

$$E\left(\pi_{\mathrm{sc,d}}^{\mathrm{R}^*}\right) = E\left(\pi_{\mathrm{M,d}}^{\mathrm{R}^*}\right)+E\left(\pi_{\mathrm{R,d}}^{\mathrm{R}^*}\right) = \frac{\eta(a-bc)^2\left[\eta b^2+2r\sigma^2\left(2b\eta-k^2\right)\right]\left[3\eta b^2+2r\sigma^2\left(2b\eta-k^2\right)\right]}{8\left(2b\eta-k^2\right)\left[\eta b^2+r\sigma^2\left(2b\eta-k^2\right)\right]^2}. \tag{23}$$

Equilibrium solutions and the firms' expected utility in the three game models are shown in Tables 3 and 4.

By comparing and analyzing the optimal decision variables of the three game models in Table 2, we get Proposition 1 as follows.

Proposition 1

(1) The green product's green degree satisfies $\theta_c^* > \theta_d^{R^*} > \theta_d^{M^*}$.

(2) The sale price satisfies the following:

if $b\eta < k^2 < 2b\eta$, then $p_c^* > p_d^{M^*} > p_d^{R^*}$;
if $k^2 = b\eta$, then $p_c^* = p_d^{M^*} = p_d^{R^*}$;
and if $k^2 < b\eta$, then $p_c^* < p_d^{M^*} < p_d^{R^*}$.

The proof of Proposition 1 appears in the Appendix.

Proposition 1(1) illustrates that the product's green degree is the highest in the centralized scenario, followed by the retailer-led scenario, and is lowest under the manufacturer-led scenario. If the supply chain members can integrate as a system, the manufacturer can produce a green product with a higher green degree, thereby protecting the environment. The manufacturer must invest green research cost, so if the manufacturer leads the channel, she will balance the green cost and the profit, making the green degree lower than that under the retailer-led scenario.

Proposition 1(2) indicates that if the greening investment parameter is lower than a given threshold, the green product's retail price is the highest under the centralized condition and lowest under the retailer-led condition. Such conclusion is not the same with previous studies, but it is reasonable. Because the greening investment parameter is lower and the manufacturer is fully able to bear the cost alone, so her incentive to cooperate with the retailer is lower. If the retailer has channel leadership, he will set a lower price. If the greening investment parameter is higher than that threshold, the retail price is lower in the centralized case than in the decentralized case, which is called "double marginalization" phenomenon. At the same time, with a lower consumers' sensitivity coefficient to the green product and a higher price sensitivity coefficient, the demand will decrease. Therefore, the retailer must raise retail price to balance his profit.

By analyzing the firm's expected utility under the three game models in Table 3, we get Proposition 2 as follows.

Proposition 2. *The total expected utility satisfies $E(\pi_{SC,c}^*) > E(\pi_{SC,d}^{R^*}) > E(\pi_{SC,d}^{M^*})$.*

The proof of Proposition 2 appears in the Appendix.

Proposition 2 shows that the utility under the centralized condition is higher than that under the decentralized condition. This is the same as the previous literature. In addition, compared to the manufacturer-led condition, the system utility is higher than that under the retailer-led condition. This conclusion is reasonable because the risk-averse retailer cares more about profit, while the manufacturer must consider the green cost. Thus, it is better for the whole supply chain to be led by the retailer.

By analyzing the equilibrium solutions and the firm's expected utility in the three game models in Tables 2 and 3, we get Proposition 3 as follows.

Proposition 3

(1) $dp_d^{M^*}/d\theta > 0$, $d\pi_{R,d}^{M^*}/d\theta > 0$; $dp_d^{R^*}/d\theta > 0$, $d\pi_{R,d}^{R^*}/d\theta > 0$;

Table 3: The equilibrium solutions.

	Integrated model	Manufacturer-led model	Retailer-led model
w^*	N/A	$(b[\eta(a+bc)+N]+2r\sigma^2N)/C$	$(\eta b^2[N+c(2b\eta-k^2)]+2(2b\eta-k^2)Nr\sigma^2)/B$
θ^*	$(k(a-bc))/(2b\eta-k^2)$	$(k(a-bc)(b+2r\sigma^2))/C$	$(k(a-bc)I)/B$
p^*	$((a+bc)\eta-k^2c)/(2b\eta-k^2)$	$(b(2a\eta+N)+2r\sigma^2N)/C$	$(\eta b[bN+a(2b\eta-k^2)]+2(2b\eta-k^2)Nr\sigma^2)/B$

The values of B, C, I, and N are shown in the Appendix.

Table 4: The firms' expected utility.

	Integrated model	Manufacturer-led model	Retailer-led model
$E(\pi_M)$	N/A	$\eta(b+2r\sigma^2)(a-bc)^2/2C$	$\eta(a-bc)^2I^2/4BF$
$E(\pi_R)$	N/A	$\eta^2b^2(b+2r\sigma^2)(a-bc)^2/C^2$	$b^2\eta^2(a-bc)^2I/2BF$
$E(\pi_{SC})$	$\eta(a-bc)^2/2(2b\eta-k^2)$	$\eta(b+2r\sigma^2)(a-bc)^2K/2C^2$	$\eta(a-bc)^2IJ/4BF$

The values of F, J, and K are shown in the Appendix.

(2) $d\theta_d^{M^*}/dr>0$, $d\pi_{M,d}^{M^*}/dr>0$; $d\theta_d^{R^*}/dr>0$, $d\pi_{M,d}^{R^*}/dr>0$;

(3) *if* $b\eta<k^2<2b\eta$, *then* $dp_d^{M^*}/dr>0$, $dp_d^{R^*}/dr>0$; *if* $k^2<b\eta$, *then* $dp_d^{M^*}/dr<0$, $dp_d^{R^*}/dr<0$;

(4) $d\pi_{R,d}^{R^*}/dr<0$; *if* $r<bk^2/2\sigma^2(2b\eta-k^2)$, *then* $d\pi_{R,d}^{M^*}/dr>0$; *if* $r>bk^2/2\sigma^2(2b\eta-k^2)$, *then* $d\pi_{R,d}^{M^*}/dr<0$.

The proof of Proposition 3 appears in the Appendix.

Proposition 3(1) reflects that the retail price and the retailer's profit increase as green degree increases. This is reasonable because if the green degree increases, regardless of who leads the channel, the manufacturer must increase the green research cost, and the wholesale price will increase, followed by the increase of the retail price. At the same time, the increase in green degree contributes to a greater market demand and higher retailer profit.

Proposition 3(2) indicates that the green degree and the manufacturer's profit increase as the risk aversion increases. This means that the more risk averse, the better it is for the retailer to sell products with a higher green degree, making demand increase so the profit of the manufacture will increase.

Proposition 3(3) indicates that if the greening investment parameter is lower than a given threshold, the retail price increases with the risk-averse coefficient while it is just the opposite if the greening investment parameter is higher than that threshold. This is normal, the reason being that if the greening investment parameter is low, the manufacturer is able to bear the research cost of the green product. If the retailer is more risk averse, he will increase the retail price. By contrast, if the greening investment parameter is higher, the manufacturer will decrease the product's green degree, and according to 3(1), the retailer will lower the retail price accordingly.

Proposition 3(4) indicates that the retailer's profit under the retailer-led condition decreases as the risk-averse coefficient increases. If the risk-averse coefficient satisfies a given threshold, the retailer's profit under the manufacture-led condition increases as the risk aversion increases. When the channel is led by the retailer, it is better for the retailer to avoid risk. When the channel is led by the manufacturer, moderate risk is beneficial for the retailer.

4. Green Supply Chain Coordination

To coordinate the decentralized sustainable supply chain, this paper gives a simple two-part tariff contract [17, 26, 29]. First, the manufacturer gives the wholesale price and charges a lump sum fee F from the retailer. Then, we get the green supply chain's profit as follows:

$$E(\pi_M)=(w-c)(a-bp+k\theta)-\frac{1}{2}\eta\theta^2+F,$$
$$E(\pi_R)=(p-w)(a-bp+k\theta)-F. \tag{24}$$

In order to give the coordination parameters w^C and F, we use the values of p_c^* and θ_c^* in the centralized case and derive the following results:

$$w^C=\frac{bc(2b\eta-k^2)+2r\sigma^2[(a+bc)\eta-ck^2]}{(2b\eta-k^2)(b+2r\sigma^2)}. \tag{25}$$

Then, we have

$$\pi_M^C=(w^C-c)(a-bp_c^*+k\theta_c^*)-\frac{1}{2}\eta\theta_c^*$$
$$=\frac{\eta(a-bc)^2[2r\sigma^2(2b\eta-k^2)-bk^2]}{2(2b\eta-k^2)^2(b+2r\sigma^2)},$$
$$\pi_R^C=(p_c^*-w^C)(a-bp_c^*+k\theta_c^*)=\frac{b^2\eta^2(a-bc)^2}{(2b\eta-k^2)^2(b+2r\sigma^2)}. \tag{26}$$

Let π_M^{**} denotes the manufacturer's retained profit and π_R^{**} the retailer's retained profit; when $F>F_1=\pi_M^{**}-\pi_M^C$ and $F<F_2=\pi_R^C-\pi_R^{**}$, we have $F+\pi_M^C>\pi_M^{**}$ and $\pi_R^C-F>\pi_R^{**}$.

Proposition 4. *The two-part tariff contract can achieve a win-win result if the lump sum fee F falls between F_1 and F_2.*

We observe that the manufacturer will charge a lower wholesale price in the coordination contract, compared with the decentralized scenarios, which can prompt the retailer to set a lower retail price, and the market demand will increase accordingly. The manufacturer will boost her profits through

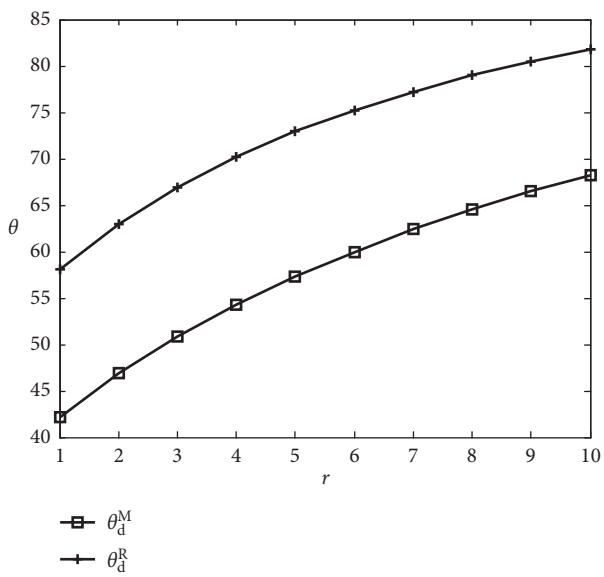

Figure 1: Optimal greening level.

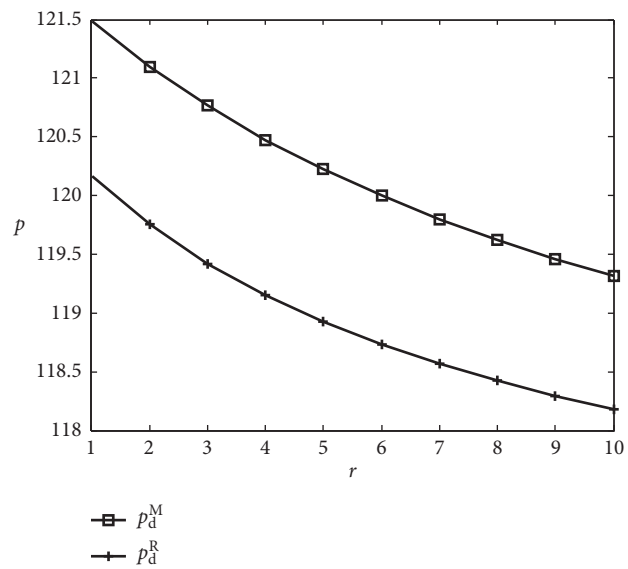

Figure 2: Optimal price.

the fixed fee, whose final value will depend on the relative channel power that each player holds. The upper boundary of the fixed fee (F_2) determines the limit beyond which the retailer will not participate in the contract. The low boundary of the fixed fee (F_1) determines the limit beyond which the manufacture will not participate in the contract. However, the green supply chain members will all be better off with the coordination contract.

5. Numerical Analysis

The paper gives a numerical example to explain the results we obtained above. The values are set as $a = 1000$, $b = 8$, $c = 30$, $k = 6$, $\sigma = 1$, $\eta = 5$, and $r = 1{:}10$.

Figure 1 demonstrates that the green degree is greater under the retailer-led condition than under the manufacturer-led condition and that they are both lower than that under the centralized condition $\theta_c^* = 103.6364$. Further, we find that the green degree is positively correlated with the risk aversion coefficient.

Figure 2 reflects that the retail price is higher under the manufacture-led condition than under the retailer-led condition and they are both higher than that under the centralized condition, $p_c^* = 116.3636$. Further, we find that the retail price decreases with the risk aversion coefficient, consistent with Proposition 3. In this scenario, it satisfies $36 = k^2 < b\eta = 40$.

Figure 3 shows that the manufacture's profit is higher under the manufacture-led condition than under the retailer-led condition, but the retailer and the whole supply chain system's profits are higher in the retailer-led scenario than in the manufacture-led scenario. The total system's profits under the decentralized condition are lower than those under the centralized condition $\pi_{SC,c}^* = 32818.1818$. This is consistent with Proposition 2. We also find that the manufacture's profit increases as the risk-averse coefficient increases, but the comparison of the retailer's profit is more

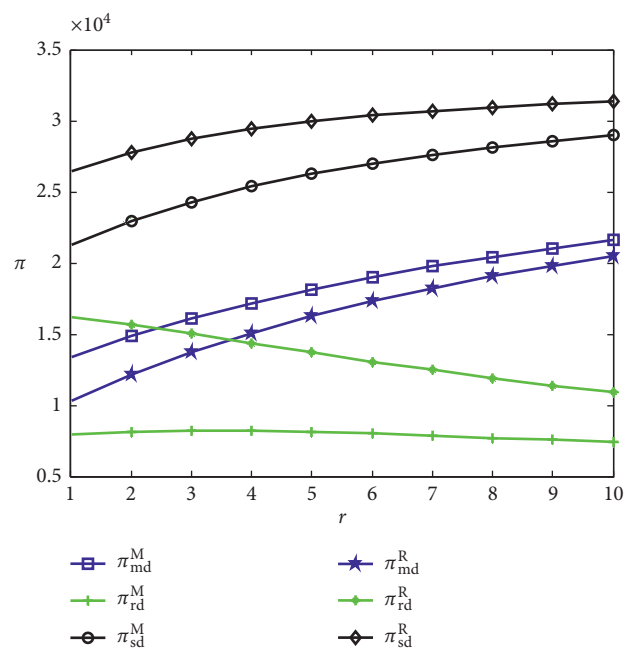

Figure 3: Profit of the supply chain members.

complex. It decreases as the risk-averse coefficient increases under the retailer-led condition. Under the manufacture-led condition, if the risk aversion satisfies a certain threshold, $r < bk^2/2\sigma^2(2b\eta - k^2) = 3.2727$, the retailer's profit increases as the risk-averse coefficient increases, while the opposite occurs when $r > bk^2/2\sigma^2(2b\eta - k^2) = 3.2727$.

Taking the risk aversion coefficient $r = 5$ and leaving other parameters unchanged, we get the comparison of the decision-making and the supply chain members' expected profits in Table 5.

Table 5 compares the results of the game equilibrium under three decision-making models: the centralized model, the manufacturer-led model, and the retailer-led model. In

Table 5: Optimal decision-making and expected profit.

	Integrated model	Manufacturer-led model	Retailer-led model
p^*	116.36	120.22	118.92
θ^*	103.64	57.32	72.93
$E(\pi_M)$	—	18150.84	16251.53
$E(\pi_R)$	—	8112.11	13685.50
$E(\pi_{SC})$	32818.18	26262.94	29937.02

Table 5, we find that, compared with the centralized decision-making, the retail price increases by 3.32% and 2.20% in the manufacturer-led model and the retailer-led model, respectively; the greenness decreases by 44.69% and 29.63%; and the total profit of the system decreases by 19.97% and 8.78%. The above data analysis shows that both the manufacturer and the retailer have a dual marginal effect on their leadership channels. The retailer price increases, and the greenness and the system's profits decrease. At the same time, compared with the retailer-led scenario, the retail price increases by 1.09% in the manufacturer-led scenario; the greenness decreases by 21.40%; the manufacturer's profit increases by 11.69%; the retailer's profit decreases by 40.72%; and the system's profits decrease by 12.27%. Data analysis shows that whoever leads the channel benefits; when the retailer leads the channel, the retail price is lower, and the greenness and the system's profits increases.

6. Conclusions

This paper examines pricing and production strategies under centralized and decentralized models by game theory considering green degree and risk aversion. We show how green degree and risk-averse coefficient affect the profits and decisions of the members of the whole supply chain. We propose a coordination contract that allows the green supply chain members to achieve win-win results. Finally, we present a numerical analysis to verify the theoretical results as follows:

(1) The product's green degree is the highest in the centralized scenario, followed by the retailer-led scenario, and is lowest under the manufacturer-led scenario. If the supply chain members can integrate as a system, the manufacturer can produce a green product with a higher green degree, thereby protecting the environment.

(2) If the greening investment parameter is lower than a given threshold, the green product's retail price is the highest under the centralized condition and lowest under the retailer-led condition. If the greening investment parameter is higher than that threshold, the retail price is lower in the centralized case than in the decentralized case.

(3) The retailer's profit and retail price increase with the green degree. The manufacturer's profit and green degree increase with the retailer's risk aversion coefficient. This means that the more risk-averse the retailer is, the more willing he is to sell green products, which is favorable for the manufacturer. If the greening investment parameter is lower than a certain threshold, the retail price increases with the risk-averse coefficient, while just the opposite occurs if the greening investment parameter is higher than that threshold. By contrast, if the greening investment parameter is higher, the manufacturer will lower the green degree and the retailer will lower the retail price accordingly.

In summary, when the channel is led by the retailer, his profit is negatively correlated with the risk aversion coefficient. When the channel is led by the manufacturer, the retailer's profit is positively correlated with risk aversion coefficient if it is lower than a certain threshold; just the opposite occurs if the risk-averse coefficient is higher than that value. The insight reveals that, for the retailer, it is better to avoid risk when he leads the channel, while moderate risk is beneficial for the retailer when the channel is led by the manufacturer. But the manufacturer's profit increases with the risk aversion coefficient.

This paper demonstrates the effects of the green degree and the retailer's risk aversion coefficient on the decisions of the members of the green supply chain, which has great significance for the sustainability of the operation. These results can be further broadened in many aspects, such as exploring the pricing in a multitier green supply chain, considering the complementarity of the products, supply uncertainty, inventory, and so on, which we will address in future research.

Appendix

Proof of Theorem 1. From equation (8), the first-order partial derivatives of $U(\pi_{SC})$ to p, θ, and w can be shown as

$$\frac{\partial U(\pi_{SC})}{\partial p} = (a - bp + k\theta) - b(p - c) - 2r(p - w)\sigma^2 = 0, \tag{A.1}$$

$$\frac{\partial U(\pi_{SC})}{\partial \theta} = k(p - c) - \eta\theta = 0, \tag{A.2}$$

$$\frac{\partial U(\pi_{SC})}{\partial w} = 2r(p - w)\sigma^2 = 0. \tag{A.3}$$

From the formula (A.1)—(A.3), we get the equilibrium solution in the centralized case:

$$p_c^* = w_c^* = \frac{(a + bc)\eta - k^2 c}{2b\eta - k^2}, \qquad \theta_c^* = \frac{k(a - bc)}{2b\eta - k^2}. \tag{A.4}$$

□

Proof of Theorem 2. From equation (7), the first-order partial derivatives of $U(\pi_R)$ to p can be shown as

$$\frac{\partial U(\pi_R)}{\partial p} = (a - bp + k\theta) - b(p - w) - 2r\sigma^2(p - w) = 0. \tag{A.5}$$

Then, we have

$$p = \frac{a + k\theta + (b + 2r\sigma^2)w}{2(b + r\sigma^2)}. \tag{A.6}$$

Taking equation (A.6) into (4) and (6), we obtain

$$U(\pi_M) = (w - c) \cdot \frac{(b + 2r\sigma^2)(a + k\theta - bw)}{2(b + r\sigma^2)} - \frac{1}{2}\eta\theta^2. \tag{A.7}$$

Let $\partial U(\pi_M)/\partial w = a + k\theta - 2bw + bc = 0$ and $\partial U(\pi_M)/\partial\theta = k(w - c)(b + 2r\sigma^2)/2(b + r\sigma^2) - \eta\theta = 0$; we obtain

$$\begin{aligned} w_d^{M^*} &= \frac{2\eta(a + bc)(b + r\sigma^2) - ck^2(b + 2r\sigma^2)}{4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)}, \\ \theta_d^{M^*} &= \frac{k(a - bc)(b + 2r\sigma^2)}{4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)}. \end{aligned} \tag{A.8}$$

Taking equations (18) and (19) into (16), we obtain

$$p_d^{M^*} = \frac{2ab\eta + (b + 2r\sigma^2)[\eta(a + bc) - ck^2]}{4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)}. \tag{A.9}$$

□

Proof of Theorem 3. Let $p = w + v$, then from equations (4) and (6) we obtain

$$U(\pi_M) = (w - c)[a - b(w + v) + k\theta] - \frac{1}{2}\eta\theta^2, \tag{A.10}$$

$$\begin{aligned} U(\pi_R) &= (p - w)(a - bp + k\theta) - r(p - w)^2\sigma^2 \\ &= v[a - b(w + v) + k\theta] - rv^2\sigma^2. \end{aligned} \tag{A.11}$$

From equation (A.10), the first-order partial derivatives of $U(\pi_M)$ to w and θ can be shown as

$$\frac{\partial U(\pi_M)}{\partial w} = a - b(w + v) + k\theta - b(w - c) = 0, \tag{A.12}$$

$$\frac{\partial U(\pi_M)}{\partial \theta} = k(w - c) - \eta\theta = 0. \tag{A.13}$$

From equations (A.12) and (A.13), we obtain

$$w = \frac{\eta(a - bv + bc) - k^2c}{2b\eta - k^2}, \tag{A.14}$$

$$\theta = \frac{k(a - bv - bc)}{2b\eta - k^2}. \tag{A.15}$$

Taking equations (A.14) and (A.15) into (A.11), we obtain

$$U(\pi_R) = \frac{vb\eta(a - bv - bc)}{2b\eta - k^2} - rv^2\sigma^2. \tag{A.16}$$

From equation (A.16), the first-order partial derivatives of $U(\pi_R)$ to v can be shown as

$$\frac{\partial U(\pi_R)}{\partial v} = \frac{b\eta(a - 2bv - bc)}{2b\eta - k^2} - 2rv\sigma^2 = 0. \tag{A.17}$$

From equation (A.16), we get

$$v^* = \frac{b\eta(a - bc)}{2[\eta b^2 + r\sigma^2(2b\eta - k^2)]}. \tag{A.18}$$

Taking equations (A.18) into (A.14) and (A.15), we obtain

$$w_d^{R^*} = \frac{\eta b^2[\eta(a + 3bc) - 2k^2c] + 2(2b\eta - k^2)[\eta(a + bc) - k^2c]r\sigma^2}{2(2b\eta - k^2)[\eta b^2 + r\sigma^2(2b\eta - k^2)]}, \tag{A.19}$$

$$\theta_d^{R^*} = \frac{k(a - bc)[\eta b^2 + 2r\sigma^2(2b\eta - k^2)]}{2(2b\eta - k^2)[\eta b^2 + r\sigma^2(2b\eta - k^2)]}. \tag{A.20}$$

Taking equations (A.18) and (A.19) into $p = w + v$, we obtain

$$p_d^{R^*} = \frac{\eta b[b\eta(3a + bc) - k^2(a + bc)] + 2(2b\eta - k^2)[\eta(a + bc) - k^2c]r\sigma^2}{2(2b\eta - k^2)[\eta b^2 + r\sigma^2(2b\eta - k^2)]}. \tag{A.21}$$

□

Proof of Proposition 1

(1) From equations (10) and (13), we obtain

$$\begin{aligned} \theta_c^* - \theta_d^{M^*} &= \frac{k(a - bc)}{2b\eta - k^2} - \frac{k(a - bc)(b + 2r\sigma^2)}{4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)} \\ &= \frac{k(a - bc)A}{(2b\eta - k^2)[4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)]}, \end{aligned} \tag{A.22}$$

where $A = 4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2) - (b + 2r\sigma^2)(2b\eta - k^2) = 2b^2\eta > 0$, so

$$\theta_c^* > \theta_d^{M^*}. \tag{A.23}$$

From equations (13) and (19), we obtain

$$\theta_d^{R^*} - \theta_d^{M^*} = \frac{\eta b^2[bk^2 + 2r\sigma^2(2b\eta - k^2)]}{BC} > 0, \tag{A.24}$$

where $B = 2(2b\eta - k^2)[\eta b^2 + r\sigma^2(2b\eta - k^2)]$ and $C = b(4b\eta - k^2) + 2r\sigma^2(2b\eta - k^2)$.

From equations (10) and (19), we obtain

$$\theta_c^* - \theta_d^{R^*} = \frac{k\eta b^2(a - bc)}{2(2b\eta - k^2)[\eta b^2 + r\sigma^2(2b\eta - k^2)]} > 0. \quad (A.25)$$

From Inequalities (A.23)–(A.25), we obtain $\theta_c^* > \theta_d^{R^*} > \theta_d^{M^*}$.

(2) From equations (9) and (14), we obtain

$$p_c^* - p_d^{M^*} = \frac{(a + bc)\eta - k^2 c}{2b\eta - k^2} - \frac{2ab\eta + (b + 2r\sigma^2)[\eta(a + bc) - ck^2]}{4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)} = \frac{D}{(2b\eta - k^2)[4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)]}, \quad (A.26)$$

where

$$\begin{aligned} D &= 4b\eta(b + r\sigma^2)[(a + bc)\eta - k^2 c] + 2b\eta(b + 2r\sigma^2)[k^2 c - (a + bc)\eta] - 2ab\eta(2b\eta - k^2) \\ &= 2b\eta(a - bc)(k^2 - b\eta). \end{aligned} \quad (A.27)$$

So, $p_c^* - p_d^{M^*}$ and $k^2 - b\eta$ are of the same sign.

From equations (14) and (20), we obtain

$$p_d^{M^*} - p_d^{R^*} = \frac{b\eta(a - bc)(k^2 - b\eta)[bk^2 + 2r\sigma^2(2b\eta - k^2)]}{BC}. \quad (A.28)$$

From equations (9) and (20), we obtain

$$p_c^* - p_d^{R^*} = \frac{b\eta(a - bc)(k^2 - b\eta)}{B}. \quad (A.29)$$

From equations (A.26), (A.28), and (A.29), we obtain Proposition 1(2). □

Proof of Proposition 2. From equations (11) and (17), we obtain

$$\Delta E(\pi_{SC}) = E(\pi_{SC,c}^*) - E(\pi_{SC,d}^{M^*}) = \frac{\eta(a - bc)^2 E}{2(2b\eta - k^2)[4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)]^2}, \quad (A.30)$$

where

$$\begin{aligned} E &= [4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)]^2 - (2b\eta - k^2) \\ &\quad \cdot (b + 2r\sigma^2)[2b\eta(3b + 2r\sigma^2) - k^2(b + 2r\sigma^2)] \\ &= 16b^2\eta^2(b + r\sigma^2)^2 + 2b\eta(b + 2r\sigma^2) \\ &\quad \cdot (bk^2 + 2k^2 r\sigma^2 + 4b\eta r\sigma^2 + 6b^2\eta) \\ &= 4b^4\eta^2, \end{aligned} \quad (A.31)$$

$\Delta E(\pi_{SC})$ and E are of the same sign, so we obtain

$$E(\pi_{SC,c}^*) > E(\pi_{SC,d}^{M^*}). \quad (A.32)$$

From equations (11) and (23), we obtain

$$E(\pi_{SC,c}^*) - E(\pi_{SC,d}^{R^*}) = \frac{\eta^3 b^4(a - bc)^2}{8(2b\eta - k^2)[\eta b^2 + r\sigma^2(2b\eta - k^2)]^2} > 0. \quad (A.33)$$

From equations (17) and (23), we obtain

$$E(\pi_{SC,d}^{R^*}) - E(\pi_{SC,d}^{M^*}) = \frac{\eta(a - bc)^2[IJC^2 - 4KF^2(2b\eta - k^2)(b + 2r\sigma^2)]}{8(2b\eta - k^2)C^2F^2}, \quad (A.34)$$

where $F = \eta b^2 + r\sigma^2(2b\eta - k^2)$, $I = \eta b^2 + 2r\sigma^2(2b\eta - k^2)$, $J = 3\eta b^2 + 2r\sigma^2(2b\eta - k^2)$, and $K = b(6b\eta - k^2) + 2r\sigma^2(2b\eta - k^2)$.

Let

$$\begin{aligned} L &= IJC^2 - 4KF^2(2b\eta - k^2)(b + 2r\sigma^2) \\ &= b^6\eta^2k^2(8b\eta - k^2) + 4b^5\eta^2(2b\eta - k^2)(4b\eta + k^2)r\sigma^2 \\ &\quad + 12b^4\eta^2(2b\eta - k^2)^2 r^2\sigma^4 > 0, \end{aligned} \quad (A.35)$$

So we have Proposition 2. □

Proof of Proposition 3

(1) From equations (14), (16), (20), and (22), we obtain $\mathrm{d}p_{\mathrm{d}}^{\mathrm{M}^*}/\mathrm{d}\theta = k/2(b + r\sigma^2) > 0$, $\mathrm{d}\pi_{\mathrm{R,d}}^{\mathrm{M}^*}/\mathrm{d}\theta = (k(b + 2r\sigma^2)/2(b + r\sigma^2)^2)(a + k\theta - bw) > 0$, $\mathrm{d}p_{\mathrm{d}}^{\mathrm{R}^*}/\mathrm{d}\theta = k/\ 2b > 0$, and $\mathrm{d}\pi_{\mathrm{R,d}}^{\mathrm{R}^*}/\mathrm{d}\theta = k\eta b(a - bc)/4[\eta b^2 + r\sigma^2(2b\eta - k^2)] > 0$. So, we have Proposition 3(1).

(2) From equations (13) and (19), we obtain $\mathrm{d}\theta_{\mathrm{d}}^{\mathrm{M}^*}/\mathrm{d}r = 4k\eta b^2\sigma^2(a - bc)/[4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)]^2 > 0$, $\mathrm{d}\pi_{\mathrm{M,d}}^{\mathrm{M}^*}/\mathrm{d}r$ and $\mathrm{d}\theta_{\mathrm{d}}^{\mathrm{M}^*}/\mathrm{d}r$ are of the same sign. $\mathrm{d}\theta_{\mathrm{d}}^{\mathrm{R}^*}/\mathrm{d}r = k\eta b^2\sigma^2(a - bc)\quad(2b\eta - k^2)/2(2b\eta - k^2)[\eta b^2 + r\sigma^2(2b\eta - k^2)]^2 > 0$, $\mathrm{d}\pi_{\mathrm{M,d}}^{\mathrm{R}^*}/\mathrm{d}r$ and $\mathrm{d}\theta_{\mathrm{d}}^{\mathrm{R}^*}/\mathrm{d}r$ are of the same sign. So, we have Proposition 3(2).

(3) From equations (14) and (20), we obtain $\mathrm{d}p_{\mathrm{d}}^{\mathrm{M}^*}/\mathrm{d}r = 4b\eta\sigma^2(a - bc)(k^2 - b\eta)/[4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)]^2$ and $\mathrm{d}p_{\mathrm{d}}^{\mathrm{R}^*}/\mathrm{d}r = \eta b\sigma^2(a - bc)(k^2 - b\eta)/2[\eta b^2 + r\sigma^2(2b\eta - k^2)]^2$. So, we have Proposition 3(3).

(4) From equations (16) and (22), we obtain $\mathrm{d}\pi_{\mathrm{R,d}}^{\mathrm{M}^*}/\mathrm{d}r = 2b^2\eta^2\sigma^2(a - bc)^2\quad[bk^2 - 2r\sigma^2(2b\eta - k^2)]/[4b\eta(b + r\sigma^2) - k^2(b + 2r\sigma^2)]^3$ and $\mathrm{d}\pi_{\mathrm{R,d}}^{\mathrm{R}^*}/\mathrm{d}r = -\ (r\eta^2b^2\sigma^4(a - bc)^2\ \ (2b\eta - k^2)/2[\eta b^2 + r\sigma^2(2b\eta - k^2)]^3) < 0$. So, we have Proposition 3(4). □

Data Availability

The data are listed within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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