Wholesale-price vs cost-sharing contracts in a green supply chain with reference price effect under different power structures

Ranran Zhang
School of Economics and Management, Shanghai Polytechnic University, Shanghai, China
Jinjin Liu
Business School, Yangzhou University, Yangzhou, China, and
Yu Qian
Department of Shipping and Logistics Management, Shanghai Communications Polytechnic, Shanghai, China

Abstract

Purpose – This research aims to examine which cooperative contract (wholesale-price contract or cost-sharing contract) can more effectively upgrade the green degree of product and promote demand when considering consumer reference price effect under different power structures.

Design/methodology/approach – This research investigates a dyadic green supply chain composed of one manufacturer and one retailer. Four Stackelberg game models with a cost-sharing contract or a wholesale-price contract are built in retailer-led and manufacturer-led scenarios, respectively. Using backward induction, the optimal green decision under each model is obtained. In addition, the optimal cooperative contract is proposed by comparing these four models.

Findings – It is found that under consumer reference price effect, a cost-sharing contract outperforms a wholesale-price contract in upgrading product greenness and promoting demand. Under any single contract, the retailer-led situation is more conducive to improving product greenness than the manufacturer-led situation. Moreover, consumer reference price effect would reduce the sharing ratio of a cost-sharing contract when the manufacturer dominates, but it could mitigate the problem of double marginalization by reducing wholesale and retail prices under both types of contracts, which would enhance consumer surplus.

Originality/value – It is a new attempt to incorporate consumer reference price effect and power structure into a green supply chain framework and proposes a novel demand function that simultaneously emphasizes consumer reference price effect, consumer environmental awareness and product green attribute. In addition, it provides managerial insights for business managers to choose green cooperative contracts with consumer reference price effect under different power structures.

Keywords Cost-sharing contract, Green supply chain, Power structure, Reference price effect, Wholesale-price contract

Paper type Research paper

1. Introduction

Nowadays, ever-growing consumer environmental awareness (Ding and Wang, 2020) has become a crucial market driver (Dong et al., 2019) for enterprises to develop and market green products (Liu et al., 2020). For example, a well-known fast fashion retailer, H&M, has adopted sustainable practices by offering customers a discount in exchange for old clothing and...
applying emission-reduction technologies in its production process (Mccall, 2015). Similarly, PepsiCo and Coca-Cola have pledged to work hard to reduce plastic waste and improve recycling. Their goal is to make their packaging and products recyclable, reusable, compostable or biodegradable by 2025 (Newburger, 2019). Despite such green efforts having achieved excellent environmental performance (Ghosh and Shah, 2015), there is few widespread efforts to restructure the supply chain for greening because of the relatively high cost of going green (Tseng et al., 2013).

In a green supply chain, firms typically agree to contractual arrangements to overcome costly green R&D activities (Ghosh and Shah, 2015). Among various contract arrangements, there are two classic contracts that are widely used in multiple industries and have attracted the attention from academia: wholesale-price contract (WPC) (Perakis and Roels, 2007; El Ouardighi, 2014; Niederhoff and Kouvelis, 2019) and cost-sharing contract (CSC) (Yang and Chen, 2018; Liu et al., 2020). Under WPC, green manufacturers would pass on some green R&D costs to retailers by charging retailers a higher wholesale price for each product (Ji et al., 2020), and under CSC, retailers would like to share some of green R&D costs with manufacturers to obtain a lower wholesale price (Ma et al., 2020). For example, in 2002, Alpha Labs, a small listed biotechnology company in the USA, reached a cost-sharing agreement with Mega Pharmaceuticals, one of the world’s top 100 pharmaceutical companies. Under this agreement, the two companies agreed to split the investment cost in drug development (Bhaskaran and Krishnan, 2009). Cooperative contract, as a typical issue in supply chain coordination, has aroused widespread concern from academia in the past decades (Zhang et al., 2013), but an important market phenomenon, namely market power structure, has not received enough attention in the research of cooperative contract. In practice, due to the emergence and rapid development of retail giants such as Carrefour, Walmart and Amazon, the traditional manufacturer-led supply chain structure has been broken. Moreover, such retail giants have gradually gained the dominance over manufacturers in the supply chain (Liu et al., 2020). Generally, different power structures directly lead to different decision order of each supply chain member, which would affect pricing, profit and cooperation mode. Hence, it is a necessity to examine the impact of different power structures on cooperative contract selection, so that managers can better formulate green cooperative strategies.

Consumers’ purchase decisions on green products are often affected by reference prices, which are formed over time by the information of consumers’ purchasing experiences (Kalwani et al., 1990). When consumers buy a certain product repeatedly, they form a memory of past prices. These past prices, used as a benchmark for comparison with future product prices, are called reference prices (Wang, 2016). Generally, reference prices are affected by historical prices, suggested retail prices, competitor product prices, advertisements, promotions, price discounts, quality and other factors (Zhang et al., 2013). A large number of studies also have shown that reference price will significantly affect consumer demand (Popescu and Wu, 2007). When consumers make new purchasing decision, they often judge the current price of the product according to the reference price in their mind. If the current price is below the reference price, consumers feel benefit and accelerate demand; conversely, if the current price is above the reference price, consumers feel loss and reduce demand (Kalyanaram and Little, 1994). Many enterprises have realized the importance of reference price effect (RPE), developed appropriate pricing strategies and made use of it to achieve success (Lu et al., 2016). For example, Apple first announced a high iPhone sales price of $599 to establish a high reference price. Then, by rapid price reduction, such as a discount of iPhone to $399 at Christmas, consumers can feel cost-effective and get a sense of benefit, thus greatly stimulate consumer demand. This strategy has made Apple a great success and made huge profits. The production and operation decisions of enterprises will be influenced by the change of consumer demand, which is affected by RPE. Hence, consumer reference price effect (CRPE), like the above market power structure, is another key factor that affects the
choice of cooperative contract between enterprises. These two factors are considered from different perspectives. One is from the internal perspective of enterprises, while the other is from the external perspective of enterprises, that is, the consumer perspective. Although these two factors both have a crucial impact on the choice of cooperative contract between enterprises, there are few studies on the joint impact of these two factors. Thus, it is significant to examine the joint influence of market power structure and CRPE on the choice of cooperative contract, which can enable enterprise managers to develop appropriate strategies to chase maximum profit.

Based on the above discussion, this research aims to explore these following research questions:

1. Which cooperative contract (WPC or CSC) could efficiently improve the level of greenness and demand under different power structures considering CRPE?
2. What effect does the power structure have on cooperative contracts and product greenness?
3. How does CRPE affect the effectiveness of cooperative contracts and decision variables?

To answer the above questions, a dyadic green supply chain consisting of one green manufacturer and one retailer is studied, wherein the green manufacturer undertakes to produce green products and distribute these green products to the retailer, who then sells them to consumers. To start with the analysis, WPC and CSC under two different market power structures (i.e. retailer-dominated or manufacturer-dominated situation) are investigated. Accordingly, four Stackelberg game models considering CRPE are built. Then, using the backward induction method, optimal green decisions and supply chain members’ profits under each model are obtained. Next, a comparative analysis between these four models is carried out. To investigate how CRPE affects the decision variables under these two cooperative contracts, numerical analysis is carried out. At last, the managerial implications from these findings are further discussed.

Our study has four research contributions. First, it is a new attempt to integrate CRPE and power structure into a green supply chain framework. To our knowledge, there are few joint studies of these two market phenomena in the literature on cooperative contracts, so our study has a novel dimension that can enrich the literature on green supply chain management. Second, a new demand function incorporating CRPE is put forward, which simultaneously emphasizes CRPE, consumer environmental awareness and product green attribute. This new form of demand function yields a better understanding of factors affecting consumer demand and is helpful to study how CRPE affects green decision-making and pricing strategy. An interesting finding is come up that CRPE hinders the improvement of product greenness, but it can alleviate the double marginalization problem, which is beneficial to the improvement of consumer surplus. Third, two kinds of cooperative contracts under different power structures have been thoroughly studied and compared, and it is found that under CRPE, CSC is better for improving the green degree and demand of products than WPC. Especially in the manufacturer dominance case, CSC could enable the retailer and the manufacturer to achieve Pareto improvement in profits. Fourth, our study has practical guiding significance and can provide valuable reference for enterprise managers to make cooperative decisions under different market power structures with CRPE.

The rest of this study includes the following sections. Section 2 carries out literature review research. Section 3 presents assumptions and notations. Section 4 builds WCS and CSC models under retailer-dominated and manufacturer-dominated situations, respectively. Section 5 conducts a comparative analysis and comes up with some interesting findings.
Numerical analysis is performed in Section 6 to verify part of the results. Managerial insights are provided in Section 7. Section 8 summarizes this study and puts forward future research directions.

2. Literature review
There exist three main research lines closely related to this research. The first one concerns about cooperation contract in green supply chain, the second concentrates on CRPE, and the third focuses on power structure in supply chains. The literature of these three research streams is reviewed, and the differences between ours and theirs are discussed.

2.1 Cooperation contract in green supply chain
Cooperative contracts have been extensively discussed in the literature of green supply chain management, and most studies have focused on the comparison between different types of cooperative contracts (e.g. Xu et al., 2017; Ma et al., 2019a; Liu et al., 2020). For instance, Ghosh and Shah (2015) examined the influence of two kinds of CSC (i.e. a retailer-offered and a bargaining CSC) on green degree, price and profit through a game theoretic approach. Their results revealed that CSC can generate higher green levels and greater supply chain profits, especially the bargaining contract has a larger incentive effect in these aspects than the retailer-offered contract. Under the regulation of cap-and-trade, Xu et al. (2017) investigated the production and emission reduction decision-making in a manufacturing-to-order supply chain under WPC and CSC. They indicated that this manufacturing-to-order supply chain could be coordinated through these two contracts. Following Ghosh and Shah (2015), Song and Gao (2018) carried out research from the perspective of revenue-sharing contracts in a similar logic way. They established a game model of green supply chain under two revenue-sharing contracts (i.e. retailer-led case and bargaining case, respectively) and examined the effect of these two contracts on decision variables and profit. They pointed out that a revenue-sharing contract helps upgrade the green degree of product, especially the bargaining contract outperforms the retailer-led contract in this aspect. Dey and Saha (2018) discussed the joint effect of retailers’ strategic inventory decisions and consumer’s expectations on manufacturers’ green investment decisions in two-period models under three scenarios (i.e. presence of SI, absence of SI and single procurement) with and without CSC. They concluded that retailers’ participation in green investment does not always incentivise manufacturers to upgrade product greenness. Later, Ma et al. (2019a) investigated two cooperative mechanisms (i.e. a CSC and a revenue-sharing contract) among supply chain members after receiving subsidies from the government. They concluded that, with government subsidies, a revenue-sharing contract is more conducive to improving the green level of products. Under a manufacturer-led or a retailer-led condition, Liu et al. (2020) also built differential game frameworks to investigate revenue-sharing contract and CSC. Their analysis indicated that only in the case of the retailer dominance, CSC could lead to higher levels of greenness. However, when the manufacturer dominates, the revenue-sharing contract could produce higher levels of greenness.

The above literature has discussed the impact of cooperative contract on product greenness and supply chain performance and has conducted comparative analysis between different kinds of cooperative contracts, but they did not take CRPE into account. Despite it being common for consumers to exhibit RPE when purchasing green products, and such RPE would affect the choice of cooperative contracts among supply chain members, literature that incorporates CRPE into cooperative contract research is still sparse. Hence, this study aims to discuss cooperative contracts in green supply chain considering CRPE.
2.2 Consumer reference price effect (CRPE)
Reference price has been investigated as a key factor influencing market demand since at least the 1980s (Zhang et al., 2013). For the concept, formation and influence of reference price, please refer to the review of Mazumdar et al. (2005). Previous research on reference price mainly focuses on empirical studies (e.g. Rust and Zahorik, 1993; Kalyanaram and Winer, 1995; Pauwels et al., 2002). Subsequently, with the development of reference price theory, many researchers have explored RPE in supply chain management by establishing theoretical models. For example, by building dynamic cooperative advertising models, Zhang et al. (2013) examined the influence of RPE on supply chain members’ decisions. Their results indicated that if consumer behavior would be affected by reference price, firms need to increase their investment in national advertising. Later, Lin (2016) investigated price promotions in a manufacturer–retailer supply chain considering CRPE through establishing Stackelberg game model. He suggested that CRPE helps to alleviate “double marginalization” effects. By extending previous research and establishing joint dynamic models, Zhang et al. (2019) investigated how the asymmetric RPE affects optimal pricing and production strategies. They introduced a systematic approach to nonsmooth optimization problems based on the principle of optimality and argued that the asymmetry is bad for optimal production and profits. Recently, Zha et al. (2021) studied two-period pricing problems between two competing sellers taking the effects of intertemporal and horizontal reference price into account by establishing a duopoly game model. They showed that intertemporal RPE would lead to a high-low pricing strategy, while horizontal RPE would reduce the selling price in these two periods.

Despite some literature on supply chain management having explored RPE, existing research is silent on investigating cooperative contracts in green supply chain while simultaneously exploring CRPE and power structure. To fill this research gap, CRPE and product greenness are incorporated into a new demand function in our study. This function form is helpful to explore how CRPE affects green supply chain cooperation contract under different power structures.

2.3 Power structure in supply chains
Most studies regarding power structure center on the effect of power structure on optimal decision-making in supply chains (e.g. Luo et al., 2017; Agi and Yan, 2020). Among the studies on this topic, Choi (1991) discussed the effect of three different power structures (i.e. manufacturer-led, vertical Nash and retailer-led situations) on channel price and profit under three noncooperative game models considering two manufacturers and one retailer. They pointed out that with a linear demand function, channel members and consumers are better off when there is no market leadership. However, with a nonlinear demand function, everyone loses when no one dominates the market. With the same supply chain structure setting as Choi (1991), that is, two manufacturers and one retailer, Luo et al. (2017) examined the effects of horizontal and vertical power structures on optimal pricing strategies as well as profits by developing multiple-stage game models. They concluded that when the retailer is dominant and there exists a balanced power relationship between manufacturers, all supply chain members are more profitable. Dey et al. (2019) investigated the influence of power structure and inventory strategy on green marginal-cost-intensive and development-intensive products under three procurement strategies of retailers (i.e. maintaining strategic inventory, not maintaining strategic inventory and purchasing product in a single lot). They argued that power structure and procurement strategy have no impact on the greening level of marginal-cost-intensive green products. In Stackelberg games led by a manufacturer and a wholesaler, Nielsen et al. (2019) examined the impacts of intermediaries on green optimal decisions of a green three-echelon supply chain. They pointed out that under a
manufacturer-led game, the dominant intermediary leads the manufacturer to produce products with low green degree, and a two-period purchase plan is better than a single-period optimal plan. On the basis of existing brown products, Agi and Yan (2020) investigated the product line expansion under retailer-led and manufacturer-led supply chains and indicated that the manufacturer-led situation outperforms the retailer-led situation to launch green products and grasp the benefit growth of the green consumption market in the early development stage. Despite these studies having considered power structure in supply chain operations, the research about the influence of power structure on cooperative contracts has been largely ignored.

A few studies have discussed cooperative contracts under different power structures. For instance, Chen et al. (2017) explored the coordination mechanism under different power structures in a sustainable supply chain and suggested that the supply chain can be coordinated via a two-part tariff contract. Also, Liu et al. (2020) examined the incentive effects of a revenue-sharing contract and a CSC on the improvement of product greenness and profit under manufacturer or retailer Stackelberg games. Their results showed that in the retailer-dominated game, the revenue-sharing contract hurts the supply chain members’ profits. Even though some literature has considered the influence of power structure on cooperative contracts, few studies have explored the joint impacts of CRPE and power structure on cooperative contracts. Our study supplements the existing literature, especially provides an analytical framework to verify the joint effects of CRPE and power structure on cooperative contracts in green supply chain environment.

3. Assumptions and notations
We focus on a green supply chain, wherein a green manufacturer produces green products and distributes them to a retailer, who then sells them to consumers. We investigate two cooperative contracts (WPC and CSC) with CRPE under two different power structures. Under WPC, the green manufacturer and retailer cooperate only by a wholesale price, and the green research and development (R&D) cost is borne solely by the green manufacturer. Under CSC, cooperation between the green manufacturer and retailer not only takes place through a wholesale price, but also the retailer takes initiatives to share partial of the green R&D costs for the green manufacturer. Thus, four contract models, namely a retailer-led WPC (Model RW), a manufacturer-led WPC (Model MW), a retailer-led CSC (Model RC) and a manufacturer-led CSC (Model MC), are designed, respectively. By establishing these four models, we aim to explore which cooperative contract is more conducive to improving product greenness and demand considering CRPE under two different power structures. Further, we aim to examine the influence of power structure and CRPE on decision variables in the two contracts. The framework of this study is shown in Figure 1.

Figure 1.
The framework of this study
Before establishing models, we first present the following assumptions. The notations and explanations used in this study are shown in Table 1.

**Assumption 1.** There is only one kind of product for sale, which is similar to Cai (2010). Although, in practice, there are different types of green products, for the sake of simplicity, we consider a simple green supply chain with only one green product. This setting applies to a broader study of cooperative contracts, see Li and Li (2016).

**Assumption 2.** The cost of green products includes two parts: production cost and total green R&D cost (Adhikari and Bisi, 2020). The unit production cost is assumed to be zero because it is negligible compared to the high total expenditure of green R&D, which is similar to Ma et al. (2019b). Such assumptions can simplify calculations and better present analytic results (Zhang et al., 2021). The green R&D cost is assumed as a quadratic function of product greenness \( \theta \) (Chen et al., 2019), that is, \( C(\theta) = \kappa \theta^2 \), where \( \kappa \) represents the green R&D cost coefficient (Wang et al., 2020). The quadratic form of green R&D cost suggests that the marginal return of green innovation investment is decreasing (Ma et al., 2019a).

**Assumption 3.** Consumers are environmentally conscious (Yenipazarli, 2016), and the improvement of product greenness would increase consumer demand (Ghosh and Shah, 2012). The parameter \( \beta \) is used to represent consumer preference for product greenness. The greater the \( \beta \), the greater the promotion effect of greenness improvement on the demand (Gao et al., 2018). In addition, consumers exhibit RPE when buying green products (Kalwani et al., 1990). They make purchasing decisions according to the green product’s current retail and reference prices. If the retail price is above the reference price, consumers would feel losses (Kalyanaram and Winer, 1995); otherwise, they would feel gains (Bell and Lattin, 2000). According to Tversky and Kahneman (1991), RPE could be denoted as \( \delta (p - r) \), where \( p \) signifies the retail price, \( r \) represents the reference price, and \( \delta \) is the coefficient of RPE. The higher the \( \delta \), the more sensitive consumers are to the price difference between retail and reference prices (Zhang and Chiang, 2020).

<table>
<thead>
<tr>
<th>Notations</th>
<th>Explanations</th>
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<tbody>
<tr>
<td>( \beta )</td>
<td>Consumer preference coefficient of product greenness, ( 0 &lt; \beta &lt; 1 )</td>
</tr>
<tr>
<td>( \theta )</td>
<td>Product greenness degree</td>
</tr>
<tr>
<td>( \kappa )</td>
<td>The cost coefficient of green R&amp;D, ( \kappa &gt; 0 )</td>
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<tr>
<td>( m )</td>
<td>The retail margin</td>
</tr>
<tr>
<td>( r )</td>
<td>The reference price, ( 0 &lt; r \leq 1 )</td>
</tr>
<tr>
<td>( \delta )</td>
<td>The reference price effect coefficient, ( 0 &lt; \delta &lt; 1 )</td>
</tr>
<tr>
<td>( p )</td>
<td>The retail price of the green product</td>
</tr>
<tr>
<td>( q )</td>
<td>The demand of the green product</td>
</tr>
<tr>
<td>( w )</td>
<td>The wholesale price of the green product</td>
</tr>
<tr>
<td>( \varphi )</td>
<td>The sharing ratio that a retailer keeps under a cost-sharing contract, ( 0 &lt; \varphi &lt; 1 )</td>
</tr>
<tr>
<td>( \pi_r )</td>
<td>The profit of the retailer</td>
</tr>
<tr>
<td>( \pi_m )</td>
<td>The profit of the green manufacturer</td>
</tr>
</tbody>
</table>

Table 1. Notations and explanations.
Assumption 4. The demand function is assumed to be linear, similar to Ghosh and Shah (2015). A rise of retail price will reduce market demand, but the improvement of product greenness will increase market demand (Nielsen et al., 2020). Moreover, CRPE affects market demand from two directions. If the retail price exceeds the reference price, the market demand would decrease; if the reference price exceeds the retail price, the market demand would increase. Therefore, the demand function could be assumed as $q = 1 - \beta + \beta \theta - \delta (p - r)$.

4. Model
This section investigates two kinds of cooperative contracts (WPC and CSC) under different power structures considering CRPE. The optimal product greenness, pricing strategies and profit equilibria under each model are derived using the Stackelberg game method.

4.1 Wholesale-price contract (WPC)
In this case, the green manufacturer cooperates with the retailer via a contract with a wholesale price $w$. The optimal decision variables of WPC under retailer-led and manufacturer-led scenarios are discussed.

4.1.1 Retailer-dominated scenario (RW). In Model RW, the retailer is a market leader, while the manufacturer is a market follower. First, the retailer sets the retail price $p$ by determining a retail margin $m$, where $m = p - w$, and then the manufacturer decides on $w$ and product greenness $\theta$. Figure 2 exhibits the game sequence in Model RW.

The profit functions of the supply chain members are given as:

$$\pi_{m}^{RW} = wq - \kappa \theta^2,$$

$$\pi_{r}^{RW} = mq.$$  

The equilibrium solutions of Model RW can be obtained by backward induction. To make sure that the profit functions are concave, the condition of $\kappa > \frac{\beta^2}{4(1+\delta)}$ holds. The equilibrium solutions of Model RW are presented in Theorem 1.

**Theorem 1.** Under a retailer-led WPC, when $\kappa > \frac{\beta^2}{4(1+\delta)}$, the optimal product greenness, wholesale price and retail price are as follows:

$$\theta_{RW} = \frac{\beta (1 + r\delta)}{2[4(1+\delta)\kappa - \beta^2]},$$

$$w_{RW} = \frac{\kappa (1 + r\delta)}{4(1+\delta)\kappa - \beta^2},$$

$$p_{RW} = \frac{(1 + r\delta)[6(1 + \delta)\kappa - \beta^2]}{2(1 + \delta)[4(1+\delta)\kappa - \beta^2]}.$$  

Figure 2. Sequence of events in Model RW

- The retailer determines the retail margin
- The manufacturer decides on the wholesale price and product greenness
Theorem 1 shows the optimal green degree of product, wholesale and retail price in Model RW. It can be found that the product greenness ($\theta$) is affected by four parameters: the consumer preference coefficient of product greenness ($\beta$), the reference price ($r$), the coefficient of RPE ($\delta$) and the cost coefficient of green R&D ($\kappa$). Obviously, consumers’ green preference ($\beta$) and reference price ($r$) help to improve product greenness, while the other two parameters ($\delta$ and $\kappa$) inhibit the improvement of product greenness.

4.1.2 Manufacturer-dominated scenario (MW). In Model MW, the green manufacturer acts as a market leader, while the retailer plays as a market follower. The game sequence is shown in Figure 3. The green manufacturer firstly decides on $w$ and $\theta$, and then the retailer determines on $p$.

The profit functions of the supply chain members are given as:

\[
\pi_{m}^{MW} = wq - \kappa\theta^2, 
\]
\[
\pi_{r}^{MW} = (p - w)q. 
\]

The equilibrium solutions of Model MW can be obtained by backward induction. Under the condition of $\kappa > \frac{\beta^2}{8(1 + \delta)}$, the equilibrium solutions of Model MW are presented in Theorem 2.

Theorem 2. Under a manufacturer-led WPC, when $\kappa > \frac{\beta^2}{8(1 + \delta)}$, the optimal product greenness, wholesale and retail price are as follows:

\[
\theta_{MW} = \frac{\beta(1 + r\delta)}{8(1 + \delta)\kappa - \beta^2}, 
\]
\[
w_{MW} = \frac{4(1 + r\delta)\kappa}{8(1 + \delta)\kappa - \beta^2}, 
\]
\[
p_{MW} = \frac{6(1 + r\delta)\kappa}{8(1 + \delta)\kappa - \beta^2}. 
\]

Theorem 2 shows the optimal product greenness, wholesale and retail price of Model MW. Similarly, it can be found that the product greenness ($\theta$) is also affected by four parameters: $\beta$, $r$, $\delta$ and $\kappa$. Obviously, consumers’ green preference ($\beta$) and reference price ($r$) have positive influence on the improvement of product greenness ($\theta$), while the coefficient of green cost ($\kappa$) and the coefficient of RPE ($\delta$) have a negative effect on the improvement of product greenness.

4.2 Cost-sharing contract (CSC)

This section models and analyzes a CSC between a green manufacturer and a retailer. In general, the green manufacturer undertakes the full green R&D costs in green innovation activities. Under this contract, the retailer shares the green innovation cost in the proportion of $\varphi$ to incentive the green manufacturer to make green innovation, and the green manufacturer incurs the green innovation cost in the proportion of $1 - \varphi$. Here, $0 < \varphi < 1$. Next, we discuss the optimal decisions of CSC under different power structures.

![Sequence of events in Model MW](image-url)
4.2.1 Retailer-dominated scenario (RC). In Model RC, the retailer plays as a market leader, and the manufacturer acts as a market follower. The retailer is willing to share the green innovation cost in proportion to \( w \). Then, the green manufacturer would accept or reject the offer. If the green manufacturer accepts it, he would share the green innovation cost in the proportion of \( \frac{1}{C_0} \).

The game sequence of Model RC is shown in Figure 4.

The profit functions of the supply chain member are given as:

\[
\pi_{RC}^m = wq - (1 - \varphi) \kappa \theta^2, \tag{11}
\]

\[
\pi_{RC}^r = mq - \varphi \kappa \theta^2. \tag{12}
\]

The solutions of Model RC would be obtained by backward induction. Under the condition \( \kappa > \frac{\beta}{4(1+\delta)(1-\varphi)} \), the optimal solutions of Model RC are presented in Theorem 3.

**Theorem 3.** Under a retailer-led CSC, when \( \kappa > \frac{\beta}{4(1+\delta)(1-\varphi)} \), the optimal product greenness, wholesale price and retail margin are as follows:

\[
\theta_{RC} = \frac{\beta (1 - m - m\delta + r\delta)}{4(1 + \delta)(1 - \varphi) \kappa - \beta^2} \tag{13}
\]

\[
w_{RC} = \frac{2(1 - m - m\delta + r\delta)(1 - \varphi) \kappa}{4(1 + \delta)(1 - \varphi) \kappa - \beta^2} \tag{14}
\]

\[
m_{RC} = \frac{(1 + r\delta)[4(1 + \delta)(1 - \varphi)^2 \kappa - \beta^2(1 - 2\varphi)]}{(1 + \delta)[8(1 + \delta)(1 - \varphi)^2 \kappa - \beta^2(2 - 3\varphi)]} \tag{15}
\]

To explore the conditions under which the retailer is willing to provide a CSC, the profit of the retailer in CSC is compared with that in WPC in the retailer-led case. The analysis results are presented in Lemma 1.

**Lemma 1.** In the retailer-led game model, when \( \kappa > \frac{\beta}{4(1+\delta)(1-\varphi)} \), whether the retailer is willing to provide a CSC depends on the range of cost-sharing ratio:

1. if \( 0 < \varphi < \frac{1}{2} \), the retailer offers a CSC \( (\pi_{RC}^r > \pi_{RW}^r) \);
2. if \( \frac{1}{2} < \varphi < 1 \), the retailer does not offer a CSC \( (\pi_{RC}^r < \pi_{RW}^r) \).

Lemma 1 indicates that the retailer does not always choose to offer a CSC in the case of retailer-dominance. The contract choice decision of the retailer relies on the retailer’s profit comparison between WPC and CSC. Furthermore, the comparison result depends on the value of the cost-sharing ratio. Specifically, if the ratio is not large \( 0 < \varphi < \frac{1}{2} \), the retailer will choose a CSC over a WPC. However, once the ratio is large enough \( \frac{1}{2} < \varphi < 1 \), the retailer will choose a WPC not a CSC. It is intuitive because a greater ratio implies that the
retailer needs to bear a greater part of the green R&D cost, which will directly cut down the retailer’s profit in CSC. Thus, it enlightens enterprise managers that it is necessary to establish a reasonable ratio in adopting a CSC.

Next, we would explore what the optimal cost-sharing ratio would be when the retailer is willing to offer a CSC. The results are presented in Proposition 1.

**Proposition 1.** Under a retailer-led CSC, when \( \kappa > \frac{3\beta^2}{8(1+\delta)} \), the optimal cost-sharing ratio, product greenness, wholesale price and retail price are as follows:

\[
\varphi^{RC} = \frac{1}{3}, \quad (16)
\]

\[
\theta^{RC} = \frac{6\beta(1 + r\delta)}{32(1 + \delta)\kappa - 9\beta^2}, \quad (17)
\]

\[
u^{RC} = \frac{8(1 + r\delta)\kappa}{32(1 + \delta)\kappa - 9\beta^2}, \quad (18)
\]

\[
p^{RC} = \frac{3(1 + r\delta)[8(1 + \delta)\kappa - \beta^2]}{(1 + \delta)[32(1 + \delta)\kappa - 9\beta^2]}. \quad (19)
\]

Proposition 1 shows the optimal equilibrium results when the retailer is willing to provide a CSC. According to Proposition 1, the optimal ratio of the retailer-led situation is determined as \( \varphi = \frac{1}{3} \), which can ensure the retailer’s maximum profit. It suggests that no matter what the green R&D cost is, the retailer always chooses to bear one-third of the total cost of green R&D. To unify the equilibrium solutions under four models and facilitate the later comparative analysis, in the subsequent parts, we would use the optimal solutions of Model RC (i.e. the optimal solutions when \( \varphi = 1/3 \)).

4.2.2 Manufacturer-dominated scenario (MC). In Model MC, the green manufacturer acts as a market leader, and the retailer plays as a market follower. The retailer is willing to share the green innovation cost in proportion to \( \varphi \). The game sequence of Model MC is shown in Figure 5.

The profit functions of the supply chain members are given as:

\[
\pi^{MC}_m = wq - (1 - \varphi)\kappa\theta^2, \quad (20)
\]

\[
\pi^{MC}_r = (p - w)q - \varphi\kappa\theta^2. \quad (21)
\]

The solutions of Model MC could be derived by backward induction. Under the condition of \( \kappa > \frac{3\beta^2}{16(1+\delta)} \), the optimal solutions of Model MC are presented in Theorem 4.

**Theorem 4.** Under a manufacturer-led CSC, when \( \kappa > \frac{3\beta^2}{16(1+\delta)} \), the optimal cost-sharing ratio, product greenness, wholesale price and retail price are as follows:

![Figure 5. Sequence of events in Model MC](image)
5. Comparative analysis

Now, we focus on comparing the green degree of product, demand and supply chain members’ profits in WPC and CSC in different market power structures to study which cooperative contract is more beneficial to upgrade the greenness of product and to examine the influence of power structure on decision variables in different cooperative contracts.

5.1 Comparison of product greenness and demand under two contracts

Corollary 1. Under the condition of $\kappa > \frac{3\beta^2}{8(1+r\delta)}$, the comparison results of product greenness and demand in WPC and CSC are as follows:

<table>
<thead>
<tr>
<th>Model</th>
<th>RW</th>
<th>Model MW</th>
<th>Model RC</th>
<th>Model MC</th>
</tr>
</thead>
</table>
| $\varphi$ | $-\beta(1+r\delta)$ | $\frac{3\beta}{8(1+r\delta)}$ | $\frac{1}{3}$ | $2\beta^2$ |}

Table 2.
The equilibrium solutions for the four models
\( \theta^{RC} > \theta^{RW}, \theta^{MC} > \theta^{MW}; \)

\( q^{RC} > q^{RW}, q^{MC} > q^{MW}. \)

**Corollary 1** shows that the product greenness and demand of the CSC are superior to those of the WPC regardless of whether the retailer or the manufacturer dominates. It suggests that the CSC has a more remarkable impact on upgrading product greenness than the WPC. It is an intuitive finding because the manufacturer undertakes the entire green R&D cost alone in a WPC, while the retailer takes initiatives to share some costs of green R&D for the manufacturer in a CSC, which lowers the green manufacturer’s burden and motivates him to upgrade the product greenness. In addition, for environmentally conscious consumers, the improvement of product greenness helps to pull consumer demand. As a result, the demand in the CSC is also greater than that in the WPC.

5.2 **Comparison of supply chain members’ profit under two contracts**

**Corollary 2.** Under the condition of \( \kappa > \frac{3\rho^2}{8(1+\delta)} \), the profit comparison results of supply chain members in the WPC and the CSC are as follows:

\( \pi^{RC}_r > \pi^{RW}_r, \pi^{MC}_r > \pi^{MW}_r; \)

\( \pi^{RC}_m < \pi^{RW}_m, \pi^{MC}_m > \pi^{MW}_m. \)

**Corollary 2** demonstrates that for the retailer, the profit under CSC is always greater than that under WPC, regardless of whether the retailer is dominant or the manufacturer is dominant. But interestingly, for the manufacturer, the profit relationship between the two contracts depends on power structure. Specifically, if the retailer dominates, the manufacturer’s profit under WPC exceeds that under CSC. However, if the manufacturer dominates, the manufacturer’s profit under CSC exceeds that under WPC. It further suggests that the manufacturer may not always accept CSC provided by the retailer if the retailer is dominant, but will accept it if the manufacturer is dominant.

The reasons for this situation are mainly attributed to the following two aspects: First, different power structures directly result in different decision order of each supply chain member, which would affect the determination of the optimal price, product greenness level, cost-sharing ratio and profit. Especially when the retailer is in a dominant position, the strategies formulated by the retailer is always aimed at maximizing her own profit and often at the cost of the manufacturer’s profit. Second, different market power structures represent different market bargaining power. Generally, the market leader has first-mover advantages and has greater negotiation power when formulating cooperative contracts to determine more favorable cooperation terms. For example, under a manufacturer-led CSC, the manufacturer would have a greater say in the market when negotiating with the retailer about the ratio and can strive for greater profit margin by making the retailer bear a larger share of green R&D costs. Thus, when the manufacturer dominates, the manufacturer is more likely to choose CSC over WPC.

Even though **Corollary 1** shows that CSC outperforms WPC in improving the green degree and promoting sales, only when the manufacturer dominates, the CSC can be truly implemented. That is, in the manufacturer-dominant case, CSC can achieve profit Pareto improvements for both two supply chain members, thus achieving a win-win situation. Because when the retailer dominates, the manufacturer would prefer WPC instead of CSC for its own profit maximization, and only when the manufacturer dominates, the manufacturer would be inclined to choose CSC.
5.3 Comparison of wholesale and retail price under two contracts

Corollary 3. Under the condition of \( \kappa > \frac{3p}{8(1+\delta)} \), the comparison results of wholesale and retail prices under WPC and CSC are as follows:

1. \( w^{RC} > w^{RW}, \ p^{RC} > p^{RW} \).
2. \( w^{MC} > w^{MW}, \ p^{MC} > p^{MW} \).

Corollary 3 demonstrates that both the wholesale and retail price under CSC exceed those under WPC regardless of the retailer or manufacturer dominates. It suggests that the double marginalization problem in CSC is more serious than that in WPC. These results of Corollary 1 help us understand the reasons for the double marginalization problem.

As Corollary 1 shows, the product greenness of CSC outperforms that of WPC. A high green degree means that the manufacturer should increase green R&D investment, which would force the manufacturer to wholesale products with high greenness at high prices. The retailer, in turn, would retail products via high retail prices to offset the high wholesale price to make a profit. Overall, it is the increased product greenness in CSC that induces the green manufacturer to set high wholesale prices, which further prompts the retailer to set high retail prices. The rise of these two prices makes the double marginalization problem in CSC worse than that in WPC.

5.4 Comparison of product greenness and demand under different power structures

Corollary 4. Under the condition of \( \kappa > \frac{3p}{8(1+\delta)} \), the comparison results of product greenness and demand under the retailer-dominated and the manufacturer-dominated Stackelberg games are:

1. \( \theta^{MW} < \theta^{RW}, \ q^{MW} < q^{RW} \).
2. \( \theta^{MC} < \theta^{RC}, \ q^{MC} < q^{RC} \).

Corollary 4 shows that under any single cooperative contract, both product greenness and demand dominated by the retailer are higher than those dominated by the manufacturer. In any single contract, the retailer-led situation is more conducive to improving the product greenness and demand than the manufacturer-led situation. It is mainly because the retailer has a greater advantage over the manufacturer in terms of being closer to consumers. Therefore, the retailer can better obtain information about consumers’ preferences for product greenness and demand. After capturing the information of consumers, in the case of retailer dominance, the retailer can first set more reasonable retail price and then guide the manufacturer to determine the greenness level in line with consumers’ expectations, to better meet the green needs of consumers. This well explains why, in reality, some giant retailers, such as Walmart and Carrefour, can bring greener products to the market and promote green products to consumers better when they are market leaders.

5.5 Comparison of sharing ratio under different power structures

Corollary 5. Under the condition of \( \kappa > \frac{3p}{8(1+\delta)} \), the comparison results of the cost-sharing ratio in the retailer-led and manufacturer-led cases are:

1. \( \varphi^{MC} < \varphi^{RC} \).
\[
\frac{\partial \gamma_{RC}}{\partial \beta} = 0, \frac{\partial \gamma_{RC}}{\partial \kappa} = 0, \text{ and } \frac{\partial \gamma_{RC}}{\partial r} = 0;
\]

\[
\frac{\partial \gamma_{MC}}{\partial \beta} > 0, \frac{\partial \gamma_{MC}}{\partial \kappa} < 0, \text{ and } \frac{\partial \gamma_{MC}}{\partial r} < 0.
\]

Corollary 5 suggests that the cost-sharing ratio in the manufacturer dominance case is less than that in the retailer dominance case. This suggests that when the retailer is as a leader, the retailer would share a larger portion of green R&D costs for the green manufacturer. This is intuitive because, as shown in Corollary 4, under CSC, both the product greenness and demand in the retailer-led case outperform those in the manufacturer-led case. On the one hand, higher demand in the retailer-led situation would bring more profits to the retailer, thus giving the retailer sufficient capital to share larger part of the green R&D cost. On the other hand, the high green degree in the retailer-led situation would also encourage the retailer to be more willing to shoulder the R&D cost to better meet consumers’ green demand.

Interestingly, Corollary 5 also indicates that the two sharing ratios are affected differently by different coefficients. The retailer-dominated sharing ratio is a constant, which is not affected by the consumer preference coefficient of product greenness, the coefficient of green R&D cost and the CRPE coefficient. But the manufacturer-dominated sharing ratio is affected by these three coefficients. Specifically, the greater the preference coefficient of consumers for product greenness, the greater the sharing ratio; however, the higher the R&D cost or the greater the CRPE, the smaller the sharing ratio. The improvement of consumers’ preference for the greenness level can promote the retailer to share a larger part of green R&D costs, while the increase in green costs and the improvement in CRPE will have a certain inhibitory effect on the retailer to share the green R&D costs. It is mainly because the improvement of the first coefficient can bring more profits to the retailer, while the improvement of the last two coefficients is not conducive to improving the retailer’s profit.

6. Numerical analysis

This section conducts numerical analysis to verify the above theoretical results. In addition, the impact of CRPE on product greenness, demand and profit is examined, respectively. Based on existing green supply chain literature (Ma et al., 2019a, b; Nielsen et al., 2020) on the assignment of relevant parameters and observations of the real-world green consumer market, the parameters are assigned as follows: \(\beta = 0.8\), \(\kappa = 0.5\), and \(r = 1\). Through a series of numerical calculations, it is verified that the values of these parameters satisfy all the inequality constraints in the above four models, which not only guarantees that the profit function is concave but also guarantees the existence of optimal solutions.

6.1 The impact of CRPE on product greenness

Corollaries 1 and 4 suggest that CSC is more effective than WPC in improving product greenness. Under a single contract, the retailer-dominated situation is also more beneficial to upgrading the green degree of product than the manufacturer-dominated situation. Next, numerical analysis is conducted to verify these results and investigate the influence of CRPE on product greenness. Figure 6 shows the numerical analysis results.

Figure 6 shows that \(\theta_{RC} > \theta_{RW}\) and \(\theta_{MC} > \theta_{MW}\), which verifies the finding that CSC goes beyond WPC in improving product greenness, whether the retailer is dominant or the manufacturer is dominant. In addition, Figure 6 also indicates that \(\theta_{RW} > \theta_{MW}\) and \(\theta_{RC} > \theta_{MC}\), which verifies the finding that under any single cooperative contract, the product greenness in the retailer dominance case exceeds that in the manufacturer dominance case.

Moreover, the product greenness decreases in the CRPE coefficient, which indicates that CRPE hinders the improvement of product greenness. It is mainly because CRPE will make consumers consider the gain or loss from purchasing green products. In specific, if the price of
green product exceeds the price of reference product (e.g. a nongreen product with the same functional attributes), consumers will feel that the green product is not worth the price, thereby reducing the green product’s demand. But if the price of green product is below the price of reference product, consumers will feel that the values of green product are more than what they are worth, thus increasing the green product’s demand. However, the above two situations hinder the improvement of product greenness. If the green price is high, the reduction of consumer demand will directly reduce the green manufacturer’s profit, which would lead to less incentive to upgrade greenness. Similarly, in the second case of low green price, which can bring relatively more demand, thus increasing the profit of the green manufacturer. But the low green price could not cover the high R&D cost, which would force the manufacturer to be reluctant to upgrade the green product.

6.2 The impact of CRPE on retail price

Corollary 3 reveals that the retail price under CSC exceeds that under WPC. Next, we would conduct a numerical analysis to verify this finding and investigate the influence of CRPE on the retail price. The analysis result is shown in Figure 7.
From Figure 7, we can know that $p_{RC} > p_{RW}$ and $p_{MC} > p_{MW}$, which verifies the finding that the retail price in CSC exceeds that in WPC regardless of the retailer-led or the manufacturer-led situation. This further illustrates that the CSC would aggravate the problem of double marginalization.

Intuitively, the retail price decreases in the coefficient of CRPE, as shown in Figure 7. This means that as the CRPE coefficient increases, the retailer should lower the green product’s retail price to grasp more profits. It is because when the coefficient of CRPE increases, consumers value the comparison with the retail price of reference products when buying green products, and a slight difference between prices would lead to a large change in demand. Thus, a rational retailer would lower the green product’s retail price to obtain more demand, which further demonstrates the importance of CRPE in the price decision of the retailer.

6.3 The impact of CRPE on wholesale price

As with the relationship between the retail prices mentioned above, Corollary 3 also suggests that the wholesale price in CSC exceeds that in WPC. To verify this result, we conduct the following numerical analysis and examine the influence of CRPE on the wholesale price. Figure 8 shows the numerical results.

Figure 8 indicates that $w_{RC} > w_{RW}$ and $w_{MC} > w_{MW}$, which verifies the finding that the wholesale price in CSC exceeds that in WPC whether the retailer dominates or the manufacturer dominates. This means that although CSC could generate higher green degree, the double marginalization in CSC is more severe than that in WPC because of high wholesale and retail prices.

Similarly, the wholesale price also decreases in the CRPE coefficient, as shown in Figure 8. This indicates that with the increase of CRPE coefficient, manufacturer’s wholesale price will decrease. Two main reasons contribute to this result. First, the increase in CRPE coefficient means that consumers value the price difference between green products and reference products. A rational manufacturer will take this into account and charge the retailer a low wholesale price to seek greater market share of green products. Second, the increase in CRPE coefficient would reduce the product greenness, and a low product greenness corresponds to a low R&D expenditure. As a result, the green manufacturer would also be willing to charge lower wholesale prices.
7. Managerial insights
This section discusses the managerial insights of our findings, which can provide effective guidance on the choice of cooperative contracts between supply chain members under different market power structures when facing environmentally conscious consumers who have RPE.

7.1 Insight 1: attention to CRPE
CRPE has a crucial role in green supply chain, and it directly affects the green product’s retail price and thus indirectly affects wholesale price, product greenness and profit. Hence, before making green decisions and pricing strategies, the enterprise managers need to evaluate the level of CRPE by market surveys. In particular, if CRPE is relatively large, the enterprise managers need to reduce their wholesale and retail prices to attract more consumers. Besides, our results also show that CRPE would reduce the cost-sharing ratio when the manufacturer dominates. For this reason, before establishing the terms of CSC, enterprise managers need to learn from the opinions of experts to understand how CRPE affects cooperative contracts.

7.2 Insight 2: concern about market power structure
Different market power structures directly lead to different decision order of each supply chain member, which would affect the determination of optimal price, product greenness level, cost-sharing ratio and profit. Specifically, our results show that regardless of the contract, the retailer-dominated situation always leads to a higher level of product greenness. This gives retail managers a valuable enlightenment that they should give play to the advantages of the market leader and capture consumers’ preference information to guide the production of products with higher levels of greenness. Besides, the manufacturer’s profit differs under different market power structures, which indirectly affects the manufacturer’s acceptance of CSC. In the retailer-led situation, the manufacturer would reject CSC. However, in the manufacturer dominance case, the manufacturer would accept CSC. It suggests that enterprise managers need to pay attention to the market power of each enterprise when choosing cooperative contracts.

7.3 Insight 3: option of a cost-sharing contract
CSC outperforms WPC in upgrading product greenness and promoting demand under CRPE. This finding can well explain why in the real green innovation cooperative activities, most enterprises adopt a typical CSC over a simple WPC. Additionally, the results also indicate that in the manufacturer-led case, a CSC can make a bigger pie and achieve profit Pareto improvement of supply chain members. This enlightens enterprise managers that they should give priority to a CSC rather than a WPC when manufacturing enterprises dominate the market. Only in this way can enterprises truly achieve win-win and ensure the realization of green R&D innovation cooperation.

8. Conclusion
This study considers a dyadic green supply chain wherein a green manufacturer produces and sells green products to a retailer. We examine which type of cooperative contract is more effective to upgrade the greenness level and improve demand in a green supply chain with CRPE under two different market power structures. Further, the influence of market power structure and CRPE on decision variables of different cooperative contracts is examined. Key findings and management insights are summarized below.
First, under CRPE, CSC outperforms WPC in improving product greenness and promoting demand. Especially when the manufacturer is dominant, both supply chain members could achieve the Pareto improvement in profits under CSC.

Second, market power structure has a crucial impact on decision variables of different contracts. Specifically, under a single contract, the product greenness and demand under the retailer’s dominant situation are higher than those under the manufacturer’s dominant situation. In addition, the ratio under CSC led by the retailer is larger than that led by the manufacturer.

Third, CRPE is detrimental to the improvement of product greenness, but it can alleviate the problem of double marginalization, that is, it can lower wholesale and retail prices and thus is beneficial to the improvement of consumer surplus. However, CRPE will reduce the proportion of R&D cost shared by the retailer to the manufacturer under CSC.

This study has some deficiencies for further research. Firstly, this study assumes that there exists symmetric information in the supply chain, but information asymmetry is common in practice. Therefore, the choice of cooperative contract under information asymmetry is worthwhile to explore. Secondly, this study primarily concentrates on the research of CRPE in a single period, but consumers often refer to not only the prices of other similar products in the current period, but also the prices of the green product in other periods when making purchase decisions. Thus, considering CRPE in two-period or multiperiod models is our future research direction. Finally, this study assumes that consumers have environmental awareness and are sensitive to product greenness. However, in reality, there exist some consumers with weak environmental awareness, who care little about the green attributes of the product and only focus on the price and function of the product. Future studies considering different consumer market segments and exploring the influence of different types of consumers on decision-making of cooperative contract selection will be more realistic.

References


From the above Hessian matrix, we can obtain that 
\[ \frac{\partial^2 \pi_{RW}}{\partial \beta \partial \theta} = -2 - 2\delta < 0, \quad \frac{\partial^2 \pi_{RW}}{\partial \theta \partial \theta} = -2\kappa < 0, \]
and \( |H_{RW}| = 4(1 + \delta)\kappa - \beta^2 \). To ensure that the Hessian matrix is negative definite, it needs to satisfy that \( 4(1 + \delta)\kappa - \beta^2 > 0 \), that is, \( \kappa > \frac{\beta^2}{4(1 + \delta)} \). Combined with the first-order conditions \( \frac{\partial \pi_{RW}}{\partial \omega} = 0 \) and \( \frac{\partial \pi_{RW}}{\partial \theta} = 0 \), the optimal wholesale price and product greenness can be derived: \( \omega = \frac{2(1 - m - m\delta + \delta\kappa)}{4(1 + \delta)\kappa - \beta^2} \) and 
\[ \theta = \frac{\beta(1 - m - m\delta + \delta\kappa)}{4(1 + \delta)\kappa - \beta^2}. \]
Then, substitute the optimal \( \omega \) and \( \theta \) into \( \pi_{RW}^* \) and take its second derivative relative to \( m \), we can gain that 
\[ \frac{\partial^2 \pi_{RW}}{\partial m^2} = \frac{4(1 + \delta)\kappa}{\beta^2 - 4(1 + \delta)\kappa} < 0. \]
Hence, \( \pi_{RW}^* \) is concave in \( m \). Through solving the function that \( \frac{\partial \pi_{MW}}{\partial m} = 0 \), we can gain that \( m = \frac{1 + \delta}{2\beta} \). Then, substitute the optimal \( m \) into \( \omega \) and \( \theta \), we can get Theorem 1. \( \square \)

Proof: Theorem 2.

The second derivative of \( \pi_{MW}^* \) to \( \rho \) is 
\[ \frac{\partial^2 \pi_{MW}}{\partial \rho^2} = -2 - 2\delta < 0. \]
Hence, \( \pi_{MW}^* \) is concave in \( \rho \). From the first-order condition of \( \pi_{MW}^* \) relative to \( \rho \), the optimal reaction is derived: 
\[ \rho = \frac{1 + \omega + \beta + \delta + \beta\delta}{2 + 2\delta}. \]
Then, substitute \( \rho \) into \( \pi_{MW}^* \) and take the first and second derivatives to \( \omega \) and \( \theta \) to get the Hessian matrix as:

\[ H_{MW} = \begin{bmatrix} -1 - \delta & \frac{\beta}{2} \\ \frac{\beta}{2} & -2\kappa \end{bmatrix}. \]

From the above Hessian matrix, we can obtain that \( \frac{\partial^2 \pi_{MW}}{\partial \omega \partial \theta} = -2 - 2\delta < 0, \quad \frac{\partial^2 \pi_{MW}}{\partial \theta \partial \theta} = -2\kappa < 0, \)
and \( |H_{MW}| = 2(1 + \delta)\kappa - \beta^2 \). To make sure that the Hessian matrix is negative definite, it needs to satisfy that 
\( 2(1 + \delta)\kappa - \beta^2 > 0 \), that is, \( \kappa > \frac{\beta^2}{2(1 + \delta)} \). Combined with the first-order conditions \( \frac{\partial \pi_{MW}}{\partial \omega} = 0 \) and \( \frac{\partial \pi_{MW}}{\partial \theta} = 0 \), the optimal wholesale price and product greenness could be derived: \( \omega = \frac{4(1 + \delta)\kappa}{8(1 + \delta)\kappa - \beta^2} \) and 
\[ \theta = \frac{\beta(1 + \delta)}{8(1 + \delta)\kappa - \beta^2}. \]
Then, substitute the optimal \( \omega \) and \( \theta \) into \( \rho \), we can get Theorem 2. \( \square \)

Proof: Theorem 3.

Using reverse induction, the optimal wholesale price and green degree could be derived. Then, the first and second derivatives of \( \pi_{RC}^* \) to \( \omega \) and \( \theta \) are taken to obtain the Hessian matrix:

\[ H_{RC} = \begin{bmatrix} -2 - 2\delta & \frac{\beta}{2} \\ \frac{\beta}{2} & -2\kappa(1 - \varphi) \end{bmatrix}. \]

From the above Hessian matrix, we can obtain that \( \frac{\partial^2 \pi_{RC}}{\partial \omega \partial \theta} = -2 - 2\delta < 0, \quad \frac{\partial^2 \pi_{RC}}{\partial \theta \partial \theta} = -2\kappa(1 - \varphi) < 0, \)
and \( |H_{RC}| = 2(1 + \delta)\kappa - \beta^2 \). To make sure that the Hessian matrix is negative definite, it needs to satisfy that 
\( 2(1 + \delta)\kappa - \beta^2 > 0 \), that is, \( \kappa > \frac{\beta^2}{2(1 + \delta)} \). Combined with the first-order conditions \( \frac{\partial \pi_{RC}}{\partial \omega} = 0 \) and \( \frac{\partial \pi_{RC}}{\partial \theta} = 0 \), the optimal wholesale price and product greenness could be derived: \( \omega = \frac{4(1 + \delta)\kappa}{8(1 + \delta)\kappa - \beta^2} \) and 
\[ \theta = \frac{\beta(1 + \delta)}{8(1 + \delta)\kappa - \beta^2}. \]

Using reverse induction, the optimal wholesale price and green degree could be derived. Then, the first and second derivatives of \( \pi_{RC}^* \) to \( \omega \) and \( \theta \) are taken to obtain the Hessian matrix:

\[ H_{RC} = \begin{bmatrix} -2 - 2\delta & \frac{\beta}{2} \\ \frac{\beta}{2} & -2\kappa(1 - \varphi) \end{bmatrix}. \]
$|H^{RC}| = 4(1+\delta)(1−\varphi)κ−β^2$. To ensure that the Hessian matrix is negative definite, it needs to satisfy that $4(1+\delta)(1−\varphi)κ−β^2 > 0$, that is, $κ > \frac{β^2}{4(1+\delta)(1−\varphi)}$. Combined with the first-order conditions $\frac{∂π^{RC}_r}{∂κ} = 0$ and $\frac{∂π^{RC}_m}{∂κ} > 0$, the optimal wholesale price and product greenness are obtained: $w = \frac{2(1+\delta)(1−\varphi)κ}{4(1+\delta)(1−\varphi)κ−β^2}$ and $θ = \frac{(1−κ−δκ+δκ+βκ)}{4(1+\delta)(1−\varphi)κ−β^2}$. Then, substitute the optimal $w$ and $θ$ into $π^{RC}_m$ and take its second derivative relative to $κ$, we can gain that $\frac{∂^2π^{RC}_m}{∂κ^2} = \frac{-2(1+\delta)(1−\varphi)κ−β^2}{4(1+\delta)(1−\varphi)κ−β^2}$. To ensure that $π^{RC}_m$ is concave in $κ$, it needs to satisfy that $8(1+\delta)(1−\varphi)κ−β^2(2−3\varphi) > 0$, that is $κ > \frac{β^2(2−3\varphi)}{8(1+\delta)(1−\varphi)}$. Because $\frac{β^2(2−3\varphi)}{8(1+\delta)(1−\varphi)} < 0$, the prerequisites need to satisfy that $κ > \frac{β^2}{8(1+\delta)(1−\varphi)}$. Submitting the optimal $κ$ into $π^{RC}_m$, we can gain that $π^{RC}_m = \frac{(1+\delta)(1−\varphi)κ−β^2(1−2\varphi)}{8(1+\delta)(1−\varphi)κ−β^2}$.

### Proof. Lemma 1.

In the case of retailer dominance, the retailer’s profit in CSC is compared with that in WPC. From Theorem 1, we can know that $π^{RW}_r = \frac{(1+\delta)(1−\varphi)κ−β^2}{2(1+\delta)(1−\varphi)κ−β^2}$ with the condition of $κ > \frac{β^2}{8(1+\delta)(1−\varphi)}$. Since $\frac{∂^2π^{RW}_r}{∂κ^2} = \frac{(1+\delta)(1−\varphi)κ−β^2}{8(1+\delta)(1−\varphi)κ−β^2}$, we can gain that $m = \frac{(1+\delta)(1−\varphi)κ−β^2}{δκ(1−\varphi)}$. Substituting the values of $m$, $κ$, and $w$ into the function of $π^{RC}_m$ and $π^{RC}_r$, we can gain that $π^{RC}_m = \frac{(1+\delta)(1−\varphi)κ−β^2}{8(1+\delta)(1−\varphi)κ−β^2}$. A s0 < $w_0$, the optimal wholesale price and product greenness are obtained:

### Proof. Proposition 1.

According to the results of Theorem 3, we take the second derivative of $π^{RC}_r$ relative to $κ$, we can gain that $\frac{∂^2π^{RC}_r}{∂κ^2} = \frac{2(1+\delta)(1−\varphi)κ−β^2}{8(1+\delta)(1−\varphi)κ−β^2}$. To ensure that $π^{RC}_r$ is concave in $κ$, it needs to satisfy that $κ > \frac{β^2}{8(1+\delta)(1−\varphi)}$. As $0 < ϕ < 1$, through solving the function that $\frac{∂^2π^{RC}_r}{∂κ^2} = 0$, we can gain that $ϕ = \frac{1}{2}$ into the conditions of $κ > \frac{β^2}{8(1+\delta)(1−ϕ)}$ and $κ > \frac{β^2}{8(1+δ)(1−ϕ)}$. We can gain that $κ > \frac{β^2}{8(1+δ)(1−ϕ)}$ and $κ > \frac{β^2}{8(1+δ)(1−ϕ)}$. Because $\frac{3β^2}{8(1+δ)} = \frac{3β^2}{8(1+δ)} > 0$, it needs to satisfy that $κ > \frac{3β^2}{8(1+δ)}$. Submitting the optimal $ϕ$ into $m$, $w$, and $θ$, we can get Proposition 1.

### Proof. Theorem 4.

The second derivative of $π^{MC}_r$ to $ϕ$ is $\frac{∂^2π^{MC}_r}{∂ϕ^2} = −2−2δ < 0$. Hence, $π^{MC}_r$ is concave in $ϕ$. From the first-order condition of $π^{MC}_r$ to $ϕ$, the reaction function is derived: $ϕ = \frac{1+δ+κ+δκ+βκ}{2+2δ}$. Then, substitute $ϕ$ into $π^{MC}_m$ and take the first and second derivatives to $w$ and $θ$ to obtain the Hessian matrix:

$$H^{MC} = \begin{bmatrix} -1−δ & \frac{β}{2} \\ \frac{β}{2} & -2κ(1−ϕ) \end{bmatrix}.$$  \hspace{1cm} (A4)
satisfy that $5\beta^2 - 16(1 + \delta)\kappa(1 + 2\varphi) < 0$, that is, $\kappa > \frac{5\beta^2}{16(1 + \delta)(1 + 2\varphi)}$. Through solving the function that 
$\frac{\partial\varphi}{\partial\varphi} = 0$, we can gain that $\varphi = \frac{\beta}{8\kappa(1 + 16\delta)}$. Submitting the value of $\varphi$ into the conditions, we can get that 
$\kappa > \frac{2\beta^2}{16(1 + \delta)\kappa - \beta}$; and $\kappa > \frac{5\beta^2}{8\beta^2 + 8(1 + \delta)\kappa}$; that is, $\kappa > \frac{5\beta^2}{16(1 + \delta)}$. Submitting the optimal $\varphi$ into $w$, $\theta$ and $\beta$, we can get Theorem 4. □

Proof. Corollary 1.

Because $\frac{3\beta^2}{8(1 + \delta)} > \frac{\beta}{8(1 + \delta)} > \frac{3\beta^2}{8(1 + \delta)} > \frac{\beta}{8(1 + \delta)}$, it needs to satisfy $\kappa > \frac{3\beta^2}{8(1 + \delta)}$. Under this condition, we can obtain that

$$
q^{RC} - q^{RW} = \frac{\beta(1 + r\delta)}{32(1 + \delta)\kappa - 9\beta^2(1 + r\delta) - \beta^2} > 0, \quad q^{MC} - q^{MW} = \frac{\beta^2(1 + r\delta)\kappa - 9\beta^2(1 + r\delta) - \beta^2}{4\kappa(1 + \delta)\kappa - \beta} > 0.
$$

Proof. Corollary 2.

Because $\frac{3\beta^2}{8(1 + \delta)} > \frac{\beta}{8(1 + \delta)} > \frac{3\beta^2}{8(1 + \delta)} > \frac{\beta}{8(1 + \delta)}$, it needs to satisfy $\kappa > \frac{3\beta^2}{8(1 + \delta)}$. Under this condition, we can obtain that $\pi^{RC} - \pi^{RW} = \frac{(\beta + r\delta)^2}{2[32(1 + \delta)\kappa - 9\beta^2(1 + r\delta) - \beta^2]} > 0, \quad \pi^{MC} - \pi^{MW} = \frac{\beta^2(1 + r\delta)^2}{16(1 + \delta)\kappa - \beta^2} > 0,

and $\pi^{MC} - \pi^{MW} = \frac{\beta^2(1 + r\delta)^2}{8(1 + \delta)\kappa - \beta^2} > 0$. □

Proof. Corollary 3.

Given the condition of $\kappa > \frac{3\beta^2}{8(1 + \delta)}$, we can gain that $w^{RC} - w^{RW} = \frac{\beta(1 + r\delta)}{32(1 + \delta)\kappa - 9\beta^2(1 + r\delta) - \beta^2} > 0, \quad \upsilon^{MC} - \upsilon^{MW} = \frac{6\beta^2(1 + \delta) - 8\beta^2(1 + \delta)\kappa + 29\beta^2(1 + \delta)^2}{4} > 0$, and $w^{RC} - w^{RW} = \frac{\beta^2(1 + r\delta)}{[32(1 + \delta)\kappa - 9\beta^2(1 + r\delta) - \beta^2]} > 0$. □


Given the condition of $\kappa > \frac{3\beta^2}{8(1 + \delta)}$, we can obtain that $\theta^{MC} - \theta^{MW} = \frac{\beta^2(1 + r\delta)}{16(1 + \delta)\kappa - \beta^2} < 0, \quad \theta^{RC} - \theta^{RW} = \frac{32(1 + \delta)\kappa - 9\beta^2(1 + r\delta) - \beta^2}{4\kappa(1 + \delta)\kappa - \beta^2} < 0, \quad \theta^{RC} - \theta^{RW} = \frac{\beta(1 + r\delta)}{8\kappa(1 + \delta)\kappa - \beta^2} < 0$.

Proof. Corollary 5.

Given the condition of $\kappa > \frac{3\beta^2}{8(1 + \delta)}$, we can gain that $\varphi^{MC} - \varphi^{RC} = \frac{\beta^2(1 + 16\delta)\kappa}{48(1 + \delta)\kappa} < 0, \quad \varphi^{MC} - \varphi^{RC} = \frac{\beta^2(1 + 16\delta)\kappa}{(16e + 168e)^2} < 0, \quad \varphi^{MC} - \varphi^{RC} = \frac{\beta^2(1 + 16\delta)\kappa}{(16e + 168e)^2} < 0$. □

Corresponding author
Jinjin Liu can be contacted at: 1531107@tongji.edu.cn

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