Research Article

Green Supply Chain Decisions and Revenue-Sharing Contracts under Manufacturers’ Overconfidence

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Overconfidence is a prevalent and potentially catastrophic behaviour in judgment and decision-making. In this paper, we define manufacturers’ overconfidence as a belief bias that they overestimate the impact of product greenness on demand and the accuracy of demand uncertainty. We build a game theory model based on overconfident beliefs, address the decisions of product greenness and price, and discuss the impact of manufacturers’ overconfidence on supply chain decisions and profits. For the adverse effects brought by overconfidence, we further investigate whether revenue-sharing contracts can coordinate green supply chains. We find three new insights. (1) Manufacturers’ overconfidence leads to higher product greenness, a higher wholesale price, and a greater retail price, but resulting in lower profits. (2) Under the cooperation based on revenue-sharing contracts, product greenness is greater, and wholesale price is lower than the case without cooperation. The greenness increases with the manufacturer’s overconfidence, but counter-intuitively, the wholesale price is not affected by overconfidence. (3) Both the overconfident manufacturer and the retailer have an incentive to reach a revenue-sharing contract. Retailers benefit from collaboration, and overconfident manufacturers assume that retailers can make more profit through revenue sharing, but this model does not exist.

1. Introduction

To cope with increasingly stringent environmental regulations and meet the growing demand for green consumption, it is an inevitable trend for manufacturing companies to implement green supply chain management. In 2010, GAC-Honda launched the “Green Service” project, requiring dealers to adopt new equipment, new materials, and new processes that are conducive to environmental protection, and to strengthen waste management in daily business activities. In 2012, FAW-Volkswagen launched the “Green Partner Action Plan,” requiring its distributors to fully implement the concept of energy conservation and environmental protection in their operations to reduce the consumption of natural resources and reduce the damage to the natural environment. Dell, a well-known computer manufacturer, asked its suppliers to participate in carbon emission reduction projects and had made a grand plan to reduce carbon emissions in 2015 by more than 40% compared with 2007 [1]. In a given economy, it is a challenging task to integrate environment and social issue in supply chain management [2]. Many international leading manufacturing companies, such as Apple, Microsoft, and HP, have carried out green supply chain management practices and actively developed and produced green products, which not only enhanced their trademark but also enhanced their competitive advantage. However, corporate managers may exhibit overconfidence in decision-making, such as overestimating the attractiveness of product greenness to consumers. Jiangxi Saiwei LDK Solar High-Tech Co., Ltd. was a high-tech photovoltaic enterprise, which can be called a new energy star enterprise.
2.1. Green Supply Chain Decisions. The research on green supply chain decisions has been developing rapidly during the past few years. Ghosh and Shah [1,3] took the fashion industry as an example to study the impact of channel structure, greening cost, and consumer green sensitivity coefficient on product greenness, pricing, and corporate profits. Two-part tariff contracts and cost-sharing contracts are used to achieve green supply chain coordination. Swami and Shah [4] studied greening investment and supply chain coordination issues in green supply chains and used a two-part tariff contract to achieve channel coordination. Zhang and Liu [5] studied the supply chain decisions under four game models through a game-theoretic approach in a three-level green supply chain and discussed the coordination of green channels by managers using revenue-sharing contracts, Sharpe value method coordination mechanism, and asymmetric Nash negotiation mechanism. Zhang et al. [6] investigated the issues of product pricing and green supply chain coordination when manufacturers produce green products and common products simultaneously in both cooperative games and noncooperative games. Based on the newsvendor inventory model, Sana [7] studied the price competition between green and nongreen products under green strategies such as low carbon emission, government tax, subsidy, and corporate social responsibility. Rana et al. [8] investigated the effect of the carbon emissions from the poultry industry. Barman et al. [9] explored the pricing strategies and greening strategies in a green supply chain in which two manufacturers separately produce green and nongreen items sold through a common retailer. Taleizadeh et al. [10] studied the decisions of a dual-channel supply chain and investigated the impact of green production on lowering carbon emissions. Xu et al. [11] discussed the production and emission abatement decisions of a green supply chain under cap-and-trade regulation and used both wholesale price and cost-sharing contracts to coordinate the supply chain. Ashkan [12] established a model for competition and cooperation in green differentiated products under government intervention (tax or subsidy). Song and Gao [13] studied the impact of two revenue-sharing contracts on product greenness and supply chain profits in green supply chains and analysed the influence of consumers’ green sensitivity on supply chain decisions. Zhu and He [14] studied the impact of supply chain structures (centralized or decentralized) and the green product types (development-intensive product or marginal-cost intensive product) on product greenness decisions. Sinayi and Rasti [15] studied the impact of government subsidies on product greenness, pricing, and profit under the situation of manufacturers’ pursuit of profits and consumer surplus. Li et al. [16] considered contracting designing and contracting marketing in a green supply chain in which the manufacturer determines product greenness and the retailer exerts marketing effort level, to examine three contract strategies in such supply chain. Ghosh et al. [17] explored decisions and coordination of a green supply chain in the setting of the manufacturer’s advanced payment policy and trade credit facility to the retailer. Gao et al. [18] took subsidies from the government when green products satisfy the ecolabel standard into consideration to analyse competition and corporation in a dual-channel green supply chain. Hong et al. [19] investigated the decisions of product greenness and pricing based on wholesale price contracts, cost-sharing contracts, and two-part tariff contracts, and compared the product greenness, price, and profits of supply chain members under different contracts.

2.2. Overconfidence-Based Supply Chain Decisions. Plus [20] pointed out that “no problem in judgment and decision-making is more prevalent and more potentially catastrophic than overconfidence.” As one of the most prevalent psychological behaviours, overconfidence has an important...
impact on decision-making. However, different researchers have different views on overconfidence. The meaning of overconfidence that is commonly used in supply chain decisions is summarized by Moore and Healy [21]. They consulted more than 350 papers on various types of overconfidence and summarized three different types: overestimation, overprecision, and overplacement. In overestimation, people generally overestimate what is good for them, such as the chance of success, advantages, or personal skills. In overprecision, people always underestimate the uncertainty of random results; that is, their belief in random results is more accurate than the theoretical result. In overplacement, individuals think that they do better than other people.

In the traditional supply chain decision literature, it is often assumed that the decision-makers are completely rational, ignoring the influence of psychological behaviour, which leads to the inconsistency between the decisions and reality. In recent years, people began to consider the influence of decision-makers psychological behaviour in supply chain decisions. There is much literature on supply chain decisions involving fairness concern, loss-averse, risk-averse, etc. Meanwhile, some progress has been made in overconfidence-based supply chain decisions. Croson et al. [22] were the first to consider the impact of overconfidence in operational management. Based on Schweizer and Cachon’s findings that even if the expected profit-maximizing order quantity is known, newsvendors’ choice still systematically deviates from the quantity that maximizes expected profit, and the deviation cannot be explained by risk-aversion, risk-seeking preferences, waste aversion, etc. [23], they found the bias may be caused by overconfidence and explored a theoretical model to show that overconfident newsvendors make suboptimal orders and earn fewer profits than rational newsvendors. Furthermore, Ren and Croson [24,25] provided experiments supporting this theoretical conclusion and demonstrated that order bias is linear in the level of overconfidence. Li et al. [26] proposed a decision model in which consumers overestimated the precisions of their valuation predictions to study the retailer’s advance selling decisions in a two-period setting. They found that advance selling was not always beneficial to the retailer and the retailer would set a higher price with overconfident consumers than that without. Li et al. [27] studied the effects and implications of overprecision in a competitive newsvendor setting. They found overconfidence can benefit the overconfident competing newsvendors when the product’s profit is high. Ma et al. [28] studied decisions on advertising and price in a dual-channel supply chain composed of two overconfident (specifically and overestimation) manufacturers and two retailers. They found that the profits of overconfident manufacturers under the master-slave game are more than that under the decentralized decision model, and the profits of retailers under the master-slave game are less than that of the decentralized model. Jiang and Liu [29] discussed the problems of inventory financing in the setting of suppliers overestimating demand precision. They found that overconfidence led to a deviation of the decisions of the retailer, supplier, and bank from the rational decisions. Pu et al. [30] proposed a Cournot model in which a firm is rational and the other is overconfident (overestimated) to analyse the effect of the firm’s overconfidence on quantities and profits. They found that the rational firm always suffers a loss because of the competitor’s overconfidence, while the overconfident firm does not benefit constantly from its overconfidence. Jain et al. [31] studied the influence of the buyer’s overconfidence on decisions concerning its capacity reservation and number of suppliers. They found that when the buyer’s mean demand is very high, the overconfident buyer reserves more capacity and selects more suppliers than the rational buyer, while the situation is opposite when the buyer’s mean demand is very low. Xu et al. [32] investigated the influence of the retailer’s overconfidence on pricing, ordering decisions, and profits in a duopolistic supply chain composed of one manufacturer, one rational retailer, and one overconfident retailer. They found that, for the overconfident retailer, price is increasing and profit is decreasing with the level of its overconfidence. However, for the rational retailer, his price relates to whether he realizes the overconfident retailer’s overconfidence and his profit increases with the level of overconfidence. Liu et al. [33] build a newsvendor-based model to investigate how overconfidence affects the decisions of the green product manufacturer. They found that overconfidence led to an increase in product greenness and a decrease in the manufacturer’s profits. Zhang et al. [34] explored the interactive impacts of overconfidence and fairness concerns in a two-echelon supply chain. They found that the retailer can always benefit from his two behaviours since the negative effects caused separately can be offset each other. Wu and Chen [35] investigated the optimal order quantity of perishable products when the newsvendor is overconfident and ambiguity-averse. They concluded that the optimal order is linear in overconfidence level, and the newsvendor’s profit is decreased in the high-profit case while increased in the low-profit case. Song et al. [36] studied the optimal decisions and three inventory strategies in a supply chain where the supplier is risk-averse and the manufacturer is overconfident. They found the overconfident manufacturer may get more profit and order more products under the push strategy.

From previous research studies, we find that the existing green supply chain decision papers do not consider overconfidence behaviour, while overconfidence-based operational management seldom involves green supply chains. While Ghosh and Shah [1] studied the pricing of green products and coordination in a fully rational supply chain, they failed to consider the influence of overconfidence in their research. Other research studies, such as Zhang and Liu [5] and Song and Gao [13], have discussed the problem of achieving green supply chain coordination through revenue-sharing contracts but have not discussed whether supply chain coordination can be achieved under overconfidence. In this paper, we not only study the impact of manufacturers’
overconfidence on green supply chain decisions, especially the influence of overconfidence on product greenness, prices, and profits, but also explore whether revenue-sharing contracts can achieve green supply chain coordination in an overconfident environment. We make two contributions. First, we present a green supply chain model under the setting of overconfidence and show how the overconfident manufacturer’s decisions deviate from optimal choices. Second, we construct a revenue-sharing contract under manufacturers’ overconfidence, to verify that although revenue sharing can coordinate the green supply chain in a rational setting, it may not work in the environment of manufacturers’ overconfidence. Our research contributes to the literature on behavioural operational management and supply chain coordination.

3. Model Assumption

We consider a two-stage green supply chain composed of an overconfident manufacturer and a rational retailer. The manufacturer produces green products and sells them through the retailer. In reality, the process of commodity transportation will produce costs. It is very important to make transportation cost decisions, such as in the literature [37]. However, in this setting, the transportation cost is not considered. The following assumptions simplify our analysis:

(1) The manufacturer produces development-intensive green products (DIGPs) with greenness $g$ through product R&D and supplies them to the retailer at a wholesale price of $w$. Then, the retailer sells the product to consumers at a retail price of $p$ according to the market demand. $g$, $w$, and $p$ are decision variables.

(2) For products development-intensive green products DIGPs, they need significant R&D investment before to improve product greenness being widely adopted. Besides, DIGPs also need R&D to reduce the manufacturing costs so that they can be affordable to users. Hence, the major cost for a DIGP is the fixed cost [14]. Referring Zhu and He [14], the cost of a DIGP is modelled as an increasing quadratic function as $Ig^2/2$, independent of the product quantity, where $I$ is the green investment cost coefficient, reflecting the difficulty of product greening. We assume the variable manufacturing costs, such as direct material and direct labour, to be a constant $c$, since for DIGPs, such variable costs are insignificant as compared to the R&D costs. In the next, the cost of greening is called green investment cost, and it is incurred by the manufacturer. To ensure there is an optimal solution of the model, the value of $I$ is assumed to satisfy the inequality $I > 2k^2$. That is to say, $I$ should take a larger value, which is consistent with the fact that the greening cost is often higher in reality.

(3) The demand function is stochastic, and the linear demand model is widely adopted in the economic modelling literature [14]. Referring to the literature [1, 2, 11, 13, 14], the market demand for green products is a linear function of the retail price and product greenness. The demand function is assumed to be

$$d = a - bp + kg + \varepsilon,$$

where $a$ is the market size; $b$ is consumers’ sensitivity to retail price; $k$ is consumers’ sensitivity to product greenness; $\varepsilon$ is a continuous random variable with a mean of 0. The greater the $k$, the more utility consumers think the product greenness brings. To make the model meaningful, it is assumed $a, b, k > 0$ and $a - bc > 0$.

(4) When the manufacturer is overconfident, his overconfidence is reflected in two aspects. (a) He overestimates the impact of product greenness on demand; that is, the overconfident manufacturer deems that consumers’ sensitivity to product greenness is higher than it was. The higher the level of overconfidence, the greater the attractiveness of the product greenness to consumers. (b) He overestimates the accuracy of demand uncertainty; that is, the demand variance that the overconfident manufacturer deems is lower than the actual variance. The former is called overestimation and the latter is called overprecision [22, 24]. Using the existing modelling method of overconfidence [22, 24], product demand beliefs of the overconfident manufacturer is

$$d_0 = a - bp + (1 + \gamma)kg + (1 - \gamma)\varepsilon.$$  

Here, $\gamma (0 \leq \gamma \leq 1)$ represents the overconfidence level of the manufacturer: $\gamma = 0$ corresponds to a perfectly rational manufacturer, whereas $\gamma = 1$ corresponds to an infinitely overconfident manufacturer.

(5) Both the manufacturer and the retailer are risk-neutral, and they pursue the maximum expected profit. The manufacturer does not realize his overconfidence behaviour, but the retailer can observe and know the level of overconfidence.

(6) The above information is the common knowledge of the manufacturer and the retailer. That is, their information is symmetrical.

The main notations in this paper are shown in Table 1.

4. Model Construction and Analysis

In our model, the manufacturer and the retailer both maximize their imaginary profits. Based on assumptions, there is a two-stage Stackelberg game in the green supply chain. The Stackelberg game model is widely used to solve such problems. In the game, the overconfident manufacturer is leader, and he decides the product greenness and the wholesale price first to maximize his profit.
However, his actual profit is 

\[
p^*(g, w) = \frac{a + bw + kg}{2b}.
\]  

(7)

However, the manufacturer is overconfident, and he deems that the retailer’s demand belief is the same as him. Hence, the price that the overconfident manufacturer deems the retailer chooses is 

\[
p^{**}(g, w) = \frac{a + bw + (1 + \gamma)kg}{2b}.
\]  

(8)

Substituting (8) into (3), we get the expected profit that the overconfident manufacturer deems he earns 

\[
E \Pi_m^o = \frac{(w - c)(a - bw + (1 + \gamma)kg) - \frac{1}{2}Ig^2}{2}.
\]  

(9)

The Hessian Matrix of \( E \Pi_m^o \) is 

\[
H = \begin{bmatrix}
\frac{\partial^2 E \Pi_m^o}{\partial g^2} & \frac{\partial^2 E \Pi_m^o}{\partial g \partial w} \\
\frac{\partial^2 E \Pi_m^o}{\partial w \partial g} & \frac{\partial^2 E \Pi_m^o}{\partial w^2}
\end{bmatrix} = \begin{bmatrix}
-1 & \frac{(1 + \gamma)kg}{2} \\
\frac{(1 + \gamma)kg}{2} & -b
\end{bmatrix}.
\]  

(10)

If \( bl > k^2 \), for \( \forall y \in [0, 1] \), we have \( |H| = bl - (1 + y)^2k^2/2 > 0 \). Hence, \( H \) is negative definite. There is a maximum in (9). Taking the first-order conditions of \( E \Pi_m^o \) concerning \( g \) and \( w \), we obtain 

\[
\frac{\partial E \Pi_m^o}{\partial g} = \frac{k(w - c)(1 + \gamma) - Ig}{2} = 0,
\]  

(11)

\[
\frac{\partial E \Pi_m^o}{\partial w} = \frac{a + bc - 2bw + (1 + \gamma)kg}{2} = 0.
\]  

(12)

Solving equations (11) and (12) simultaneously, we get the product greenness and the wholesale price chosen by the overconfident manufacturer: 

\[
g^o = \frac{k(1 + \gamma)(a - bc)}{4bl - k^2(1 + \gamma)^2},
\]  

(13)

\[
w^o = \frac{2l(a - bc)}{4bl - k^2(1 + \gamma)^2} + c.
\]  

(14)

Substituting (13) and (14) into (7), we obtain the retail price chosen by the retailer: 

\[
p^o = \frac{(a - bc)[6bl - k^2(1 + \gamma)]}{2b[4bl - k^2(1 + \gamma)^2]} + c.
\]  

(15)

Then, it is easy to derive the manufacturer’s profit and the retailer’s profit according to (4) and (5): 

\[
E \Pi_m^* = \frac{I(a - bc)[4bl - k^2(1 + \gamma)(1 + 3\gamma)]^2}{2[4bl - k^2(1 + \gamma)^2]^2},
\]  

(16)

\[
E \Pi_r^* = \frac{(a - bc)^2[2bl - k^2\gamma(1 + \gamma)]^2}{4b[4bl - k^2(1 + \gamma)^2]^2}.
\]  

(17)
The total profit of the green supply chain is
\[
\Pi^* = \frac{(a-bc)^2[12b^2I^2 + k^4y(1+y)^3 - 2bk^2(1+y)(1+5y)]}{4b[4bI - k^2(1+y)^2]^2}
\]
(18)

The following propositions describe the findings on green supply chains when the manufacturer is overconfident.

**Proposition 1.** When the manufacturer is overconfident, product greenness, the wholesale price, and retail price are higher than the corresponding values when the manufacturer is rational. Product greenness, wholesale price, and retail price are all increasing with the level of the manufacturer’s overconfidence.

**Proof of Proposition 1.** We can prove the proposition by the sign of the first derivatives. Taking the first derivatives of \(g^*, w^*, \) and \(p^*\) for \(\gamma\), respectively, we get
\[
\begin{align*}
\frac{\partial g^*}{\partial \gamma} &= \frac{k(a-bc)[4bI + k^2(1+y)^2]}{[4bI - k^2(1+y)^2]^2} > 0, \quad (19) \\
\frac{\partial w^*}{\partial \gamma} &= \frac{4Ik^2(a-bc)(1+y)}{[4bI - k^2(1+y)^2]^2} > 0, \quad (20) \\
\frac{\partial p^*}{\partial \gamma} &= \frac{k^2(a-bc)[4bI(2+y) + k^2(1+y)^2]}{2b[4bI - k^2(1+y)^2]^2} > 0. \quad (21)
\end{align*}
\]

The derivatives of \(g^*, w^*, \) and \(p^*\) concerning \(\gamma\) are all strictly positive. Therefore, product greenness, the wholesale price, and retail price are increasing with the level of the manufacturer’s overconfidence. □

**Proposition 2.** The manufacturer’s profit is decreasing with the level of its overconfidence. However, with the increase of the manufacturer’s overconfidence, both the retailer’s profit and the supply chain’s profit increase first and then decrease.

**Proof of Proposition 2.** Taking the first derivative of \(\Pi^*_m\) to \(\gamma\), we obtain
\[
\frac{\partial \Pi^*_m}{\partial \gamma} = -\frac{k^2(a-bc)^2[4bI + 3k^2(1+y)^2]}{[4bI - k^2(1+y)^2]^3} \leq 0. \quad (22)
\]

Hence, the higher the level of the manufacturer’s overconfidence, the lower the profit he achieves.

Taking the first derivative of \(\Pi^*_r\) to \(\gamma\), we get
\[
\frac{\partial \Pi^*_r}{\partial \gamma} = \frac{-k^2(a-bc)^2[2bI - k^2(1+y)^2]}{2b[4bI - k^2(1+y)^2]^3} \quad (23)
\]

The sign of equation (23) is opposite to \(4bIy - k^2(1+y)^2\). It is immediate to see that the value of \(4bIy - k^2(1+y)^2\) is increasing with \(\gamma\). When \(\gamma = 0\), we have \(\partial \Pi^*_r/\partial \gamma > 0\), and when \(\gamma = 1\), we get \(\partial \Pi^*_r/\partial \gamma < 0\). Therefore, with \(\gamma\) varies from 0 to 1, \(\Pi^*_r\) increases first and then decreases. The difference of the retailer’s profits between \(\gamma = 1\) (the manufacturer is infinitely overconfident) and \(\gamma = 0\) (the manufacturer is perfectly rational) is
\[
\Pi_r = -\frac{k^2(a-bc)^2(8bI - k^2)}{16b(4bI - k^2)^2} < 0. \quad (24)
\]

Hence, when the manufacturer’s overconfidence is high, the retailer’s profit is less than the profit he achieves when the manufacturer is rational.

Taking the first derivative of \(\Pi^*_s\) to \(\gamma\), we obtain
\[
\frac{\partial \Pi^*_s}{\partial \gamma} = \frac{(a-bc)^2k^2[k^2y(1+y)^3 + 2bk^2y(1+3y+y^2) + 16b^2I^2y - 2bIk^2]}{2b[4bI - k^2(1+y)^2]^3} \quad (25)
\]

The sign of equation (25) is opposite to \(k^2y(1+y)^3 + 2bk^2y(1+3y+y^2) + 16b^2I^2 - 2bIk^2\). It is easy to prove that the value of \(k^2y(1+y)^3 + 2bk^2y(1+3y+y^2) + 16b^2I^2 - 2bIk^2\) is increasing with \(\gamma\). Hence, when \(\gamma = 0\), we get \(\partial \Pi^*_s/\partial \gamma > 0\), and when \(\gamma = 1\), we derive \(\partial \Pi^*_s/\partial \gamma < 0\). That is, with \(\gamma\) varies from 0 to 1, \(\Pi^*_s\) increases first and then decreases. The difference of the supply chain’s profits between \(\gamma = 1\) and \(\gamma = 0\) is
\[
\Pi = -\frac{(a-bc)^2k^2(16b^3I^3 - 3b^2k^2I^2 + 6bk^4I - k^6)}{16b(bI - k^2)^2(4bI - k^2)^2} < 0. \quad (26)
\]

Hence, when the manufacturer’s overconfidence is high, the supply chain’s profit is less than the total profit when the manufacturer is rational.
manufacturer’s overconfidence can lead to biased decisions. The profit maximization decision based on overconfident beliefs cannot achieve the actual profit maximization, so the manufacturer’s profit under overconfidence is less than that in the rational setting. However, the rational retailer has a second-mover advantage. He can observe the manufacturer’s overconfidence and then make decisions accordingly. When the level of overconfidence is low, overconfidence benefits the retailer. However, when the level of overconfidence is high, the bias is so large that the retailer’s profit decreases, so does the profit of the green supply chain.

5. Revenue-Sharing Contracts under Manufacturers’ Overconfidence

A large number of studies have proved that revenue sharing can achieve green supply chain coordination in the rational setting. However, it can do under manufacturers’ overconfidence? Next, we explore whether revenue-sharing contracts can coordinate green supply chains in an overconfident environment. The sequence of decision-making is assumed as follows:

1. The rational retailer offers to share λ proportion of the total revenue to the overconfident manufacturer. The manufacturer can accept or reject the offer. If he accepts the offer, the retailer will get 1 − λ proportion of the total revenue and the manufacturer will gain λ proportion of the total revenue, 0 < λ < 1.

2. The overconfident manufacturer determines the product greenness and wholesale price considering the revenue-sharing proportion.

3. The retailer chooses the retail price taking the revenue-sharing proportion, product greenness, and wholesale price into consideration.

Under the given assumptions, the expected profit functions of the overconfident manufacturer and the rational retailer are

\[ E_{\Pi_m}^{rs} = (w - c)(a - bp + kg) - \frac{1g^2}{2} + \lambda (p - w)(a - bp + kg), \]

\[ E_{\Pi_r}^{rs} = (1 - \lambda)(p - w)(a - bp + kg). \]  

The superscript “rs” indicates the case of revenue-sharing contracts under the overconfident manufacturer. However, the expected profits that the overconfident manufacturer deems they earn are

\[ E_{\Pi_m}^{ors} = (w - c)[a - bp + (1 + \gamma)kg] - \frac{1g^2}{2} + \lambda (p - w)[a - bp + (1 + \gamma)kg], \]

\[ E_{\Pi_r}^{ors} = (1 - \lambda)(p - w)[a - bp + (1 + \gamma)kg]. \]  

The superscript “ors” indicates the case of revenue-sharing contracts under the overconfident manufacturer. The first-order condition of the rational retailer’s profit maximization is

\[ \frac{\partial E_{\Pi_r}^{rs}}{\partial p} = (1 - \lambda)(a - 2bp + bw + kg) = 0. \]  

Solving the equation (31) for \( p \), we derive the retailer’s reaction function:

\[ p^{rs}(\lambda, g, w) = \frac{a + bw + kg}{2b}. \]  

However, the overconfident manufacturer deems that the retailer determines retail price based on equation (30), and the reaction function of retail price that the overconfident manufacturer think is

\[ p^{ors}(\lambda, g, w) = \frac{a + bw + (1 + \gamma)kg}{2b}. \]  

Substituting (33) into (29), we get the profit function that the overconfident manufacturer aims to maximize. It is easy to see that \( E_{\Pi_m}^{ors} \) has a maximum when \( bI > 2k^2 \). Next, we restrict attention to this situation. We get the greenness and wholesale price chosen by the overconfident manufacturer in the setting of revenue sharing are

\[ g^{ors}(\lambda) = \frac{k(a - bc)(1 + \gamma)}{2bl(2 - \lambda) - k^2(1 + \gamma)^2}, \]

\[ w^{ors}(\lambda) = \frac{2I(a - bc)(1 - \lambda)}{2bl(2 - \lambda) - k^2(1 + \gamma)^2} + c. \]

Hence, according to (32), the retail price is given by

\[ p^{ors}(\lambda) = \frac{[2bl(3 - 2\lambda) - k^2\gamma(1 + \gamma)](a - bc)}{2bl[2bl(2 - \lambda) - k^2(1 + \gamma)^2]} + c. \]

Substituting (34)–(36) into (28), the profit function of the retailer can be rewritten as

\[ E_{\Pi_r}^{ors}(\lambda) = \frac{(1 - \lambda)[2bl - k^2\gamma(1 + \gamma)]^2(a - bc)^2}{4b[2bl(2 - \lambda) - k^2(1 + \gamma)^2]^2}. \]

The optimal revenue-sharing proportion that maximizes equation (37) is

\[ \lambda^* = \frac{k^2(1 + \gamma)^2}{2bl}. \]

Then, the product greenness, wholesale price, retail price, the overconfident manufacturer’s profit, the rational retailer’s profit, and the supply chain’s profit in the case of revenue sharing are given, respectively, as

\[ g^{ors} = \frac{k(a - bc)(1 + \gamma)}{2[2bl - k^2(1 + \gamma)^2]}, \]

\[ w^{ors} = \frac{a + bc}{2b}. \]
According to the above equilibrium values, we derive the following valuable conclusions.

**Proposition 3.** The equilibrium value of product greenness in revenue-sharing contracts is greater than that without cooperation, and the larger the manufacturer’s overconfidence, the higher the value of product greenness.

**Proof of Proposition 3.** According to equations (13) and (39), we get

\[
p^{**} = \frac{[6bI - k^2 (1 + \gamma)(2 + 3\gamma)](a - bc)}{4b[2bI - k^2(1 + \gamma)^2]} + c, \quad (41)
\]

\[
E_{\text{r}}^{**} = \frac{[8b^2I[2bI - k^2 (1 + \gamma)(1 + 2\gamma)] + k^5\gamma^2 (1 + \gamma)^4](a - bc)^2}{32b^2I[2bI - k^2(1 + \gamma)^2]^2}.
\]

\[
E_{\text{m}}^{**} = \frac{(a - bc)^2[2bI - k^2(1 + \gamma)]^2}{32b^2I[2bI - k^2(1 + \gamma)^2]^2},
\]

\[
E_{\text{m}}^{**} = \frac{[2bI[6bI - k^2 (1 + \gamma)(3 + 7\gamma)] + k^5\gamma(2 + 3\gamma)(1 + \gamma)^2](a - bc)^2}{16b[2bI - k^2(1 + \gamma)^2]^2}.
\]

This result is simple. Although the product greenness is raised, the increased green investment cost will be completely offset by the \(\lambda\) proportion of the total revenue that the retailer offers. Thus, revenue-sharing contracts are beneficial from an environmental protection perspective. However, it seems counter-intuitive that the manufacturer’s overconfidence does not affect the decision of wholesale price. □

**Proposition 5.** The equilibrium value of product retail price in revenue-sharing contracts increases with the level of the manufacturer’s overconfidence. The equilibrium retail price is in the following order in comparison to the value without cooperation: (1) if \(bl > 3k^2\), \(p^{**} < p^*\); (2) if \(2k^2 < bl \leq 3k^2\), when \(0 \leq \gamma < \sqrt{8bl + k^2/2k - 3/2}\), then \(p^{**} < p^*\); when \(\gamma = \sqrt{8bl + k^2/2k - 3/2}\), then \(p^{**} = p^*\); when \(\sqrt{8bl + k^2/2k - 3/2} \leq \gamma \leq 1\), then \(p^{**} > p^*\).

**Proof of Proposition 5.** From equations (15) and (41), we derive

\[
p^{**} - p^* = \frac{k^2(1 + \gamma)^2(a - bc)[2bI - k^2(1 + \gamma)(2 + \gamma)]}{4b[2bI - k^2(1 + \gamma)^2]^2[4bI - k^2(1 + \gamma)^2]}, \quad (48)
\]

\[
\frac{\partial p^{**}}{\partial \gamma} = \frac{k^2(a - bc)[2bI + k^2(1 + \gamma)^2]}{4b[2bI - k^2(1 + \gamma)^2]^2}, \quad (49)
\]

It is immediately to see that \(\partial p^{**}/\partial \gamma > 0\) and the sign of \(p^{**} - p^*\) is the opposite of \(2bI - k^2(1 + \gamma)(2 + \gamma)\). Note that we assume \(bl > 2k^2\) to ensure the model has an optimal solution. The relationship between \(p^{**}\) and \(p^*\) is derived through algebraic comparison.

Proposition 5 suggests that, although retail price is positively correlated with the manufacturer’s overconfidence in revenue-sharing contracts, consumers’ sensitivity to product greenness and green investment cost coefficient have a greater impact on retail price. Especially, when consumers are more sensitive to retail price, or the green investment cost coefficient is larger (i.e., \(bl > 3k^2\)), revenue-sharing contracts give rise to a lower retail price. □
Proposition 6. Revenue-sharing contracts lead to a larger demand, a greater per-unit margin, and a higher retailer’s profit in comparison with the case of noncooperation.

Proof of Proposition 6. From the equilibrium values (13), (15), (39), and (41), we derive the expected demand in revenue sharing \((q^{rs*})\) and noncooperation \((q^*)\), respectively. The difference in demand is

\[
q^{rs*} - q^* = \frac{k^2(a-bc)(1+\gamma)^2[2bl - k^2\gamma(1+\gamma)]}{4[2bl-k^2(1+\gamma)]^2} > 0. \tag{50}
\]

Let \(m^{rs*}\) and \(m^*\) denote the per-unit margin in revenue sharing and noncooperation, respectively. The difference in margin is

\[
m^{rs*} - m^* = (\rho^{rs*} - w^{rs*}) - (\rho^* - w^*)
\]

\[
= \frac{k^2(a-bc)(1+\gamma)^2[2bl - k^2\gamma(1+\gamma)]}{4[2bl-k^2(1+\gamma)]^2} > 0. \tag{51}
\]

According to equations (17) and (43), we get

\[
\begin{align*}
E\Pi_r^{rs*} - E\Pi_r^* &= k^4(a-bc)^2(1+\gamma)^4[2bl - k^2\gamma(1+\gamma)]^2 \\
&= \frac{32b^2k^4[2bl-k^2(1+\gamma)]^2[4bl - k^2(1+\gamma)^2]}{16[2bl-k^2(1+\gamma)]^4} > 0. \tag{52}
\end{align*}
\]

From the above, we have \(q^{rs*} > q^*\), \(m^{rs*} > m^*\), \(E\Pi_r^{rs*} > E\Pi_r^*\).

Proposition 6 implies that the retailer incurs higher profit in revenue-sharing contracts than the noncooperation case. Obviously, sharing revenue with the overconfident manufacturer benefits the retailer. The reason is as follows. The manufacturer shares part of the retailer’s sales revenue, which greatly reduces the green investment cost. That is to say, given the same total investment, the product greenness will increase significantly, and the wholesale price will decrease. The increase of product greenness leads the retailer to choose a higher retail price while the decrease in wholesale price leads the retailer to set a lower retail price. Hence, the retail price set by the retailer is the trade-off between the two factors. However, no matter how strong or weak the two factors are, they are beneficial to the retailer. The retailer will set a price that maximizes his profit and get a larger per-unit margin. A significant increase in product greenness makes the clear sale increase. In the rational setting, revenue-sharing contracts help the manufacturer and the retailer to increase profits. However, in the setting of overconfidence, we cannot get to this conclusion. On one side, revenue-sharing contracts can bring about the manufacturer derive more profit; on the other side, overconfidence results in a decision deviation which leads to a decline in profit. The manufacturer’s profit is also determined by these two factors. The reason why the overconfident manufacturer accepts the retailer’s revenue-sharing proposal is that he deems he can benefit from the contract. The overconfident belief leads to a biased decision, which reduces the manufacturer’s profit.

Proposition 7. The higher the level of the manufacturer’s overconfidence, the greater the proportion of profit-sharing provided by the retailer.

Proof of Proposition. 7. From equation (38), it is immediate to see that \(\partial \lambda^* / \partial \gamma = k^2(1+\gamma)/bl > 0\).

Proposition 7 shows that, when the manufacturer is more overconfident, the rational retailer will offer a higher proportion of revenue sharing to the manufacturer. The larger overconfidence leads to a higher product greenness which requires the manufacturer to invest more money in greening. The retailer benefits more from the improved greenness, but the greening cost increased is incurred by the manufacturer. Hence, the retailer increases his profit-sharing to offset the green investment cost borne by the overconfident manufacturer.

From Propositions 1–7, we obtain the following managerial insights.

In the case of noncooperation, the manufacturer’s overconfidence helps to improve product greenness, as product greenness is increasing with the overconfidence level. However, this will lead to a decline in manufacturers’ own profits. Especially, when the manufacturer’s overconfidence level is high, both the retailer’s profit and the total profit of the supply chain decrease. Hence, if the purpose of social development is to promote green development, appropriate overconfidence will help achieve this goal. If the purpose of social production is to improve the efficiency of the industry, particularly to improve the manufacturer’s profit, retailers should timely transmit market demand information, reduce the manufacturers’ expectations of market demand, and especially reduce the impact of greenness on demand.

In the case of cooperation, revenue-sharing contracts lead to a higher greenness and a larger demand, but the retail price does not necessarily increase. Therefore, enabling manufacturers and retailers to reach revenue-sharing contracts can help to improve greenness and expand the green products market; especially, the retailer should actively establish contracts with manufacturers, as his profit will be increased. Although the manufacturer is motivated to reach revenue-sharing contracts with the retailer, his profit does not necessarily increase due to his overconfidence. Hence, the overconfident manufacturer should always pay attention to the changes in his profits in order to correct the adverse effects of his overconfidence accordingly.

6. Conclusions

Overconfidence is one of the most universal psychological behaviours, which can lead to decisions deviating from the optimum. There is no exception in the decisions of green products manufacturer. In this paper, we focus on the
influence of manufacturers’ overconfidence on decisions of green supply chains. Our setting consists of one manufacturer who produces green products and sells them to consumers through one retailer. The manufacturer’s overconfidence is characterized as a belief bias that he overestimates the impact of product greenness on demand and the accuracy of demand uncertainty. We apply the game theory model to investigate the manufacturer’s overconfidence in product greenness, prices, and members’ profits. For the adverse effects brought by overconfidence, we further explore whether revenue-sharing contracts that are commonly used in the rational setting can achieve green supply chain coordination. Our main conclusions are given as follows:

1. The overconfident manufacturer will produce greener products and set a higher wholesale price, and the rational retailer will price the greener products more, than the case that the manufacturer is rational. The manufacturer’s profit is decreasing with his overconfidence level. As the manufacturer’s overconfidence increases, both the retailer’s profit and the supply chain’s profit increase first and then decrease.

2. In the setting of revenue-sharing contracts, product greenness is greater, and wholesale price is lower than that without cooperation. The relationship of retail prices between cooperation and nonoperation depends on consumers’ price sensitivity, green sensitivity, and green investment cost coefficient. Moreover, the greater the level of overconfidence, the higher the product greenness and the retail price. However, the wholesale price is not affected by the manufacturer’s overconfidence.

3. When decision-makers are completely rational, revenue-sharing contracts can coordinate green supply chains. However, in an overconfident environment, it does not always work. Although revenue sharing makes the retailer’s profit increase, the manufacturer’s distorted demand belief ultimately reduces his profit.

While this study adds to the growing literature on behavioural operational management and supply chain coordination, there are also some limitations in our work. First, we only examined whether revenue-sharing contracts that used in rational setting can coordinate the green supply chain under manufacturers’ overconfident, and do not propose a contract that can fully achieve green supply chain coordination. The next study would be to explore the coordination mechanism to eliminate the adverse effects of overconfidence on manufacturers and retailers simultaneously, such as cost-sharing contracts, buyback contracts, or sales rebate contracts. Second, we mainly discuss product greenness and product pricing decisions. However, in the process of green product development, government subsidies and tax policies play an important role. In following study, external factors such as government subsidies and tax policies need to be included in the supply chain decisions. Third, besides manufacturers, retailers may also have overconfidence behaviour. Further analyses could be conducted in future incorporating retailers’ overconfidence into green supply chain decisions and explore supply chain coordination under retailers’ overconfidence.

**Data Availability**

Our paper mainly adopts a mathematical approach to analyse green supply chain decisions and revenue-sharing contracts under manufacturers’ overconfidence and does not involve specific data exploration.

**Conflicts of Interest**

The authors declare that they have no conflicts of interest.

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