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Green supply chain decisions based on overconfidence under manufacturers' competition

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Abstract: Overconfidence is a common psychological behavior in decision-making, and members of green supply chains also have overconfidence behavior. This paper discusses the influence of overconfidence in a dual-channel green supply chain with manufacturers' competition. We incorporate overconfidence into demand function, and establish three supply chain decision models: both manufacturers and retailers are rational, only retailers are overconfident and only one manufacturer is overconfident. In each case, we study the product greenness, wholesale price and retail price decisions, and explore the influence of overconfidence of decision-makers on the profits of manufacturers and retailers. We find that,in the setting of retailers' overconfidence, the two rational manufacturers choose the same greenness, and both wholesale price and greenness are lower than the cases of rational setting; in the case of one manufacturer is overconfident, product greenness and wholesale price selected by the overconfident manufacturer increase with his overconfident level, and the product greenness, wholesale price and retail price are higher than the corresponding decision value of the rational manufacturer.

Keywords: overconfidence; green supply chains; manufacturers' competition; product greenness.

1. Introduction

There is a common phenomenon in the retail industry: two manufacturers with competitive relationships often sell their products through common retailers, that is, the manufacturer's competition situation. For example, Coca Cola and Pepsi Cola, sell their products on the same shelf in community stores, convenience stores and even the same supermarket at the same time. Many competitive small manufacturers sell their products through Wal Mart, Carrefour Supermarket, etc. In reality, it is rare for manufacturers to completely monopolize, and they are generally facing fierce market competition. However, decision-makers are not completely rational when making decisions, and may have overconfidence behavior. Plous [1] pointed out that "no problem in judgment and decision making is more prevalent and more potentially catastrophic than overconfidence". At the beginning of the 21st century, researchers found that even when the optimal value of rational order quantity was known, the optimal order quantity chosen by the newsvendor still deviated from the rational optimal value, and this deviation was difficult to explain with loss aversion, fairness concern and other behaviors [2]. Later, researchers found that considering the influence of overconfidence in supply chain decision-making could reasonably explain the order deviation of newsvendor [3]. Ren and Croson [3,4] provided experiments supporting this theoretical conclusion and demonstrated that order bias is linear in overconfidence level. Based on this overconfidence model, many researchers began to study operational decisions, including green supply chain decisions. Li et al [5] explored the impacts of overconfidence in a competitive newsvendor setting, they found overconfidence may benefit the overconfident competing newsvendors when the per-unit product's profit is high. Li and Shan [6] discussed retailers' advanced selling decisions in the setting of consumers were confident in product value, and they found that retailers would set a higher price than the rational scene. Ma et al. [7] studied problems of advertising and pricing in a dual-channel supply chain composed of two overconfident manufacturers and two retailers. Jiang and Liu [8] explored financing supply chain decision under supplier's overconfidence and studied supply chain coordination between the supplier, the retailer and the bank. Liu et al. [9] investigated green product manufacturer's decision based on newsboy model. Zhou et al. [10] proposed a green supply chain model to study the decision of pricing and product greenness under retailers' overconfidence. For the adverse consequences caused by overconfidence, they further discussed the problem of cost sharing contract coordination of green supply chain.

In this paper, we deliver the following questions:

(1) In the setting of manufacturers' competition, how do the overconfident decision-maker make decisions?
(2) What impact does overconfidence of decision-makers have on product greenness, price and profit.

2. Problem description and model assumption

Consider the case where two green product manufacturers produce products separately and sell them through a common retailer. Manufacturer i produces products with greenness g_i, and supplies them to the retailer at a wholesale price w_i($i = 1, 2$). The retailer then sell green products to consumers in the same market at retail price p_i. There is a two-stage Stackelberg game: In the first stage, two manufacturers decide the product greenness and wholesale price simultaneously; In the second stage, the retailer set the retail prices of two products respectively. The supply chain structure is shown in Figure 1.

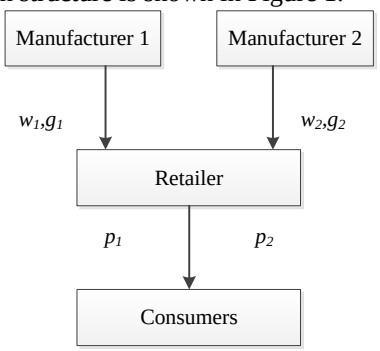

Figure 1: Green supply chain structure under manufacturers' competition

To simplify the solution model, the following assumptions are made.

(1) Two manufacturers produce R&D-intensive green products, and the unit product cost has nothing to do with the greenness of the product, both of which are c. The total greening input for converting ordinary products into green products is a fixed cost, which is closely related to the greenness of the product. It is assumed that the total greening investment of a product with a greenness of $g$is $Ig^2/2$, where $I$is the green input cost coefficient. Product greening costs are all borne by the manufacturer. When considering the overconfidence of decision makers, in order to ensure that the models have optimal solutions, it is assumed that the value of $I$is large.

(2) The market demand for green products is random, not only affected by its own greenness and retail price, but also related to the greenness and retail price of competing products. Referring to [11, 12, 13], it is assumed that the demand function of product i is

$$D_i = a - b_1 p_i + b_2 p_j + k_1 g_i - k_2 g_j + \varepsilon_i \quad (1)$$

where a is the potential total market demand; b_1 and b_2 are consumers' sensitivity coefficients of the retail price to their own products and the retail price to competing products, respectively, b_2 reflects the intensity of price competition of products [11], $0 < b_2 < b_1$; k_1 and k_2 are consumers' sensitivity coefficient to the greenness of its own products and the greenness of competing products, k_2 reflects the intensity of product greenness competition [11], $0 < k_2 < k_2$;$\varepsilon$is the random disturbance term, reflecting the uncertainty of demand.

(3) When decision makers are overconfident, their overconfidence behavior is manifested in two aspects: overestimating consumers' sensitivity to product greenness and overestimating the uncertainty of product demand. Overconfidence decision makers' belief in product demand is

$$D_{oi} = a - b_1 p_i + b_2 p_j + (1+\gamma)k_1 g_i - (1+\gamma)k_2 g_j + (1-\gamma)\varepsilon_i \quad (2)$$

where γ is the overconfidence level of the decision maker, $0 \le \gamma \le 1$. Decision makers are not overconfident when $\gamma = 0$.

(4) Manufacturers and retailers alike seek to maximize expected profits. When a decision maker is overconfident, he does not feel that he has overconfidence behavior, but other decision makers can observe the overconfidence of the decision maker and know the exact level of overconfidence.

In the competition structure of manufacturers, it is discussed in three situations: (a) the situation where both manufacturers and retailers are rational; (b) Rational manufacturers and overconfident retailers; (c) Manufacturer 1 is overconfident, and manufacturer 2 and retailer are rational. The three cases represented by the letters I, II and III respectively. For easy reference, the symbols and their meanings used in this paper are listed below.

g_i: greenness of product i, g_i^{j*}represents the decision value of greenness of product $i$in the case of j, $i = 1,2, j = I, II, III$;

w_i: wholesale price of product i, w_i^{j*}represents the decision value of wholesale price of product $i$in the case of j;

p_i: retail price of product i, p_i^{j*} represents the decision value of retail price to product i in the case of j;
a: potential total market demand;
b_1: consumers' price sensitivity to their own products;
b_2: consumers' price sensitivity to competing products;
k_1: consumers' green sensitivity to their own products;
k_2: consumers' green sensitivity to competing products;
γ_1: manufacturers' overconfidence level;
γ_2: retailers' overconfidence level;
c: per-unit cost;
I: green input cost coefficient;
$E(\pi_X^j)$: expected profit of decision maker X in case j.

3. Modeling and Solving

In our model, manufacturers and retailers constitute a Stackelberg game, which we solve by reverse induction.

3.1 Both manufacturers and retailers are rational

First analyze the retailer's decision in the second stage. When the retailer is rational, his expected profit is

$$E(\pi_R^I) = (p_1 - w_1)(a - b_1p_1 + b_2p_2 + k_1g_1 - k_2g_2) + (p_2 - w_2)(a - b_1p_2 + b_2p_1 + k_1g_2 - k_2g_1) \quad (3)$$

The calculation shows that the Hessian matrix of $E(\pi_R^I)$ is negative definite, so there is a maximum value of $E(\pi_R^I)$. Its first-order partial derivatives are

$$\frac{\partial E(\pi_R^I)}{\partial p_1} = a - 2b_1p_1 + 2b_2p_2 + k_1g_1 - k_2g_2 + b_1w_1 - b_2w_2 \quad (4)$$

$$\frac{\partial E(\pi_R^I)}{\partial p_2} = a - 2b_1p_2 + 2b_2p_1 + k_1g_2 - k_2g_1 + b_1w_2 - b_2w_1 \quad (5)$$

Let formulas (4) and (5) equal to zero respectively, and solve them simultaneously, the retail price selected by the retailer satisfies

$$p_1^{I*}(g_1, g_2, w_1) = \frac{ab_1+ab_2+g_1(b_1k_1-b_2k_2)+g_2(b_2k_1-b_1k_2)}{2(b_1^2-b_2^2)} + \frac{w_1}{2} \quad (6)$$

$$p_2^{I*}(g_1, g_2, w_2) = \frac{ab_1+ab_2+g_2(b_1k_1-b_2k_2)+g_1(b_2k_1-b_1k_2)}{2(b_1^2-b_2^2)} + \frac{w_2}{2} \quad (7)$$

The expected profit of a rational manufacturer is

$$E(\pi_i^I) = (w_i - c)(a - b_1p_i + b_2p_j + k_1g_i - k_2g_j) - \frac{I(g_i)^2}{2}, i, j = 1,2, i \neq j \quad (8)$$

Substituting equations (6) and (7) into equation (8), the expected profits of the two manufacturers are obtained as

$$E(\pi_1^I) = \frac{(w_1-c)(a+k_1g_1-k_2g_2-b_1w_1+b_2w_2)}{2} - \frac{Ig_1^2}{2} \quad (9)$$

$$E(\pi_2^I) = \frac{(w_2-c)(a+k_1g_2-k_2g_1-b_1w_2+b_2w_1)}{2} - \frac{Ig_2^2}{2} \quad (10)$$

It is easy to prove that both $E(\pi_1^I)$ and $E(\pi_2^I)$ have maxima when $4b_1I > k_1^2$. Calculate the first-order partial derivatives of $E(\pi_1^I)$ with respect to w_1, g_1, and $E(\pi_2^I)$ with respect to w_2 and g_2, respectively, set the partial derivatives equal to zero, and solve simultaneously to obtain the greenness and wholesale price of the products selected by the two manufacturers:

$$g_1^{I*} = g_2^{I*} = \frac{k_1(a-b_1c+b_2c)}{A_1} \quad (11)$$

$$w_1^{I*} = w_2^{I*} = \frac{2I(a-b_1c+b_2c)}{A_1} + c \quad (12)$$

Here, $A_1 = 2I(2b_1 - b_2) - k_1(k_1 - k_2)$.

Substituting equations (11) and (12) into equations (6) and (7), the optimal retail prices selected by the retailer is

$$p_1^{I*} = p_2^{I*} = \frac{I(3b_1-2b_2)(a-b_1c+b_2c)}{(b_1-b_2)A_1} + c \quad (13)$$

According to each decision value, it can be calculated that when both manufacturers and retailers are rational, their profits are

$$E(\pi_1^{I*}) = E(\pi_2^{I*}) = \frac{I(4b_1I-k_1^2)(a-b_1c+b_2c)^2}{2A_1^2} \quad (14)$$

$$E(\pi_R^{I*}) = \frac{2b_1^2I^2(a-b_1c+b_2c)^2}{(b_1-b_2)A_1^2} \quad (15)$$

3.2 Only retailers are overconfident

Because retailers are overconfident, they will make decisions based on their beliefs and expected profits. Using $\gamma_1$represents the retailer's overconfidence level, the belief expected profit of the overconfident retailer is

$E(\pi_{OR}^{II}) = (p_1 - w_1)[a - b_1p_1 + b_2p_2 + (1+\gamma_1)k_1g_1 - (1+\gamma_1)k_2g_2] + (p_2 - w_2)[a - b_1p_2 + b_2p_1 + (1+\gamma_1)k_1g_2 - (1+\gamma_1)k_2g_1]$ (16)

According to the simultaneous solution of the first-order conditions, retail prices selected by the overconfident retailer can be obtained to satisfy:

$p_1^{II*}(g_1, g_2, w_1) = \frac{a(b_1+b_2)+(1+\gamma_1)[g_1(b_1k_1-b_2k_2)+g_2(b_2k_1-b_1k_2)]}{2(b_1^2-b_2^2)} + \frac{w_1}{2}$ (17)

$p_2^{II*}(g_1, g_2, w_2) = \frac{a(b_1+b_2)+(1+\gamma_1)[g_2(b_1k_1-b_2k_2)+g_1(b_2k_1-b_1k_2)]}{2(b_1^2-b_2^2)} + \frac{w_2}{2}$ (18)

Because the manufacturer can observe the retailer's overconfidence and know that the retailer will price according to equations (17) and (18), and substitute equations (17) and (18) into the manufacturer's profit function, we can get

$E(\pi_1^{II}) = \frac{(w_1-c)[a+(1-\gamma_1)k_1g_1-(1-\gamma_1)k_2g_2-b_1w_1+b_2w_2]}{2} - \frac{I(g_1)^2}{2}$ (19)

$E(\pi_2^{II}) = \frac{(w_2-c)[a+(1-\gamma_1)k_1g_2-(1-\gamma_1)k_2g_1-b_1w_2+b_2w_1]}{2} - \frac{I(g_2)^2}{2}$ (20)

It is easy to know that $E(\pi_1^{II})$and $E(\pi_2^{II})$have maxima when $b_1I > k_1^2$. The greenness and wholesale price of the products selected by the two manufacturers can be obtained by solving

$g_1^{II*} = g_2^{II*} = \frac{k_1(a-b_1c+b_2c)(1-\gamma_1)}{A_2}$ (21)

$w_1^{II*} = w_2^{II*} = \frac{2I(a-b_1c+b_2c)}{A_2} + c$ (22)

Here, $A_2 = 2I(2b_1 - b_2) - k_1(k_1 - k_2)(1-\gamma_1)^2$.

Substituting equations (21) and (22) into equations (17) and (18), retail prices selected by the overconfident retailer is

$p_1^{II*} = p_2^{II*} = \frac{(a-b_1c+b_2c)[I(3b_1-2b_2)+\gamma_1k_1(1-\gamma_1)(k_1-k_2)]}{(b_1-b_2)A_2} + c$ (23)

Hence, the profits of two rational manufacturers and overconfident retailers are

$E(\pi_1^{II*}) = E(\pi_2^{II*}) = \frac{I(a-b_1c+b_2c)^2[4b_1I-k_1^2(1-\gamma_1)^2]}{2A_2^2}$ (24)

$E(\pi_R^{II*}) == \frac{2Ib_1(a-b_1c+b_2c)^2[b_1I+k_1\gamma_1(k_1-k_2)(1-\gamma_1)]}{(b_1-b_2)A_2^2}$ (25)

3.3 Only one manufacturer is overconfident

For convenience of description, we suppose manufacturer 1 is overconfident and manufacturer 2 is rational. Because the retailer is rational, the retailer's decision in the second stage is the same as that when both the manufacturer and the retailer are rational. The expected profit function of the retailer is the same as formula (3), and retail prices selected by the retailer is the same as formula (6) and (7), respectively.

Next, we analyze the decisions of overconfident manufacturers in the first stage. Using γ_2 represents the overconfidence level of manufacturer 1, and manufacturer 1 deems his expected profit is

$E(\pi_{O1}^{III}) = (w_1 - c)[a - b_1p_1 + b_2p_2 + (1+\gamma_2)k_1g_1 - (1+\gamma_2)k_2g_2] - \frac{Ig_2^2}{2}$ (26)

Because Manufacturer 1 is overconfident, he thinks that retailers have the same demand belief as him.

Therefore, in equations (17) and (18), replace the overconfidence level γ_1 of the retailer with the overconfidence level γ_2 of the manufacturer, and the manufacturer 1's belief in the retailer's pricing is obtained. Therefore, the belief expectation profit of manufacturer 1 can be expressed as

$E(\pi_{OM1}^{III}) = \frac{(w_1-c)[a+(1+\gamma_2)k_1g_1-(1+\gamma_2)k_2g_2+b_2w_2-b_1w_1]}{2} - \frac{Ig_1^2}{2}$ (27)

It is easy to know that when $b_1I > k_1^2$, $E(\pi_{OM1}^{III})$ has a maximum. The greenness and wholesale price of the product selected by the overconfident manufacturer can be obtained by solving the first-order conditions simultaneously.

$g_{O1}^{III}(g_2, w_2) = \frac{k_1(1+\gamma_2)[a-b_1c-(1+\gamma_2)k_2g_2+b_2w_2]}{4b_1I-k_1^2(1+\gamma_2)^2}$ (28)

$w_{O1}^{III}(g_2, w_2) = \frac{2I[a-b_1c-(1+\gamma_2)k_2g_2+b_2w_2]}{4b_1I-k_1^2(1+\gamma_2)^2} + c$ (29)

The overconfidence of Manufacturer 1 also leads to cognitive bias on the product demand of Manufacturer 2. He believes that the expected profit of Manufacturer 2 is

$$E(\pi_{OM2}^{III}) = (w_2 - c)[a - b_1 p_2 + b_2 p_1 + (1+\gamma_2)k_1 g_2 - (1+\gamma_2)k_2 g_1] - \frac{I g_2^2}{2} \quad (30)$$

According to Formula (30), overconfident manufacturers believe that the product greenness and wholesale price selected by rational manufacturers meet the following requirements

$$g_{O2}^{III}(g_1, w_1) = \frac{k_1(1+\gamma_2)[a-b_1 c-(1+\gamma_2)k_2 g_1+b_2 w_1]}{4b_1 I - k_1^2(1+\gamma_2)^2} \quad (31)$$

$$w_{O2}^{III}(g_1, w_1) = \frac{2I[a-b_1 c-(1+\gamma_2)k_2 g_1+b_2 w_1]}{4b_1 I - k_1^2(1+\gamma_2)^2} + c \quad (32)$$

The overconfident manufacturer thinks that the product greenness and wholesale price selected by him and manufacturer 2 can be solved simultaneously by equations (28), (29), (31) and (32). Therefore, the greenness and wholesale price of products selected by overconfident manufacturers are

$$g_1^{III*} = \frac{k_1(1+\gamma_2)(a-b_1 c+b_2 c)}{A_3} \quad (33)$$

$$w_1^{III*} = \frac{2I(a-b_1 c+b_2 c)}{A_3} + c \quad (34)$$

Here, $A_3 = 2I(2b_1 - b_2) - k_1(k_1 - k_2)(1+\gamma_2)^2$.

However, manufacturer 2 is rational. Its actual product demand is not the demand that manufacturer 1 thinks, and its profit is not the expected profit that manufacturer 1 thinks. Manufacturer 2 knows that retailer price according to formula (6) and (7), so its expected profit is the same as formula (10). According to the goal of maximizing the expected profit, the product greenness and wholesale price selected by manufacturer 2 meet

$$g_2^{III*}(g_1, w_1) = \frac{k_1(a-b_1 c+b_2 w_1-k_2 g_1)}{4b_1 I - k_1^2} \quad (35)$$

$$w_2^{III*}(g_1, w_1) = \frac{2I(a-b_1 c+b_2 w_1-k_2 g_1)}{4b_1 I - k_1^2} + c \quad (36)$$

Because manufacturer 2 knows that manufacturer 1 is overconfident, and can predict that manufacturer 1 will make decisions according to equations (33) and (34). By substituting equations (33) and (34) into equations (35) and (36), it can be concluded that the product greenness and wholesale price selected by rational manufacturers are

$$g_2^{III*} = \frac{k_1(a-b_1 c+b_2 c)[4b_1 I - k_1^2(1+\gamma_2) - k_1\gamma_2(1+\gamma_2)(k_1-k_2)]}{(4b_1 I - k_1^2)A_3} \quad (37)$$

$$w_2^{III*} = \frac{2I(a-b_1 c+b_2 c)[4b_1 I - k_1^2(1+\gamma_2) - k_1\gamma_2(1+\gamma_2)(k_1-k_2)]}{(4b_1 I - k_1^2)A_3} + c \quad (38)$$

Substitute equations (33), (34), (37) and (38) into equations (6) and (7), and the pricing of rational retailers is

$$p_1^{III*} = \frac{a-b_1 c+b_2 c}{2(4b_1 I - k_1^2)(b_1^2 - b_2^2)A_3} \times \{2I(b_1+b_2)(3b_1-2b_2)(4b_1 I - k_1^2) - b_1 k_1 \gamma_2^2(k_1-k_2)(4b_1 I + 4b_2 I - k_1^2 - k_1 k_2) - b_1 k_1 \gamma_2[4I(b_1 k_1 - b_2 k_2 - 2b_1 k_2 + 2b_2 k_1) - k_1(k_1^2 - k_2^2)]\} + c \quad (39)$$

$$p_2^{III*} = \frac{a-b_1 c+b_2 c}{2(4b_1 I - k_1^2)(b_1^2 - b_2^2)A_9} \times \{2I(b_1+b_2)(3b_1-2b_2)(4b_1 I - k_1^2) - k_1(k_1-k_2)\gamma_2^2[2I(b_1+b_2)(3b_1-b_2) - b_2 k_1(k_1+k_2)] - k_1\gamma_1[b_2 k_1(k_1^2 - k_2^2) + 2I(6b_1^2 k_1 - 3b_1^2 k_2 + 2b_1 b_2 k_1 - 4b_1 b_2 k_2 - 2b_2^2 k_1 + b_2^2 k_2)]\} + c \quad (40)$$

Substitute the obtained product greenness, wholesale price and retail price into the expected profit function of manufacturers and retailers to calculate their profits.

4. Model Analysis

Proposition 1: When the retailer is overconfident, the greenness, wholesale price and retail price of the products produced by the two manufacturers are the same, which are lower than the corresponding results when the retailer is rational. With the increase of the overconfident level of the retailer, the greenness, wholesale price and retail price of the products are reduced.

Proof: It can be seen from formula (21), (22) and (23) that the greenness, wholesale price and retail price of the two products are the same when the retailer is overconfident. When $\gamma_1 = 0$, then $g_i^{II*} = g_i^{I*}$, $w_i^{II*} = w_i^{I*}$, $p_i^{II*} = p_i^{I*}$. The rational situation can be regarded as a special case of overconfidence.
For

$\frac{\partial g_i^{II*}}{\partial \gamma_1} = -\frac{k_1(a-b_1c+b_2c)[2I(2b_1-b_2)+k_1(k_1-k_2)(1-\gamma_1)^2]}{A_2^2} < 0,$
$\frac{\partial w_i^{II*}}{\partial \gamma_1} = -\frac{4k_1I(a-b_1c+b_2c)(k_1-k_2)(1-\gamma_1)}{A_2^2} \leq 0,$
$p_2^{II*} = -\frac{k_1(k_1-k_2)(a-b_1c+b_2c)[2I(b_1+b_1\gamma_1-b_2)+k_1(k_1-k_2)(1-\gamma_1)^2]}{(b_1-b_2)A_2^2} < 0,$

And at $\gamma_1 = 0$, the partial derivatives are not zero, so with the increase of retailers' overconfidence, the product greenness, wholesale price and retail price all decline.

In the manufacturer's competitive environment, when only the retailer is overconfident, the cost structure of the two manufacturers is the same, and the decision information obtained is exactly the same, so they make the same decision - choose the same product greenness and wholesale price. For retailers, the greenness and order price of the two products are the same, but the brands are different, and there is no brand value in the model, so retailers set the same price for the two products.

Proposition 2: When the retailer is rational, the product greenness and wholesale price selected by the overconfident manufacturer increase with the increase of their overconfident level, and the product greenness, wholesale price and retail price are higher than the corresponding decision value of the rational manufacturer. With the increase of manufacturers' overconfidence, the gap between the greenness, wholesale price and retail price of the two products increases.

Proof: According to formula (33)-(40), we get
$\frac{\partial g_1^{III*}}{\partial \gamma_2} = \frac{k_1(a-b_1c+b_2c)[2I(2b_1-b_2)+k_1(k_1-k_2)(1+\gamma_2)^2]}{A_3^2} > 0,$
$\frac{\partial w_1^{III*}}{\partial \gamma_2} = \frac{4k_1I(1+\gamma_2)(a-b_1c+b_2c)(k_1-k_2)}{A_3^2} > 0,$
$g_1^{III*} - g_2^{III*} = \frac{\gamma_2 k_1(a-b_1c+b_2c)[4b_1I+k_1(1+\gamma_2)(k_1-k_2)]}{(4b_1I-k_1^2)A_3} \geq 0,$
$w_1^{III*} - w_2^{III*} = \frac{2k_1I\gamma_2(a-b_1c+b_2c)[k_1+(1+\gamma_2)(k_1-k_2)]}{(4b_1I-k_1^2)A_3} \geq 0,$

$$p_1^{III*} - p_2^{III*} = \frac{k_1\gamma_2(a-b_1c+b_2c)}{2(4b_1I-k_1^2)(b_1+b_2)A_3} \times \{k_1(1+\gamma_2)(k_1^2-k_2^2)$$
$+2I[(\gamma_2(k_1-k_2)(b_1+b_2)+4b_1k_1+b_1k_2+2b_2k_1-b_2k_2]\} \geq 0.$

Therefore, the greenness, wholesale price and retail price of products of overconfident manufacturers are higher than the corresponding decision value of products of rational manufacturers, and the higher the overconfident level of manufacturers, the higher the greenness and wholesale price of their products.
$\frac{\partial(g_1^{III*}-g_2^{III*})}{\partial \gamma_2} = \frac{k_1(a-b_1c+b_2c)}{(4b_1I-k_1^2)A_3^2} \times [(4b_1I+k_1^2-k_1k_2)(4b_1I-2b_2I-k_1^2+k_1k_2)+k_1\gamma_2^2(k_1-k_2)(4b_1I-k_1^2+$
$k_1k_2)+2k_1\gamma_2(k_1-k_2)(4b_1I-2b_2I-k_1^2+k_1k_2)] > 0,$
$\frac{\partial(w_1^{III*}-w_2^{III*})}{\partial \gamma_2} = \frac{2k_1I(a-b_1c+b_2c)}{(4b_1I-k_1^2)A_3^2} \times [(4b_1I-2b_2I-k_2^2+k_1k_2) \times (2k_1\gamma_2-2k_2\gamma_2+2k_1-k_2)+k_1k_2\gamma_2^2(k_1-$
$k_2)] > 0,$
$\frac{\partial(p_1^{III*}-p_2^{III*})}{\partial \gamma_2} = \frac{k_1(a-b_1c+b_2c)}{2(b_1+b_2)(4b_1I-k_1^2)A_9^2} \times [(4b_1I-2b_2I-k_1^2+k_1k_2)(8b_1k_1I+2b_1k_2I+4b_2k_1I-2b_2k_2I+k_1^3-$
$k_1k_2^2)+k_1\gamma_2^2(k_1-k_2)(4b_1k_1I+6b_1k_2I+2b_2k_2I-k_1^3+k_1k_2^2)+2\gamma_2(k_1-k_2)(4b_1I-2b_2I-k_1^2+$
$k_1k_2)(2b_1I+2b_2I+k_1^2+k_1k_2)] > 0.$

It can be obtained that the partial derivative of each difference with respect to the manufacturer's overconfidence level is greater than zero. The higher the overconfidence level, the greater the difference in product greenness, wholesale price and retail price.

Compared with rational manufacturers, overconfident manufacturers believe that product greenness has a greater impact on demand than reality, so they increase investment in product greening and produce products with higher greenness. At the same time, manufacturers make up for the increased cost of green input by increasing the wholesale price of products. The rational manufacturer has an accurate understanding of product demand. He will not follow the overconfident manufacturer to choose the same product greenness and wholesale price, but his product demand is affected by the product competition intensity and the overconfident level of the manufacturer. Therefore, the decision of the rational manufacturer depends on a variety of factors.

In general, compared with the product greenness, wholesale price and retail price of rational manufacturers, the higher the manufacturer's overconfidence level is, the more the deviation of relevant decision value occurs.

Proposition 3: Retailers' overconfidence leads to a decline in their profits. The higher the level of overconfidence, the more profits will decline.

Proof: According to equation (25), we get

$$\frac{\partial E(\pi_R^{II*})}{\partial \gamma_2} = -\frac{2Ib_1k_1(k_1-k_2)(a-b_1c+b_2c)^2}{(b_1-b_2)A_8^3} \times [2Ib_2 + 4I\gamma_1(b_1-b_2) + k_1(k_1-k_2)(1+2\gamma_1)(1-\gamma_1)^2]$$
$$< 0$$

For the derivative is negative, we can derive this proposition.

In the setting of manufacturers' competition, the cognitive bias caused by retailers' overconfidence leads to the reduction of the retail price. Although the manufacturer has reduced the wholesale price due to the decline of product greenness, the retail price has declined more, which ultimately leads to the profit obtained by retailers being lower than that when they were rational. Therefore, overconfidence is bad for retailers. Although the retailer's overconfidence has led to the decline of product greenness and wholesale price, the competition between the two manufacturers has slowed down the decline of demand with product greenness and wholesale price. At the same time, the decline of product greenness has led to the decline of green input. The manufacturer's profit is not necessarily lower than the profit obtained by the retailer when it is rational.

5. Conclusion

In this paper, we discuss green supply chain decisions under manufacturers' competition. We explored three scenarios: both manufacturers and retailers are rational, only retailers are overconfident and only one manufacturer is overconfident. In each setting, the expected profit function of the decision-maker is established respectively, and the supply chain decision model is built based on Stackelberg game, and optimized. Then, we respectively study the product greenness, wholesale price and retail price decisions under the overconfident behavior of retailers and manufacturers, explore the impact of overconfidence of decision-makers on the profits of manufacturers and retailers. At last, we compare the three cases. We get the following main conclusions.

(1) When the retailer is overconfident, the two manufacturers choose the same greenness, wholesale price and retail price, and product greenness, wholesale price and retail price are lower than the corresponding results when the retailer is rational. With the increase of the overconfident level of the retailer, the greenness, wholesale price and retail price of the products are reduced.

(2) When the retailer is rational, product greenness and wholesale price selected by the overconfident manufacturer increase with his overconfident level, and the product greenness, wholesale price and retail price are higher than the corresponding decision value of the rational manufacturer. With the increase of manufacturers' overconfidence, the gap between the greenness, wholesale price and retail price of the two products increases.

(3) Retailers' overconfidence leads to a decline in their profits. The higher the level of overconfidence, the more profits will decline.

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