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Contracting green product supply chains considering marketing efforts in the circular economy era

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ABSTRACT

Green product design is an effective instrument for achieving a circular economy. To promote green product development, downstream retailers often enter into contracts with upstream manufacturers and market green products. This study considers a decentralized green product supply chain comprising of a manufacturer and a retailer, who determine the green level of the product and the exerted marketing effort level, respectively. We specifically consider two widely-adopted contracting formats: contracting designing (CD) and contracting marketing (CM). Under CD format, we examine three contract strategies for such the green product supply chain, namely, price-only (Strategy PO), cost-sharing (Strategy CS), and revenue-sharing (Strategy RS) game models. By comparing these strategies, we find that product greening level enhancement can benefit firms when the marketing effort effect is high or low. However, when the marketing effort effect is moderate, product greening level improvement does not necessarily lead to higher payoffs for firms. Furthermore, the equilibrium strategy for the manufacturer and retailer is either Strategy CS or RS depending on certain conditions. Specifically, when the marketing effort effect is low, the manufacturer and retailer prefer Strategy RS. On the contrary, when the marketing effort effect is high, Strategy CS is the equilibrium strategy for the manufacturer and retailer. We also investigate the corresponding contracts under CM format. Interestingly, compared with CM format, the whole supply chain always benefits more under CD format. We further extend to the case that the retailer is risk averse, and the whole supply chain can still be better off with cost-sharing contract under CD format in certain conditions. In addition, we find that the retailer's risk aversion behavior may improve the performance of the whole supply chain under CD and CM formats. Our results not only complement the conventional understanding of supply chain contract theory, but also generate important managerial implications for managers in implementing green operation strategies by choosing the appropriate contracting format and corresponding contract.

1. Introduction

With the development of the society and improvement of environmental consciousness, the concept of circular economy has elicited increasing attraction in recent years (Wu and Pagell, 2011). Countries worldwide have committed to reducing the impact of economic development on natural environment, establishing a resource-saving and environment-friendly society and striving to achieve sustainable development (Wu et al., 2014). Several regions have promulgated a series of laws and regulations to construct a circular economy-based sustainable supply chain management system that focuses on environmental issues and promotes the development of circular economy through green product design, green manufacturing, green recycling, reverse logistics, and other activities (Ji et al., 2017; Linton et al., 2017; Li et al., 2017, 2019c). By emphasizing the coordinated development of the economy and ecological environment, sustainable supply chain management is now regarded as an effective tool for achieving a circular economy (Sun et al., 2019).

Consumers' green awareness is a key market-driven factor that promotes the sustainable supply chain, and their demand for green products has elicited extensive attention. An increasing number of consumers prefer to purchase pollution-free and environmental-friendly green products (Li et al., 2020c). In a global survey performed by Accenture, more than 80% of the respondents emphasized their high

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preference to green products when making purchasing decisions (Hong and Guo, 2019). Carbon Trust surveys have also shown that green products are favored by nearly one-fifth of customers, even if these products are more expensive than ordinary ones.[1] Over the last decade, the actual green purchasing behavior of consumers is directly related to their awareness of how green products are, which to some extent influenced by the green marketing efforts implemented by retailers (Rahbar and Abdul, 2011; Ma et al., 2017; Hong and Guo, 2019). Therefore, to improve consumers' green awareness and promote green products, retailers used to invest in green marketing, such as parity marketing and advertising strategies. Under such circumstances, upstream manufacturers may contract with retailers to increase marketing efforts. For example, WalMart, one of the largest retailers in the world, has adopted a series of green marketing strategies; meanwhile, Procter & Gamble urges WalMart to improve its marketing efforts by cooperative contracts.,[23]

Nowadays, in a sharp contrast, consumers' tremendous needs for various customized green products are driving retailers to cooperate with manufacturers in another way, that is, designing much greener products in addition to green marketing (Watkins et al., 2016; Hong et al., 2019; Wang et al., 2020; Li et al., 2020c). This practical trend has witnessed the status quo that with increasing consumers' desire for much greener products, retailers may cooperate with manufacturers to improve products' greening level and simultaneously exert extra green marketing effort on these improved green products. In business practice, to achieve such cooperation for increasing sales, firms usually employ various contracts between them toward an improved sustainable supply chain. For example, to meet consumers' demand for fresh green products, FRESHIPPO, Alibaba's fresh brand, cooperates with upstream manufacturers to enhance product greening level by supporting green product design; meanwhile, FRESHIPPO puts green marketing effort on green products.[4] Another contrast example is Suning.com. As a giant retailer, Suning.com plays a positive role in improving product greening level by cooperating with upstream manufacturer (e.g., ANGEL) and guiding green consumption by implementing marketing efforts.[5]

Motivated by the two stylized stream examples, we can classify these cooperative contracts into two formats. The first is contracting marketing (CM) format where upstream manufacturers contract with downstream retailers to improve marketing efforts by demonstrating how green products are (e.g., Procter & Gamble and WalMart). The second is contracting designing (CD) format where downstream retailers cooperate with upstream manufacturers to improve product greening level through design, and simultaneously exert green marketing effort on these green products (e.g., Suning.com and ANGEL). Among these two formats, the concerning issue for firms is how to choose an appropriate cooperative contract format to enhance product greening level or marketing effort and thus maximize firms' and supply chains' profits. In previous literature, Hong and Guo (2019) investigated price-only and cost-sharing game models under CM format. However, in our study, we investigate three different contract strategies under CD format. Moreover, we compare these two practical contracting formats and derive some interesting and important managerial implications for academia and practice. Motivated by the aforementioned discussion, our motivation stems from the interest in answering the following questions: (1) What are the differences in firms' equilibrium results in each contract strategy under CD format? (2) Which contract strategy can maximize the product greening level under CD format? (3) Can the improvement of product greening level bring increased benefits to the manufacturer and retailer? (4) Which contract strategy does the manufacturer and retailer prefer under CD format? (5) Which contracting format benefits the supply chain more?

In answering the above questions, we extend current literature by establishing a green product supply chain that consists of a manufacturer (he) who determines the product greening level and a retailer (she) who decides the product marketing efforts. Specifically, the manufacturer invests in developing green technology to produce green products, and the retailer invests in marketing efforts to promote such products. In our basic model, we first consider three practical contract strategies under CD format. In Strategy PO (price-only game model), we investigate the manufacturer-led Stackelberg game model, where the manufacturer and retailer make their own decisions to maximize their own interests. In Strategy CS (cost-sharing game model), the retailer actively shares a certain percentage of greening investment costs with the manufacturer. In Strategy RS (revenue-sharing game model), the retailer provides a certain proportion of revenue to the manufacturer. Moreover, we extend our investigation on CM format and compare the total profit of supply chain under these two contracting formats.

We derive several interesting results from firms' equilibrium decisions. First, under CD format, the supply chain incurs the highest wholesale price, marketing effort and retail price in Strategy CS. Moreover, products have a higher greening level in Strategies CS and RS than that in Strategy PO. Determining which strategy can achieve the highest product greening level depends on the marketing effort effect. Second, we intriguingly find that under CD format when the marketing effort effect is high or low, the product greening level improvement can benefit firms. However, the product greening level improvement does not necessarily lead to higher payoffs for both firms when the marketing effort effect is moderate. Third, under CD format, the preferred strategy for the manufacturer and retailer is either Strategy RS or Strategy CS, and Strategy PO cannot be the dominant strategy. In specific, when the marketing effort effect is weak, the manufacturer and retailer prefer Strategy RS. On the contrary, when the marketing effort effect is strong, Strategy CS is the dominant strategy for the manufacturer and retailer. Fourth, we reveal that, compared with CM format, the whole supply chain always obtains higher performance under CD format. Finally, given the fact that the retailer is risk-averse, our core conclusions still hold under CD format. However, given the cost-sharing contract under CD and CM formats, determining which format should be used by the whole supply chain to realize higher benefits depends on the retailer's risk-aversion degree and marketing effort effect. In specific, the whole supply chain is better off under CD format when the retailer's risk-aversion degree is sufficient low, or the retailer's risk-aversion degree is low and the marketing effort effect is low or high, or the retailer's risk-aversion degree is high and the marketing effort effect is low. Otherwise, the whole supply chain attains more under CM format. We further investigate the impact of retailer's risk-aversion on supply chain performance under CD and CM formats, and find that the retailer's risk aversion behavior may improve the performance of the whole supply chain. Specifically, when the risk-aversion degree and marketing effort effect are relatively low, the retailer's risk aversion behavior can enhance the performance of the whole supply chain under CD format; otherwise, the whole supply chain obtains higher performance with the retailer's risk neutral. However, under CM format, we find that the supply chain gains more with the retailer's risk neutral when the risk-aversion degree is relatively low and the marketing effort effect is relatively high; otherwise, the whole supply chain achieves higher performance with the retailer's risk aversion.

The main contributions of our work are as follows. *First*, our study innovatively incorporates both green marketing and designing into a green product supply chain with cost- and revenue-sharing contracts under CD format, which so far has inadequately explored in existing

[1] Available at http://www.carbontrust.com/news/2011/07/consumer-demand-for-lower-carbon-lifestyles-is-putting-pressure-on-business.

[2] Available at https://club.1688.com/threadview/32056556.htm.

[3] Available at http://www.sustainablebrands.com/news _ and _ views/articles/wal-mart- outlines-green- marketing-plan- suppliers.

[4] Available at http://gz.people.com.cn/n2/2019/0710/c389100-33128353.html.

[5] Available at http://www.cinn.cn/gysj/201804/t20180416_180606_wap.html.

literature. Thus, our research, which fills a gap in the literature, is of also great importance from the theoretical aspect. *Second*, by analyzing the three contract strategies under CD format, we shed light on how these contracts help supply chains achieve greening level improvement and whether such an improvement brings positive benefits to firms. We find that when the marketing effort effect is moderate, the product greening level improvement does not necessarily lead to higher payoffs for firms. *Third*, our study helps us make a full understanding of the traditional contract theory indicated by Cachon and Lariviere (2005) that the revenue sharing may not be attractive if the demand is dependent on the promotional effort. We uncover that, compared with price-only game model (i.e., wholesale price contract), the revenue sharing game model is always beneficial for the manufacturer and retailer when such market demand depends on both the marketing effort and product greening level.[6] Moreover, we reveal that the revenue-sharing game model could still be attractive in certain conditions compared with cost-sharing game model. We further identify the specific conditions in which the dominant contract would survive, which provides the vital guidance for both academia and practice. *Fourth*, we further consider the contracts under CM format as investigated in Hong and Guo (2019). To the best of our knowledge, we are the first to compare CD and CM formats to derive interesting implications for practice, and both formats so far have inadequately been jointly examined in prior literature. We indicate that the profit of the whole supply chain is always higher under CD format than that under CM format. *Finally*, we extend our research to the case that the retailer is risk-averse. We find that determining which contracting format must be used for the whole supply chain to achieve higher performance depends on the retailer's risk-aversion degree and marketing effort effect. Moreover, we examine the impacts of risk aversion on the supply chain performance under CD and CM formats. These important results complement existing literature on contracting for green product supply chain and provide theoretical guidance for firms in selecting contract formats as well.

The rest of this paper is structured as follows. Section 2 provides a brief review of relevant literature. Section 3 introduces the model formulation, assumptions, and notations. Section 4 presents the equilibrium results under the three contract strategies and analyzes the impacts of marketing effort effect and marketing investment coefficient on the equilibrium results under CD format. Section 5 compares the equilibria of the three contract strategies under CD format. Section 6 compares CD and CM formats, and present the case study for verifying the main results. Section 7 analyzes extension models with the retailer's risk-aversion, and provides managerial implications for managers. Section 8 concludes the paper and presents possible research directions. All proofs are presented in the Appendix.

2. Literature review

Our work lies at the intersection of literature on marketing effort, sustainable supply chain management, and contract theory in the supply chain. Relevant literature can be divided into several streams.

2.1. Marketing effort

The first stream of relevant literature focuses on marketing effort (Taylor, 2002; Chen, 2005; Xing and Liu, 2012; Karray, 2013; Ma et al., 2013; Hong et al., 2015, 2019; Taleizadeh et al., 2016; Bai et al., 2017; Chen et al., 2017; Wang et al., 2017; Li et al., 2019a; Guo et al., 2020b). For instance, Taylor (2002) investigated a supply chain where a manufacturer induces a retailer to exert additional effort and order a large quantity by increasing the retailer's marginal revenue. Xing and Liu (2013) studied sales effort coordination for a supply chain with one manufacturer and two retail channels, where an online retailer offers a low price and free-rides a brick-and-mortar retailer's sales effort. Given quality and marketing effort-dependent demands, Ma et al. (2013) developed models to optimize the effort levels and profits of a manufacturer and a retailer by using different channel strategies. Taleizadeh et al. (2016) explored a dual-channel closed-loop supply chain system consisting of a manufacturer and a retailer and discussed the effect of exerting marketing effort on supply chain members. Moreover, Chen et al. (2017) investigated the roles of single manufacturer and single retailer by studying uncertain supply chains with sales effort and price-dependent demand. Li et al. (2019a) investigated pricing and service decision issues in a dual-channel supply chain wherein a retailer decides whether to improve service effort. Considering environmentally conscious consumers, Guo et al. (2020b) explored a game-theoretic model to study the green product design and marketing effort with sales platform eco-labels in a green supply chain.

2.2. Sustainable supply chain management

The second stream of relevant literature investigates optimal pricing strategies under sustainable supply chains (Chen, 2001; Linton et al., 2007; Subramanian et al., 2009; Ghose and Shah, 2015; Hong et al., 2016, 2018, 2019; Gouda et al., 2016; Yu et al., 2016; Xu et al., 2017; Dey and Saha, 2018; Li et al., 2018a; Hong and Guo, 2019; Guo et al., 2020a, 2020b; Li et al., 2020d). Chen (2001) investigated green product design coordination between traditional and environmental attributes during green product development. Linton et al. (2007) studied a sustainable supply chain with convergence and sustainability. In doing so, they shifted the focus of environmental management and operations from the local optimization of environmental factors to production, consumption, customer service, and post-disposal throughout the supply chain. Swami and Shah (2013) examined the coordination of a manufacturer and a retailer in a sustainable supply chain who work together to improve product green level and studied the impact of green cost on price and green level. By incorporating emission regulations into a model, Hong et al. (2016) studied the product design issue in which product greenness depends on the emissions generated during production. Considering three procurement scenarios under the manufacturer–leader Stackelberg game setting, Dey and Saha (2018) explored the focus on a retailer's optimal retail pricing and procurement decisions and a manufacturer's wholesale pricing and product greening level decisions under a two-stage supply chain framework. Hong et al. (2019) studied a green-product design problem in a two-echelon supply chain by considering consumers' reference behaviors. Moreover, Hong and Guo (2019) investigated the impact of cost-sharing contracts on the product greening level and green marketing of firms and integrated the environmental responsibilities of stakeholders into the supply chain. They designed a cost-sharing contract to motivate retailers to improve green marketing efforts. By contrast, in line with the practical trend that consumers drive retailers to sell improved green products, we instead consider that a retailer may use cost- and revenue-sharing contracts to motivate a manufacturer to improve product greening level. Moreover, we simultaneously investigate the impacts of cost- and revenue-sharing contracts on the product greening level and green marketing of firms.

2.3. Contract theory

The third stream of relevant literature investigates contract strategies in supply chains (Cachon and Lariviere, 2005; Mukhopadhyay et al., 2009; Hou et al., 2009; Chiu et al., 2011a; Tsao and Sheen, 2012; Kunter, 2012; Ghose and Shah, 2015; Cai et al., 2017; Dai et al., 2017; Li and Chen, 2018; Li et al., 2019c, 2020a; Zhang et al., 2019). For instance, Cachon and Lariviere (2005) investigated the performance of

[6] Note that in our study the market effort-dependent demand may reduce the retailer's preference on the revenue-sharing contract while the product greening level-dependent demand can incentivize the retailer to prefer such contract. Therefore, it would be well worth examining the counteracting effect of such decision on firms' contract preference.

revenue-sharing contracts by comparing these contracts with several other coordination contracts under the newsvendor setting. Considering the cost information symmetry and asymmetry of suppliers, Hou et al. (2009) used revenue-sharing contracts to increase profits of members. Tsao and Sheen (2012) found that the cost-sharing ratio can achieve channel coordination within a certain range and ensure increased profit distribution. Ghosh and Shah (2015) discussed a two-level sustainable supply chain decision-making problem and investigated how product greening levels, prices, and profits are affected by cost-sharing contracts within the supply chain. Dai et al. (2017) also showed that cost-sharing contracts can improve the profit of supply chain members and the total profit of supply chain compared with non-cooperative models.

Our work follows extant literature but differs in the following respects. First, we simultaneously consider cost- and revenue-sharing game models and analyze channel members' optimal decisions. Specifically, we consider a manufacturer who invests in developing green technology to produce green products and a retailer who invests in marketing effort to promote green products. To promote green product development, the retailer enters into contracts with the manufacturer and market green products, a situation unexplored in existing literature. Second, we study and compare three strategies to obtain interesting conclusions which can help each supply chain member make optimal decisions. We derive several interesting results which are not indicated in existing literature. Thus, our research complements prior literature on contract theory and green supply chain management. Third, we further consider contracts under CM format, as investigated in Hong and Guo (2019). To the best of our knowledge, we are the first to compare CD and CM formats to derive interesting implications for practice, and both formats so far have inadequately been jointly examined in prior literature. Finally, we further extend the basic model to the case where the retailer is risk averse and present several interesting implications which fill a gap in the literature. We also group the main research articles and position our work within this literature, as summarized in Table 1.

3. Model formulation

This study investigates a decentralized green product supply chain where a manufacturer produces and sells green products to consumers via a retailer. To cater to market demands and increase market competitiveness, the manufacturer invests in developing green technology to produce green products, and the retailer invests in marketing efforts to promote the products. In our basic model, we investigate three practical contract strategies under CD format in Sections 4 and 5. We add subscript or superscript i to a variable to distinguish it among various strategies, with $i = PO, CS, RS$corresponding to the price-only, cost-sharing, and revenue-sharing game models under CD format, respectively. Recall that the corresponding contracts under CM format have been examined by Hong and Guo (2019), and we omit the detailed derivation here; however, these two contract formats have been inadequately jointly investigated and compared. On this basis, in Section 6, we extend to compare these two practical contracting formats and derive important managerial implications for firms and the supply chain to choose appropriate contract formats and strategies. In the remainder of the paper, we use the pronoun "he" for the manufacturer and "she" for the retailer. Table 2 lists the main notations used in this paper.

Market demand. To characterize the demand function, this study adopts the utility function of a representative consumer introduced by Singh and Vives (1984); this function has been extensively applied in the field of marketing and operations management (Niu et al., 2019; Shi, 2019). Based on literature, customers' utility function can be formulated to be quadratic and strictly concave,

$$U = aD_i - \frac{1}{2}D_i^2 - p_iD_i + \theta_iD_i + \lambda v_iD_i, \quad (1)$$

Eq. (1) implies that the representative consumer's utility is linearly dependent on retail price, product greening level and marketing effort. The equation also indicates that utility decreases in retail prices but increases in greening level and marketing effort. Maximizing U with respect to D_i yields $D_i = a - p_i + \theta_i + \lambda v_i$, where D_i denotes the manufacturer production quantity in Strategy i; p_i is the retail price of the retailer in Strategy i; a represents the total market potential; and θ_i represents the greening level in Strategy i (Ghosh and Shah, 2012, 2015; Ji et al., 2017). The coefficient λ measures the impact of marketing effort on demand, that is, the marketing effort effect, and v_i represents the marketing efforts in Strategy i (Mukhopadhyay et al., 2009; Li et al., 2019a). To avoid trivial cases and guarantee the non-negativity of the

Table 2
Model notations.

Notation	Definition
a	Total market potential
c	Manufacturer's variable production cost
λ	Marketing effort effect
v_i	Marketing effort level in Strategy i
θ_i	Product greening level in Strategy i
w_i	Wholesale price in Strategy i
p_i	Retail price charged by the retailer in Strategy i
δ	Cost-sharing proportion in Strategy CS
φ	Revenue-sharing proportion in Strategy RS
π_M^i	Manufacturer's profit in Strategy i
π_R^i	Retailer's profit in Strategy i
π_{SC}^i	Supply chain's profit in Strategy i

Table 1
Comparison of previous literatures with the current study.

Paper	Greening level	Marketing efforts	Contract type			Risk-aversion	Contracting format
			Price-only	Cost-sharing	Revenue-sharing		
Ghosh and Shah(2012)	✓		✓				\
Liu et al. (2012)	✓		✓				\
Ghose and Shah (2015)	✓		✓	✓			CD
Taleizadeh et al. (2016)		✓	✓				\
Xu et al. (2017)	✓		✓	✓			CD
Dai et al. (2017)	✓		✓	✓			CD
Ma et al. (2017)		✓	✓				\
Song and Gao (2018)	✓		✓		✓		CD
Dey and Saha (2018)	✓		✓	✓			CD
Hong and Guo (2019)	✓	✓	✓	✓			CM
Our paper	✓	✓	✓	✓	✓	✓	**CD + CM**

Note: In line with the practical trend that consumers drive retailers to sell improved green products, downstream retailers may use contract strategy with upstream manufacturers to improve product greening level and put further green marketing effort on these products. This green and marketing interaction model is becoming increasingly popular in practice.

optimal solutions, we assume that $0 < \lambda < \widetilde{\lambda}$ in our basic model (see the appendix). Moreover, without loss of generality, we assume $a > c$ to ensure that market demand is positive when the greening and marketing effort levels are zero (Chen et al., 2017; Li et al., 2018b).

Greening and marketing investment. The investment level in green technology affects product greening level and market demand. To improve product greening level, the manufacturer must invest in capital for product research and development. We assume that the cost of greening investment by the manufacturer can be expressed as a quadratic function of the greening level, namely, θ_i^2 (Banker et al., 1998; Chen, 2001; Taleizadeh et al., 2016; Guo et al., 2020a, 2020b). In addition, consumers' consumption consciousness directly determines market demand. Therefore, to improve consumers' green awareness and promote green products, the retailer needs to increase the green marketing cost and spend a large sum on advertising. We assume that such cost can be expressed as a quadratic function of the greening level, namely, v_i^2 (Taylor, 2002; Ma et al., 2017; Guo et al., 2020a, 2020b).

Decision sequence. We model pricing and greening level decisions as a Stackelberg game, in which the manufacturer and retailer are the leader and follower, respectively. The decision sequence is depicted as follows. First, the manufacturer simultaneously determines wholesale price w_i and greening level θ_i. Second, the retailer simultaneously decides on retailer price p_i and marketing effort v_i by using the response functions of wholesale price w_i and greening level θ_i. Third, the retailer receives the green product from the manufacturer and sells it to consumers.

Contract strategies. On the basis of the motivations discussed in the Introduction, three contract strategies under CD format, namely, price-only, cost-sharing, and revenue-sharing game models, are considered as shown in Fig. 1.

- Price-only game model (Strategy PO): We investigate the manufacturer-led Stackelberg game model, in which the manufacturer and retailer make their own decisions to maximize their own interests.
- Cost-sharing game model (Strategy CS): To encourage the manufacturer to invest in developing green technology to produce green products, the retailer shares $\delta \in (0, 1)$ proportion of the total cost of greening investment.
- Revenue-sharing game model (Strategy RS): Unlike Strategy CS, the retailer provides $\varphi \in (0, 1)$ percentage of the final sales to the manufacturer.

4. Equilibrium analysis

In this section, we consider a decentralized green product supply chain under CD format in which the manufacturer and retailer make independent decisions to maximize their own expected revenue under the three strategies. Backward induction is used to solve the problem.

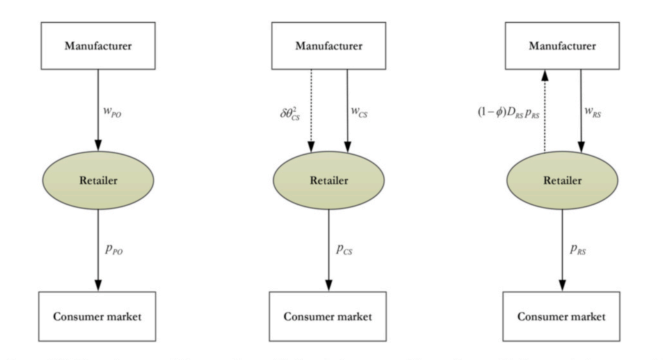


Fig. 1. Three strategies under CD format.

4.1. Strategy PO

In this strategy. We study a green product supply chain under the price-only game model, in which the manufacturer and retailer maximize their profits and make decisions according to the Stackelberg game framework. The retailer, as the Stackelberg-follower, maximizes her profit by optimally determining retail price p_{PO} and marketing effort v_{PO} given the manufacturer's decisions on w_{PO} and θ_{PO}. The consumer demand for the green product is given by $D_{PO} = a - p_{PO} + \theta_{PO} + \lambda v_{PO}$. Therefore, the profit of the retailer in Strategy PO is given as follows:

$$\underset{p_{po}, v_{PO}}{Max}\, \pi_R^{PO} = D_{PO}(p_{PO} - w_{PO}) - v_{PO}^2. \tag{2}$$

The manufacturer, as the leader, maximizes his profit by optimally determining wholesale price w_{PO} and greening level θ_{PO} simultaneously. We denote the unit production cost as c. Therefore, the profit of the manufacturer in Strategy PO is

$$\underset{w_{po}, \theta_{PO}}{Max}\, \pi_M^{PO} = D_{PO}(w_{PO} - c) - \theta_{PO}^2. \tag{3}$$

In accordance with the standard backward introduction approach, we present the equilibrium decisions of the manufacturer and retailer in Table 3.

4.2. Strategy CS

The manufacturer faces high economic risks when he is responsible for all development costs due to green product development cost. To encourage the manufacturer to develop the green product supply chain, we establish a retailer-led cost-sharing game model where the retailer shares a proportion of the total cost of greening investment δ with the manufacturer. The greening investment cost shared by the retailer is $\delta\beta\theta_{CS}^2$. Therefore, the profit of the retailer in Strategy CS is

$$\underset{p_{CS}, v_{CS}}{Max}\, \pi_R^{CS} = D_{CS}(p_{CS} - w_{CS}) - v_{CS}^2 - \delta\theta_{CS}^2. \tag{4}$$

The greening investment cost shared by the manufacturer is $(1 - \delta)\theta_{CS}^2$. Therefore, the profit of the manufacturer in Strategy CS is

$$\underset{w_{CS}, \theta_{CS}}{Max}\, \pi_M^{CS} = D_{CS}(w_{CS} - c) - (1 - \delta)\theta_{CS}^2, \tag{5}$$

where $D_{CS} = a - p_{CS} + \theta_{CS} + \lambda v_{CS}$.

The detailed equilibrium decisions of the manufacturer and retailer are presented in Table 3.

4.3. Strategy RS

Under the revenue-sharing game model, we assume that at the end of the selling period, the percentage of retailer gain from the final sales is $1 - \varphi$, and the remaining φ is shared with the manufacturer. That is, the retailer transfers φ portion of the revenue, $\varphi D_{RS} p_{RS}$, to the manufacturer. Therefore, the profit of the retailer in Strategy RS is

$$\underset{p_{RS}, v_{RS}}{Max}\, \pi_R^{RS} = D_{RS}[(1 - \varphi)p_{RS} - w_{RS}] - v_{RS}^2. \tag{6}$$

The manufacturer obtains payment $\varphi D_{RS} p_{RS}$ from the retailer at the end of the selling period. Therefore, the profit of the manufacturer in Strategy RS is

$$\underset{w_{RS}, \theta_{RS}}{Max}\, \pi_M^{RS} = D_{RS}(w_{RS} - c) - \theta_{RS}^2 + \varphi D_{RS} p_{RS}, \tag{7}$$

where $D_{RS} = a - p_{RS} + \theta_{RS} + \lambda v_{RS}$.

Using backward deduction, the equilibrium in Strategy RS is obtained in Table 3. Following the optimal decision making of the manufacturer and retailer under three strategies, we deal with the following corollaries to investigate the influence of the marketing effort effect on their decisions.

Table 3
Equilibrium results in three different strategies.

Equilibrium result	Strategy PO	Strategy CS	Strategy RS
w_i	$\frac{a(-4+\lambda^2)+c(-3+\lambda^2)}{-7+2\lambda^2}$	$\frac{15a+11c-4a\lambda^2-4c\lambda^2}{2(13-4\lambda^2)}$	$\frac{6(8a+8c-2a\lambda^2-3c\lambda^2)}{(8-\lambda^2)(16-5\lambda^2)}$
p_i	$\frac{a(6-\lambda^2)+c(1-\lambda^2)}{7-2\lambda^2}$	$\frac{a(15-4\lambda^2)(6-\lambda^2)+c[32+4\lambda^4+5\lambda^2-6(4\lambda^2+3)]}{2(4-\lambda^2)(13-4\lambda^2)}$	$\frac{8a(5-\lambda^2)+c[16+\lambda^2-8(\lambda^2+1)]}{3(16-5\lambda^2)}$
θ_i	$\frac{a-c}{7-2\lambda^2}$	$\frac{2(a-c)}{13-4\lambda^2}$	$\frac{(a-c)(8-\lambda^2)}{3(16-5\lambda^2)}$
v_i	$\frac{(a-c)\lambda}{7-2\lambda^2}$	$\frac{\lambda(a-c)(15-4\lambda^2)}{2(4-\lambda^2)(13-4\lambda^2)}$	$\frac{2\lambda(a-c)}{16-5\lambda^2}$
δ	\	$\frac{1}{4(4-\lambda^2)}$	\
φ	\	\	$\frac{2-\lambda^2}{8-\lambda^2}$
π_M^i	$\frac{(a-c)^2}{7-2\lambda^2}$	$\frac{(a-c)^2(15-4\lambda^2)}{2(4-\lambda^2)(13-4\lambda^2)}$	$\frac{(a-c)^2(8-\lambda^2)}{3(16-5\lambda^2)}$
π_R^i	$\frac{(a-c)^2(4-\lambda^2)}{(7-2\lambda^2)^2}$	$\frac{(a-c)^2(17-4\lambda^2)}{4(4-\lambda^2)(13-4\lambda^2)}$	$\frac{4(a-c)^2}{3(16-5\lambda^2)}$

Corollary 1.
(i) $\frac{\partial v_{PO}}{\partial\lambda} > 0$; ***(ii)*** $\frac{\partial\theta_{PO}}{\partial\lambda} > 0$; ***(iii)*** $\frac{\partial w_{PO}}{\partial\lambda} > 0$; ***(iv)*** $\frac{\partial p_{PO}}{\partial\lambda} > 0$; ***(v)*** $\frac{\partial D_{PO}}{\partial\lambda} > 0$; ***(vi)*** $\frac{\partial\pi_M^{PO}}{\partial\lambda} > 0$ *and* $\frac{\partial\pi_R^{PO}}{\partial\lambda} > 0$.

Corollary 1 demonstrates the impacts of the marketing effort effect on equilibria in Strategy PO. Case (i) shows that the marketing effort increases with the marketing effort effect. This conclusion is intuitive. If consumers exhibit a sensitivity to marketing for green products, then the retailer will strive to improve the marketing level of products to promote consumer demand. In such a circumstance, the manufacturer has sufficient incentive to strengthen the greening level. This observation clarifies why the greening level and marketing effort effect are positively correlated in Case (ii) of Corollary 1. Case (iii) indicates that the wholesale price increases with the marketing effort effect. According to Case (ii), the manufacturer's greening investment cost increases with the greening level improvement. Thus, to compensate for the loss in green technology investments, the manufacturer raises the wholesale price to obtain additional revenue. In such a circumstance, the retailer usually opts to increase the retail price for increased profits, as shown in Case (iv). Although high retail prices are not conducive to market demand, such a demand still increases with the marketing effort effect, as presented in Case (v). That is to say, the positive relationship implies that the benefit brought by the increased greening level and marketing effort outweighs the loss.

Case (vi) implies that the profits of the manufacturer and retailer increase with the marketing effort effect. For the manufacturer, market demand and wholesale price rise with the marketing effort effect. However, green investment increases with the marketing effort effect, indicating that the benefits of increased wholesale price and market demand outweigh the losses of green investment. For the retailer, as the marketing effort effect increases, the retailer needs to invest an additional cost (i.e., marketing investment) to market the product but gains extra revenue by setting a high retail price and market demand in accordance with Cases (iv) and (v). This situation brings high profit for the retailer, although the retailer bears high procurement (i.e., large wholesale price) and investment (i.e., marketing effort) costs in accordance with Cases (iii) and (i).

Corollary 2. ***(i)*** $\frac{\partial\theta_{CS}}{\partial\lambda} > 0$; ***(ii)*** $\frac{\partial v_{CS}}{\partial\lambda} > 0$; ***(iii)*** $\frac{\partial w_{CS}}{\partial\lambda} > 0$; ***(iv)*** $\frac{\partial p_{CS}}{\partial\lambda} > 0$; ***(v)*** $\frac{\partial D_{CS}}{\partial\lambda} > 0$; ***(vi)*** $\frac{\partial\pi_M^{CS}}{\partial\lambda} > 0$ *and* $\frac{\partial\pi_R^{CS}}{\partial\lambda} > 0$.

The logic behind Corollary 2 is identical to that of Corollary 1. Therefore, we omit the details for brevity.

Corollary 3. ***(i)*** $\frac{\partial\theta_{RS}}{\partial\lambda} > 0$; ***(ii)*** $\frac{\partial v_{RS}}{\partial\lambda} > 0$; ***(iii)*** $\frac{\partial w_{RS}}{\partial\lambda} > 0$; ***(iv)*** $\frac{\partial p_{RS}}{\partial\lambda} > 0$; ***(v)*** $\frac{\partial D_{RS}}{\partial\lambda} > 0$; ***(vi)*** $\frac{\partial\pi_M^{RS}}{\partial\lambda} > 0$ *and* $\frac{\partial\pi_R^{RS}}{\partial\lambda} > 0$.

Similarly, the logic behind Corollary 3 is identical to that of Corollary 1. Thus, we omit the details for brevity.

5. Comparison

This section compares the equilibrium results derived in Section 4 under the three strategies and highlight the role of marketing effort effect under CD format. The following propositions illustrate the comparative results on greening level, marketing effort, wholesale price, retail price, and member's profits under CD format.

Proposition 1. *The comparative results regarding greening level under the three strategies are given as follows:*

(i) If $\widetilde{\lambda}_1 < \lambda < \widetilde{\lambda}$, then $\theta_{CS} > \theta_{RS} > \theta_{PO}$.
(ii) If $0 < \lambda < \widetilde{\lambda}_1$, then $\theta_{RS} > \theta_{CS} > \theta_{PO}$.

Proposition 1 shows the variations in greening level for the three strategies. The result reveals that each case has $\theta_{RS,CS} > \theta_{PO}$. The intuition behind the observations are as follows. As mentioned, Strategies CS and RS can reduce the manufacturer's burden for greening improvement investment. Thus, unlike in Strategy PO, the manufacturer has greater incentive to improve the greening level in Strategies CS and RS (i.e., $\theta_{RS,CS} > \theta_{PO}$).

With regard to Strategies CS and RS, we can observe that the relationship of greening level under two strategies depends on the marketing effort effect. When the marketing effort effect is high (corresponding to Scenario (i) of Proposition 1), the product greening level in Strategy CS is higher than that in Strategy RS. The reason is that the revenue-sharing proportion decreases with the marketing effort effect in accordance with Table 3. Thus, the manufacturer has little incentive to make green investment when the marketing effort effect is strong in accordance with Scenario (i). Thus, we have $\theta_{RS} < \theta_{CS}$. When the marketing effort effect is low (corresponding to Scenario (ii) of Proposition 1), we have $\theta_{RS} > \theta_{CS}$. This relationship exhibits a reverse pattern in accordance with Scenario (i) of Proposition 1. Therefore, in this scenario, $\theta_{RS} > \theta_{CS}$ for a relatively weak marketing effort effect (i.e., $0 < \lambda < \widetilde{\lambda}_1$) and $\theta_{RS} < \theta_{CS}$ otherwise.

Proposition 2. *The comparative results for marketing effort under the three strategies satisfy the relationship* $v_{CS} > v_{PO} > v_{RS}$.

Proposition 2 presents the comparative results for marketing effort in the three strategies. The result shows that the marketing effort is the highest in Strategy CS and the lowest in Strategy RS. The marketing effort in Strategy RS is lower than that in Strategy PO. The reason is that, as mentioned in Proposition 1, Strategies CS and RS reduce the manufacturer's burden for greening improvement investment. Apparently, unlike in Strategy CS, the retailer bears greater financial pressures for the manufacturer in Strategy RS. Therefore, from the perspective of the retailer, the marketing effort selected by the retailer in Strategy RS is lower than that in Strategy PO (i.e., $v_{PO} > v_{RS}$) to compensate for the loss of revenue sharing and gain benefits. However, compared with Strategy RS, the retailer has greater incentive to improve her marketing effort to obtain benefits in Strategy CS. That is, the retailer invests more in marketing in Strategy CS than in Strategy PO (i.e., $v_{CS} > v_{PO}$).

Proposition 3. *The equilibrium wholesale price under the three strategies satisfy the relationship* $w_{CS} > w_{PO} > w_{RS}$.

Proposition 3 presents the comparative results regarding wholesale price in the three strategies. The result shows that the wholesale price is the highest in Strategy CS and the lowest in Strategy RS. Comparatively, the wholesale price in Strategy PO is higher than that in Strategy RS. The reason is that, compared with Strategy PO, the product greening level is higher in Strategies CS and RS according to Proposition 1. Moreover, the retailer usually chooses to enhance wholesale prices to compensate for greening investment losses. However, the retailer bears more pressure for the manufacturer in Strategy CS than that in Strategy RS. Thus, according to Propositions 1 and 2, the manufacturer opts to set the highest wholesale price in Strategy CS and the lowest wholesale price in Strategy RS.

Proposition 4. *The equilibrium retail price under the three strategies satisfy the relationship* $p_{CS} > p_{PO} > p_{RS}$.

Proposition 4 presents the comparative results regarding retail price in the three strategies. The result indicates that the equilibrium retail price in Strategy PO is always higher than that in Strategy RS but is consistently lower than that in Strategy CS. The reason for this finding lies in the following two facts. One the one hand, the retailer endures the highest procurement cost (i.e., wholesale price) in Strategy CS and the lowest procurement cost in Strategy CS in accordance with Proposition 2. On the other hand, the retailer invests the most in marketing efforts in Strategy CS and the least in marketing effort in Strategy RS, as mentioned in the analysis for Proposition 2. Thus, the ranking order of wholesale price is identical to that of the marketing effort and wholesale price in accordance with Propositions 2 and 3.

Proposition 5. *The comparative results for the manufacturer's profit under the three strategies are given as follows:*

(i) If $\widetilde{\lambda}_2 < \lambda < \widetilde{\lambda}$, then $\pi_M^{CS} > \pi_M^{RS} > \pi_M^{PO}$.
(ii) If $0 < \lambda < \widetilde{\lambda}_2$, then $\pi_M^{RS} > \pi_M^{CS} > \pi_M^{PO}$.

Proposition 5 shows the variations in the manufacturer's profit for the three strategies. As shown in Proposition 5, the retailer always profits more in Strategies CS and RS than in Strategy PO because both strategies can alleviate her greening investment burden, and product greening level can be improved, thereby driving the increase in market demand.

In terms of Strategy CS and RS, we find that the relationship of the manufacturer's profit under two strategies depends on the marketing effort effect. When the marketing effort effect is relatively weak (corresponding to Scenario (ii) of Proposition 5), the manufacturer's profit in Strategy CS is higher than that in Strategy RS. The reason for this finding lies in the following fact. According to Proposition 1, when the marketing effort effect is relatively low, the maximum product greening level is achieved by using strategy RS, leading to increased market demand. Thus, the manufacturer can benefit from the increasing demand inspired by revenue sharing despite the high investment cost (i.e., greening investment) and low wholesale price in accordance with Propositions 1 and 3. That is, the benefit brought by the increased market demand exceeds the loss caused by the increased greening investment and the decreased wholesale price. Therefore, we have $\pi_M^{RS} > \pi_M^{CS}$. When the marketing effort effect is strong (corresponding to Scenario (i) of Proposition 5), we have $\pi_M^{RS} < \pi_M^{CS}$. This relationship exhibits a reverse pattern in accordance with Scenario (ii) of Proposition 5.

Proposition 6. *The comparative results regarding the retailer's profit under the three strategies are given as follows:*

(i) If $\widetilde{\lambda}_2 < \lambda < \widetilde{\lambda}$, then $\pi_R^{CS} > \pi_R^{RS} > \pi_R^{PO}$.
(ii) If $0 < \lambda < \widetilde{\lambda}_2$, then $\pi_R^{RS} > \pi_R^{CS} > \pi_R^{PO}$.

Proposition 6 presents the comparative results for the retailer's profit in the three strategies. The result shows that the retailer earns more profit in Strategy CS and RS than in Strategy PO, indicating that Strategies CS and RS strengthen the cooperation between the manufacturer and retailer more than Strategy PO does in accordance with Proposition 5. In terms of the relationship between Strategy CS and RS, the retailer always profits more in Strategy CS than in Strategy RS for the strong marketing effort effect. According to Proposition 1, as the proportion of revenue sharing decreases with the marketing effort effect, product greening level is high in Strategy CS when the marketing effort effect is high. This situation directly incurs that the retailer can benefit from the increasing demand inspired by cost sharing despite the highest unit procurement cost (i.e., wholesale price) and marketing investment according to Propositions 2 and 3. That is, the benefit brought by the increased market demand exceeds the loss caused by the increased wholesale price and marketing investment. The opposite case holds for a weak marketing effort effect. Thus, the threshold of $\widetilde{\lambda}_2$ exists, such that $\pi_R^{CS} < \pi_R^{RS}$ for $0 < \lambda < \widetilde{\lambda}_2$ and $\pi_R^{CS} > \pi_R^{RS}$otherwise.

Discussion of equilibrium strategy. According to the comparison of greening level and firms' profits among the three contract strategies proposed in Propositions 1, 5, and 6, a quantitative analysis of equilibrium strategy is conducted. As illustrated in Propositions 1 and 5, product greening level improvement can benefit the manufacturer when the marketing effort effect is low or high (i.e., $\lambda < \widetilde{\lambda}_1$ or $\lambda > \widetilde{\lambda}_2$). However, when the marketing effort effect is moderate (i.e., $\widetilde{\lambda}_1 < \lambda < \widetilde{\lambda}_2$), such an improvement does not necessarily lead to higher payoffs for the manufacturer. A similar case applies to the retailer. Moreover, in terms of preferred strategy, the manufacturer and retailer prefer Strategy RS when the marketing effort effect is weak (i.e., $\lambda < \widetilde{\lambda}_2$). In this situation, the retailer, as a strategy maker, is willing to engage in the revenue-sharing game model. Selecting Strategy RS is of interest to the manufacturer. Thus, Strategy RS is the equilibrium strategy. When the marketing effort effect is strong (i.e., $\lambda > \widetilde{\lambda}_2$), the retailer prefers Strategy CS over Strategy RS. Meanwhile, the manufacturer also prefers Strategy RS, which is the most beneficial strategy for him. Accordingly, Strategy RS is an equilibrium strategy in this situation.

In conclusion, the equilibrium strategy is either Strategy CS or RS, and Strategy PO cannot be the dominant strategy under CD format.

6. Analysis of contracting formats

In this section, we first compare and discuss the two contracting formats from the perspective of whole supply chain, and then provide the case study to verify our main findings.

6.1. Formats discussion

In the previous section, we investigate that the downstream retailer contracts with the upstream manufacturer to improve the product greening level, and simultaneously exert extra green marketing effort on the improved green products. We denote the basic model as CD format. In business practice, another contracting format, namely, CM format, is widely adopted as well (see the example of Procter & Gamble and WalMart previously introduced). Under such a format, the upstream manufacturer may also provide cost- or revenue-sharing contract with the downstream retailer to increase its marketing effort, consequently resulting in increased consumer demand for the green product. In previous literature, Hong and Guo (2019) investigated CM format. In this regard, which contracting format can bring more benefits to the whole supply chain is still unclear and worth exploring.

From the discussions of the contracts among CM format, we find that the upstream manufacturer never provides the revenue-sharing contract with the retailer under CM format. As such, we only focus on the cost-sharing contract under CM format. We regard the cost-sharing strategy under CM format as Strategy MCS. Moreover, we use subscript "MCS" to denote the marketing cost-sharing contract under CM format. The manufacturer determines the proportion of the marketing effort cost shared with the retailer. We denote δ_{MCS} as the proportion of the cost shared by the manufacturer. The retailer's marketing effort cost is $(1-\delta_{MCS})v_{MCS}^2$. Thus, the profits of the manufacturer and retailer are given as follows:

$$\underset{p_{MCS},v_{MCS}}{Max}\ \pi_R^{MCS} = D_{MCS}(p_{MCS}-w_{MCS}) - (1-\delta_{MCS})v_{MCS}^2, \tag{8}$$

$$\underset{w_{MCS},\theta_{MCS}}{Max}\ \pi_M^{MCS} = D_{MCS}(w_{MCS}-c) - \theta_{MCS}^2 - \delta_{MCS}v_{MCS}^2. \tag{9}$$

We solve this problem similarly to the designing cost-sharing contract (Strategy CS) and present the equilibrium results in Table 4. Comparing the profit of the whole supply chain in accordance with Tables 3 and 4, we derive the following proposition that compares cost-sharing contract under two formats.

Proposition 7. *Given the cost-sharing contract under CD and CM formats, the whole supply chain is always better off under CD format.*

Proposition 7 shows that, given the cost-sharing contract, the whole supply chain attains higher profit under CD format than that under CM format. We theorize that, compared with sharing the cost of green marketing efforts (see Hong and Guo, 2019), interestingly, the supply chain benefits more from sharing the cost of designing green product. The reason lies in that, by contracting designing green products with cost sharing, the manufacturer has a stronger incentive to improve the greening level and thus benefits more from increasing market demand than by contracting marketing efforts with cost sharing. This, in turn, will increase payoffs of the supply chain as the total demand increases more under CD format. Therefore, from the perspective of the supply chain, the establishment of CD format is beneficial to raise the total profit of the supply chain, which complements the traditional understanding in existing literature (e.g., Hong and Guo, 2019).

6.2. *Case study*

In this subsection, we use the practical case mentioned in the Introduction to verify our main findings. Recall that Suning.com, as a giant retailer in China, plays a positive role in improving product greening level by cooperating with upstream manufacturer (e.g., ANGEL) and guiding green consumption by implementing marketing efforts. We first collect the corresponding data, and then normalize these data (as labeled in the corresponding figures) to facilitate our analysis.

We first compare the equilibrium greening level, marketing effort level, wholesale price, retail price as well as the profits of manufacturer and retailer among the three different strategies under CD format. As shown in Fig. 2, the product greening level in Strategies CS and RS is higher than that in Strategy PO. For the products in which strategy to achieve the highest greening level, it depends on the marketing effort effect. In specific, when the marketing effort effect is low, the highest product greening level is achieved in Strategy RS; otherwise, the products achieve the highest greening in Strategy CS. This result is consistent with what Proposition 1 predicts. Moreover, we find that the equilibrium marketing effort level, wholesale price and retail price realize the highest value in Strategy CS and lowest value in Strategy RS. All these findings are consistent with the prediction of Propositions 2, 3 and 4, which are descripted in Fig. 3(a), (b) and (c), respectively. From the perspective of the manufacturer's (i.e. ANGEL) and retailer's (i.e. Suning.com) profit, the results indicate that the manufacturer and retailer may prefer Strategy CS or Strategy RS but never choose Strategy PO. Specifically, when the marketing effort effect is strong, the manufacturer and retailer prefer Strategy CS. However, when the marketing effort effect is weak, the manufacturer and retailer choose the Strategy RS. These findings are consistent with what Propositions 5 and 6 predict, as illustrated in Fig. 4(a) and (b), respectively. These findings also verify why, in practice, Suning.com actively cooperates with ANGEL to enhance product greening level by supporting green product design; meanwhile, Suning.com also exerts green marketing effort on green products.

We then compare the contracting formats (CD and CM formats) with the cost-sharing contract from the perspective of the whole supply chain. Consistent with what Proposition 7 predicts, the supply chain benefits more from sharing the cost of designing green products under CD format (See Fig. 5), as compared with sharing the cost of green marketing efforts under CM format. This result in certain extent explains why the strategic retailer Suning.com takes the initiative to cooperate with its suppliers on designing green products.,[7,8]

Table 4
Equilibrium results in Strategy MCS.

Equilibrium result	Strategy MCS
w_{MCS}	$\frac{a(16-3\lambda^2)+2c(6-3\lambda^2)}{28-9\lambda^2}$
p_{MCS}	$\frac{3a(8-\lambda^2)+2c(2-3\lambda^2)}{28-9\lambda^2}$
θ_{MCS}	$\frac{4(a-c)}{28-9\lambda^2}$
v_{MCS}	$\frac{6\lambda(a-c)}{28-9\lambda^2}$
δ_{MCS}	$\frac{1}{3}$
π_{SC}^{MCS}	$\frac{4(a-c)^2(44-15\lambda^2)}{(-28+9\lambda^2)^2}$

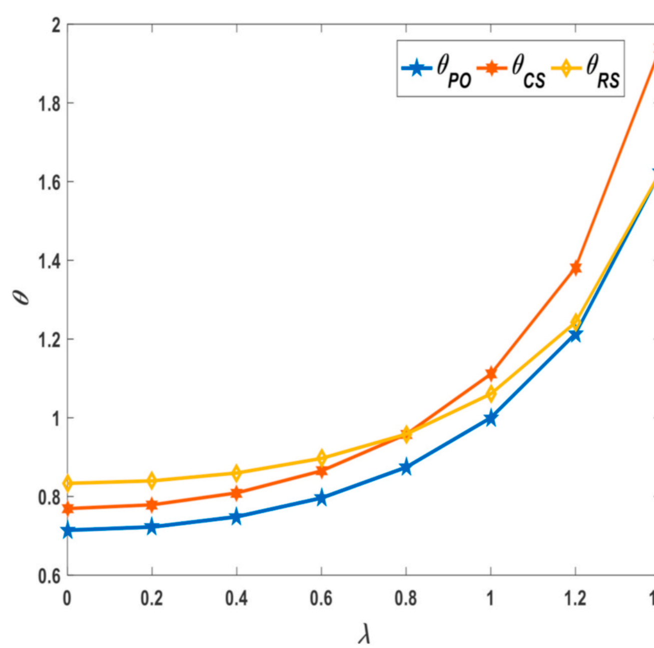


Fig. 2. Greening level in Strategies PO, CS and RS ($a = 10$ and $c = 5$). (a) Marketing effort (b) Wholesale price (c) Retail price.

[7] Available at https://baijiahao.baidu.com/s?id=1597350281673211876&wfr=spider&for=pc&qq-pf-to=pcqq.c2c.

[8] Available at https://m.zol.com.cn/article/6848231.html?tuiguangid=ifeng&qq-pf-to=pcqq.c2c.

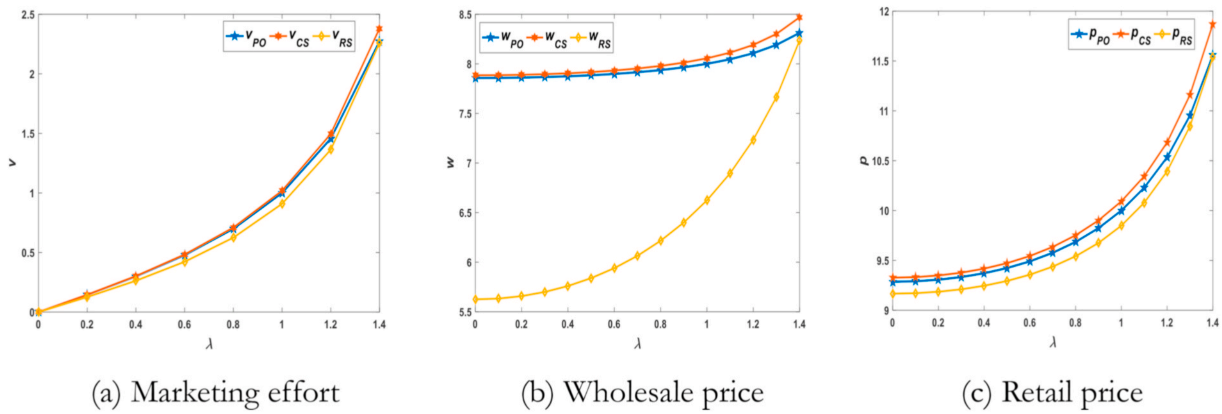


Fig. 3. Marketing effort, wholesale price and retail price in Strategies PO, CS and RS ($a = 10$ and $c = 5$). (a) Manufacturer (b) Retailer.

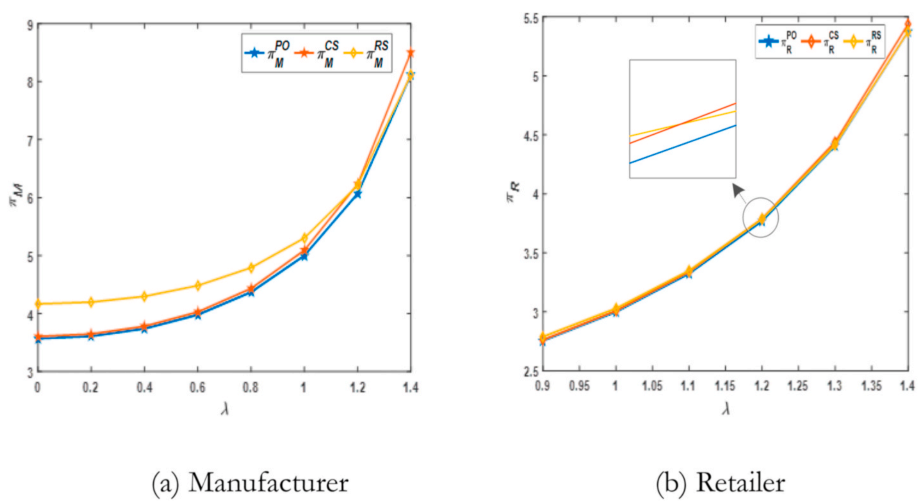


Fig. 4. Equilibrium profit comparison in Strategies PO, CS and RS ($a = 10$ and $c = 5$).

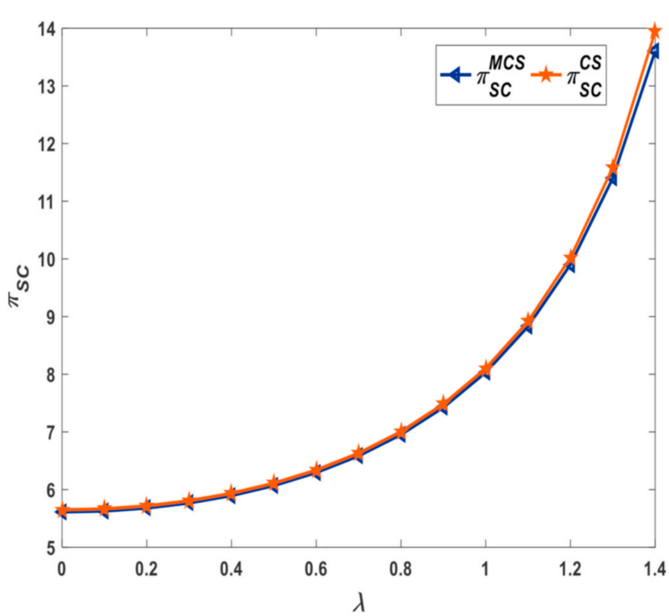


Fig. 5. Comparison of the cost-sharing contract under CD and CM formats ($a = 10$ and $c = 5$).

7. Extension and implications

In this section, we first extend our research on the basic model to the case where the retailer is risk averse, and then we present certain managerial implications which provides a guideline for the firms in selecting different contract strategies and contracting formats.

7.1. Risk aversion

In previous sections, we assume that the manufacturer and retailer are risk neutral. However, in recent years, the business environment has undergone rapid and frequent changes and has become more complex with high demand uncertainty. Existing evidence shows that, in such a fluctuating environment, the retailer, as an independent decision maker, tends to be more risk-averse in her business decision making (Liu et al., 2020). Risk aversion has also been widely used and reported in the retailer's decision-making (see Li et al., 2016; Liu et al., 2020). Motivated by this anecdotal evidence, in Section 7, we further examine a supply chain in which the manufacturer is risk neutral while the retailer has risk-averse behavior. Our extended consideration is reasonable and may prevail in practice. As indicated by Wiseman and Gomez-Mejia (1998) and Wang and Webster (2007), the retailer can be risk-averse rather than the manufacturer. Therefore, also in line with the existing literature (Gan et al., 2005 and 2009; Wang and Webster, 2007; Xiao and Yang, 2008, Chiu et al., 2011a,b; Li et al., 2016; Liu et al., 2020), we consider that the retailer may possess the risk aversion behavior while the manufacturer does not. Following Xiao and Yang (2008), Xiao and Xu

(2014) and Li et al. (2016), we express the demand function as follows: $D_i = a - p_i + \theta_i + \lambda v_i + \varepsilon$, where ε is random noise, and $\varepsilon \sim (0, \sigma^2)$. Following to Xiao and Yang (2008), Xiao and Xu (2014) and Choi et al. (2019), we investigate the case in which the retailer evaluates the random profit on the basis of the Mean-Variance function. The expected utilities for the retailer and manufacturer are:

$$U_R = E(\pi_R) - rVar(\pi_R), \tag{10}$$

$$U_M = E(\pi_M), \tag{11}$$

where r is the degree of retailer's risk-aversion. The first term of Eq. (10) is the expected profit and the second term is the retailer's risk cost incurred by the random profit. The manufacturer is risk neutral, and thus the random profit of manufacturer's utility $U(\pi_M)$ equals the expected profit $E(\pi_M)$.

In view of the three different strategies under CD format, we find that the main results derived in the basic model still hold even if the retailer is risk averse (see the appendix). In such a case, we only focus on the implication for contracting formats in this section. Moreover, from the discussions of the contracts among CM format with retailer risk-aversion, we find that the upstream manufacturer does not provide the revenue-sharing contract under CM formats with retailer risk-aversion. As such, we mainly investigate the cost-sharing contract with retailer risk-aversion under CD and CM formats in this section. We regard the cost-sharing strategy considering the retailer risk-aversion under CD and CM formats as Strategies R-CS and R-MCS, respectively. Moreover, we use subscript/superscript "R–CS" and "R-MCS" to denote the cost-sharing contract with the retailer's risk aversion under CD and CM formats, respectively.

Strategy R–CS. In this case, the retailer shares a proportion of the total cost of the greening investment $\delta_{R-CS}\theta_{R-CS}^2$ with the manufacturer. The profits of the manufacturer and the retailer, denoted by π_M^{R-CS} and π_R^{R-CS}, are listed as follows: $\pi_M^{R-CS} = (w_{R-CS} - c)(a - p_{R-CS} + \theta_{R-CS} + \lambda v_{R-CS} + \varepsilon) - (1 - \delta_{R-CS})\theta_{R-CS}^2$ and $\pi_R^{R-CS} = (p_{R-CS} - w_{R-CS})(a - p_{R-CS} + \theta_{R-CS} + \lambda v_{R-CS} + \varepsilon) - v_{R-CS}^2 - \delta_{R-CS}\theta_{R-CS}^2$. Based on the above settings, the expected utilities for the manufacturer and retailer are:

$$U_M^{R-CS} = (w_{R-CS} - c)(a - p_{R-CS} + \theta_{R-CS} + \lambda v_{R-CS}) - (1 - \delta_{R-CS})\theta_{R-CS}^2, \tag{12}$$

$$U_R^{R-CS} = (p_{R-CS} - w_{R-CS})(a - p_{R-CS} + \theta_{R-CS} + \lambda v_{R-CS}) - v_{R-CS}^2 - \delta_{R-CS}\theta_{R-CS}^2 - r(p_{R-CS} - w_{R-CS})^2\sigma^2. \tag{13}$$

We solve this problem similarly to the Strategy CS and present the Stackelberg equilibrium in Table 5.

Strategy R-MCS. In this case, the manufacturer shares a proportion of the total cost of the marketing investment $\delta_{R-MCS}v_{R-MCS}^2$ with the retailer. The profits for the retailer and manufacturer are, $\pi_R^{R-MCS} = (p_{R-MCS} - w_{R-MCS})(a - p_{R-MCS} + \theta_{R-MCS} + \lambda v_{R-MCS} + \varepsilon) - (1 - \delta_{R-MCS})v_{R-MCS}^2$ and $\pi_M^{R-MCS} = (w_{R-MCS} - c)(a - p_{R-MCS} + \theta_{R-MCS} + \lambda v_{R-MCS} + \varepsilon) - \theta_{R-MCS}^2 - \delta_{R-MCS}v_{R-MCS}^2$. Based on the above setting, the expected utilities for the manufacturer and retailer are as follows:

$$U_M^{R-MCS} = (w_{R-MCS} - c)(a - p_{R-MCS} + \theta_{R-MCS} + \lambda v_{R-MCS}) - \theta_{R-MCS}^2 - \delta_{R-MCS}v_{R-MCS}^2, \tag{14}$$

$$U_R^{R-MCS} = (p_{R-MCS} - w_{R-MCS})(a - p_{R-MCS} + \theta_{R-MCS} + \lambda v_{R-MCS}) - (1 - \delta_{R-MCS})v_{R-MCS}^2 - r(p_{R-MCS} - w_{R-MCS})^2\sigma^2. \tag{15}$$

We solve this problem similar to the marketing cost-sharing contract and present the Stackelberg equilibrium results in Table 5. Comparing the profit of the whole supply chain, we derive the following proposition that compares the cost-sharing contract under two mechanisms. Similar to the basic model, our study focuses on the case of $0 < r \le \tilde{r}(\sigma)$ and $0 < \lambda < \tilde{\lambda}$, or $\tilde{r}(\sigma) < r < \hat{r}(\sigma)$ and $\hat{\lambda}(\sigma, r) < \lambda < \tilde{\lambda}$ to obtain the channel members' optimal decisions and guarantee the non-negativity of the optimal solutions (see the appendix).

Proposition 8. *Given the cost-sharing contract under CD and CM formats with the retailer's risk aversion, the whole supply chain is better off under CM format if one of the following conditions occurs:*

(i) $\tilde{r}_1(\sigma) < r \le \tilde{r}_2(\sigma)$ *and* $\tilde{\lambda}_3(\sigma, r) < \lambda < \tilde{\lambda}_4(\sigma, r)$;

(ii) $\tilde{r}_2(\sigma) < r < \tilde{r}(\sigma)$ *and* $\tilde{\lambda}_3(\sigma, r) < \lambda < \tilde{\lambda}$;

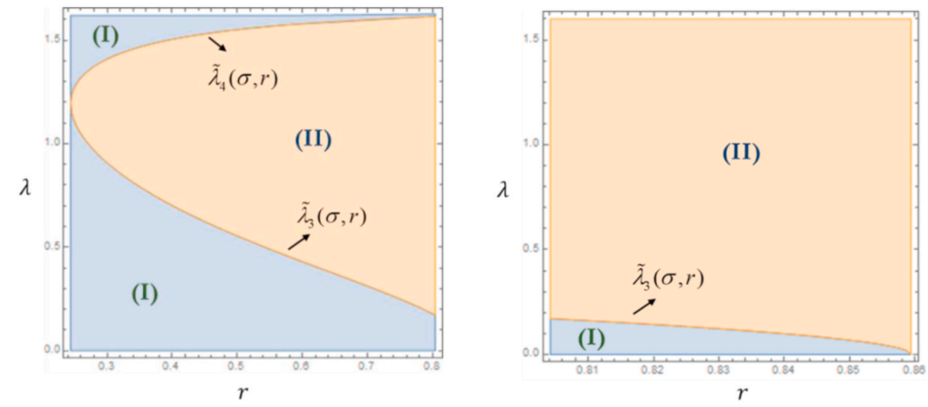
(iii) $\tilde{r}(\sigma) < r < \hat{r}(\sigma)$ *and* $\hat{\lambda}(\sigma, r) < \lambda < \tilde{\lambda}$.

Proposition 8 presents the comparative results for the performance of the whole supply chain under two contracting formats considering retailer's risk-aversion. The results show that the whole supply chain is always better off under CD format regardless of the marketing effort level when the retailers' risk-aversion level is sufficiently low. This intuitive is similar to Proposition 7. Conversely, the whole supply chain is always better off under CM format regardless of the marketing effort level when the retailer's risk-aversion level is sufficiently high, as shown in Scenario (iii). However, when the retailer's risk-aversion level is low or high, determining which contracting format (CD or CM format) can help the whole supply chain achieve the highest profit depends on the marketing effort effect, as validated in Fig. 6(a) and (b).

As illustrated in Fig. 6(a), the whole supply chain is better off under CM format when the risk aversion level is low and the marketing effort effect is moderate (i.e., Region (II) in Fig. 6(a)). The reason for this observation is that, due to the impact of the risk-aversion, the retailer

Table 5
Equilibrium results in Strategies R–CS and R-MCS.

Equilibrium result	Strategy R–CS	Strategy R-MCS
w_i	$\frac{a(-15+4\lambda^2-14r\sigma^2)+c(-11+4\lambda^2-10r\sigma^2)}{-26+8\lambda^2-24r\sigma^2}$	$\frac{2c(1+2r\sigma^2)[2(-3-2r\sigma^2)+\lambda^2(3+4r\sigma^2)]+a[\lambda^2(3+4r\sigma^2)-16(1+3r\sigma^2+2r^2\sigma^4)]}{4(-7-6r\sigma^2)(1+2r\sigma^2)+\lambda^2(3+4r\sigma^2)^2}$
p_i	$\frac{a(-15+4\lambda^2-14r\sigma^2)(-6+\lambda^2-4r\sigma^2)+c[14+4\lambda^2+56r\sigma^2+40r^2\sigma^4+\lambda^2(-19-26r\sigma^2)]}{(-26+8\lambda^2-24r\sigma^2)(-4+\lambda^2-4r\sigma^2)}$	$\frac{2c(1+2r\sigma^2)[-2(1+2r\sigma^2)+\lambda^2(3+4r\sigma^2)]+a[\lambda^2(3+4r\sigma^2)-8(3+8r\sigma^2+4r^2\sigma^4)]}{4(-7-6r\sigma^2)(1+2r\sigma^2)+\lambda^2(3+4r\sigma^2)^2}$
θ_i	$\frac{2(a-c)(1+r\sigma^2)}{13-4\lambda^2+12r\sigma^2}$	$-\frac{4(a-c)(1+2r\sigma^2)^2}{4(-7-6r\sigma^2)(1+2r\sigma^2)+\lambda^2(3+4r\sigma^2)^2}$
v_i	$\frac{(a-c)(-15+4\lambda^2-14r\sigma^2)}{2(13-4\lambda^2+12r\sigma^2)(-4+\lambda^2-4r\sigma^2)}$	$-\frac{2(a-c)\lambda(1+2r\sigma^2)(3+4r\sigma^2)}{4(-7-6r\sigma^2)(1+2r\sigma^2)+\lambda^2(3+4r\sigma^2)^2}$
δ_i	$\frac{1+4r\sigma^2[\lambda^2-3(1+r\sigma^2)]}{4(4-\lambda^2+4r\sigma^2)(1+r\sigma^2)}$	$\frac{1+4r\sigma^2}{3+4r\sigma^2}$
U_{SC}^i	$\frac{(a-c)^2[-47-108r\sigma^2-60r^2\sigma^4+4\lambda^2(3+4r\sigma^2)]}{4(13-4\lambda^2+12r\sigma^2)(-4+\lambda^2-4r\sigma^2)}$	$-\frac{4(a-c)^2(1+2r\sigma^2)^2[-4(11+24r\sigma^2+12r^2\sigma^4)+\lambda^2(15+32r\sigma^2+16r^2\sigma^4)]}{3+4r\sigma^2)(3+4r\sigma^2)(3+4r\sigma^2)^2]^2}$



(a) $\tilde{r}_1(\sigma) < r \leq \tilde{r}_2(\sigma)$ (Scenario i) (b) $\tilde{r}_2(\sigma) < r < \tilde{r}(\sigma)$ (Scenario ii)

Fig. 6. Comparison of Strategies R–CS and R-MCS. Note. **(I)** and **(II)** represent the regions in which CD and CM formats dominate, respectively.

has a stronger incentive to enhance the marketing level under CM format when the marketing effort effect are moderate and thus benefits more from increasing market demand than by contracting designing efforts with cost sharing. As a result, the payoffs of the whole supply chain increase as the total demand further grows up. Thus, the whole supply chain gains more profits under CM format in such situation. Otherwise, the whole supply chain profits more under CD format (i.e., Region (I) in Fig. 6(a)) Moreover, as indicated in Scenario (ii) of Proposition 8 (see Fig. 6(b)), when both retailer's risk-aversion level and marketing effort effect are high (i.e., Region (II) in Fig. 6(b)), the whole supply chain is better off under CM format. This is because that, considering the high risk-aversion of the downstream retailer, when the level of marketing effort effect is high, it can alleviate the profit decline of retailer through the contracting marketing cost sharing contract (i.e., CM format). In turn, the whole supply chain benefits more under CM format. On the contrary, the whole supply chain attains higher payoffs under CD format, as indicated in Region (I) in Fig. 6(b).

(a) $\tilde{r}_1(\sigma) < r \leq \tilde{r}_2(\sigma)$ (Scenario i) (b) $\tilde{r}_2(\sigma) < r < \tilde{r}(\sigma)$ (Scenario ii).

By comparing the supply chain's performance under different strategies under CD and CM formats, we have the following proposition.

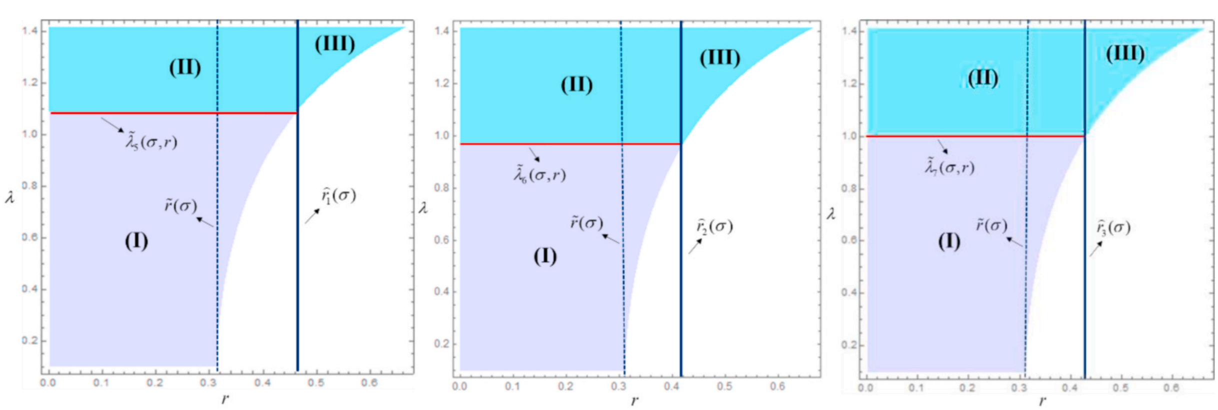
Proposition 9.

(i) *The whole supply chain achieves higher performance with the retailer's risk aversion under CD format when both the risk-aversion degree and marketing effort effect are low; otherwise, the whole supply chain achieves higher performance with the retailer's risk neutral;*

(ii) The whole supply chain obtains higher performance with the retailer's risk-neutral under CM format (i.e., marketing cost-sharing game model) when the risk-aversion degree is low and the marketing effort effect is high; otherwise, the whole supply chain obtains higher performance with the retailer's risk-aversion.

Proposition 9 indicates the impact of retailer's risk-aversion on supply chain performance under CD and CM formats. The supply chain performance under three manufacturing strategies under CD and CM format are dependent on risk-aversion degree and marketing effort effect, of which the degree of retailer's risk-aversion plays a critical role in influencing the supply chain performance, as validated in Figs. 7 and 8.

We take a close look at the condition of Scenario (i) (see Fig. 7). The retailer's risk-aversion behavior can raise the performance level of the



(a) Price-only game model (b) Cost-sharing game model (c) Revenue-sharing game model

Fig. 7. Different strategies with the retailer's risk-neutral and risk-aversion under CD format. Note. **(I)** and **(II)** represent the dominant regions in which the supply chain achieves higher performance with the retailer's risk aversion and the retailer's risk neutral, respectively, when the risk-aversion degree is low; **(III)** refers to the dominant region where the supply chain attains higher performance with the retailer's risk neutral when the risk-aversion degree is high.

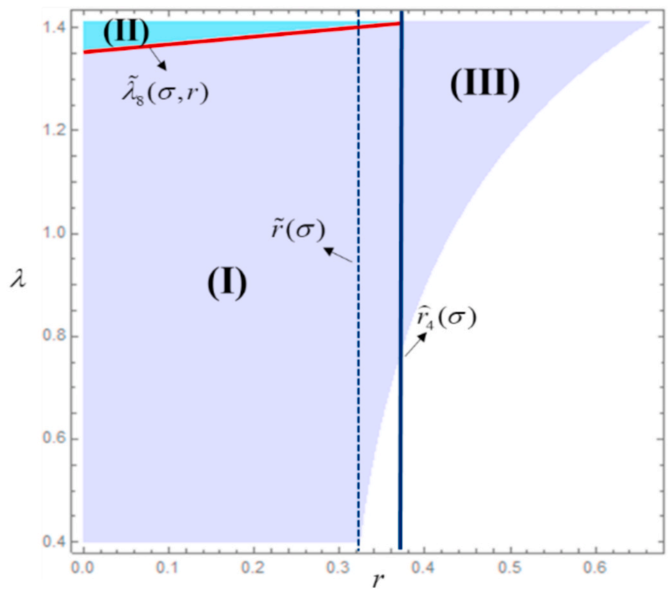


Fig. 8. Cost-sharing game model with the retailer's risk-neutral and risk-aversion under CM format. Note. **(I)** and **(II)** represent the dominant regions in which the supply chain achieves a higher performance with the retailer's risk aversion and the retailer's risk neutral, respectively, when the risk-aversion degree is low; **(III)** refers to the dominant region where the supply chain attains a higher performance with the retailer's risk neutral when the risk-aversion degree is high.

whole supply chain in different strategies under CD formats when the risk-aversion degree and marketing effort effect are low (i.e., Region (I) in Fig. 7). The reason for this finding lies in the following aspects. On the one hand, due to the impact of risk-aversion, the downstream retailer will opt to reduce marketing efforts. Correspondingly, a lower retail price will be set to increase consumers' demand. In such circumstance, risk aversion leads to the decrease in the retailer's profit. On the other hand, anticipating the retailer's reaction to risk aversion, the upstream manufacturer will enhance the products' greening level to alleviate the decrease in demand. In such case, the overall manufacturer's profit increases as the wholesale price rises up with the products' greening level. As a result, when the risk-aversion degree is low, the increase in the manufacturer's profit outweighs the decrease in the retailer's profit if the marketing effort effect is low. Therefore, the retailer's risk aversion behavior enhances the performance of the whole supply chain in such situation. If the marketing effort effect becomes sufficiently high (i.e., Region (II) of Fig. 7), the whole supply chain can attain more profit with the retailer's risk-neutral. When the risk-aversion degree is sufficiently high, the whole supply chain always profits more with the retailer's risk neutral regardless of marketing effort effect, as validated in Region (III) in Fig. 7.

In the condition of Scenario (ii) (see Fig. 8), the results derived in the CD format still hold under CM format when the risk-aversion degree is low (i.e., Regions (I) and (II) in Fig. 8). However, unlike CD format, we intriguingly find that the retailer's risk-aversion behavior always improves the performance level of the whole supply chain regardless of marketing effort effect when the retailer becomes sufficiently risk averse under CM format. The reason for this finding is that the manufacturer opts to enhance the sharing of marketing costs while increasing greening level investment due to the influence of retailer's risk-aversion under CM format. Moreover, the manufacturer provides more cost-sharing for marketing efforts as the retailer's risk-aversion degree grows up. In such circumstance, the negative impact of risk aversion on retailer's profit is effectively alleviated. Thus, the whole supply chain performance is always better off when the risk-aversion degree is sufficiently high under CM format, as shown in Region (III) in Fig. 8.

7.2. Managerial implications

Inspired by the aforementioned results and discussions, we draw some implications as follows, which provides guidelines for firms (e.g., ANGEL and Suning.com in our motivating example) in selecting different contract strategies and the contracting format in the context of circular economy era.

First, our findings suggest that downstream retailers can promote the upstream manufacturers to produce a higher level of green products through cost- or revenue-sharing contract strategies (i.e., Strategy CS or RS). Specifically, when the marketing effort effect is low, the product will be achieved a higher green level in Strategy RS. However, the product will be obtained the higher green level in Strategy CS when the marketing effort effect is high. Moreover, we find that although Strategies CS and RS increase product greenness, they are not always conducive to increasing firms' profits. In specific, product greening level improvement can benefit firms when the marketing effort effect is high or low. However, when the marketing effort effect is moderate, product greening level improvement does not necessarily lead to higher payoffs for firms. Therefore, we suggest that when determining the green incentive strategy under CD format, managers should not blindly pursue product greenness improvement to obtain a higher profit level, but should consider the actual commercial factors and understand the key drivers behind different strategies to match the 'right' type of contract strategy.

Second, in light of the equilibrium profits of the manufacturer and retailer in three different strategies under CD format, a contract strategy selection route map could be provided to operations managers. Our findings suggest that downstream retailers should actively provide cost- or revenue sharing contract strategy to upstream manufacturers. Determining which strategy can help manufacturers and retailers achieve the highest profit depends on the marketing effort effect. Specifically, engaging in revenue-sharing contract strategy is the best choice for manufacturers and retailers when the marketing effort effect is weak. However, when the marketing effort effect is strong, engaging in cost-sharing contract strategy is the best choice for manufacturers and retailers. Thus, we suggest that, in practice, downstream retailers should actively cooperate with upstream manufacturers by cost- or revenue-sharing contract strategies not only for her own sake but also for the benefit of the upstream manufacturers as well as the whole supply chain, which realizes a "win-win-win" situation.

Third, our findings reveal that, compared with CM format, the whole supply chain is always better off under CD format. That is, compared with the manufacturers' incentive on green-marketing, the retailers' incentive strategy on green innovation make the whole supply chain more profitable. Table 6 summarizes the dominant contracting strategies and formats from the perspective of the supply chain. By contracting designing green products with cost sharing, upstream manufacturers have a stronger incentive to improve product greening level and thus benefit more from increasing market demand than by contracting marketing efforts with cost sharing. This situation, in turn, can increase payoffs of the supply chain as the total demand further increases under CD format. Along with this finding, we suggest that, from the perspective of the whole supply chain, managers, such as those in Procter & Gamble and WalMart, should change their mindset and integrate green innovation into their strategic agenda in practice to reap the greatest market share and benefit.

Forth, by extending the basic model to the case where the retailer is risk-averse, we find that our core conclusions still hold under CD format (see Table 6). Moreover, for the selection of contracting format in cost-sharing contract from the perspective of the whole supply chain, we suggest that managers should consider key business factors such as risk-aversion degree and marketing effort effect to select the optimal contracting format. In specific, when the retailer's risk-aversion degree is low and marketing effort effect is moderate, or both the retailer's risk-aversion degree and marketing effort effect are high, or the retailer's

Table 6
Dominant contracting strategies and formats for the supply chain.

Models	Formats	Conditions	Price-only	Cost-sharing	Revenue-sharing
The base model	CD format	$\lambda > \widetilde{\lambda}_2$	Dominated	Dominant	Dominated
		$\lambda < \widetilde{\lambda}_2$	Dominated	Dominated	Dominant
	CM format		Dominated	Dominant	\
	Dominant formats		\	CD dominates	CD dominates
Retailer risk-aversion model	CD format	$\lambda > \widehat{\lambda}(\sigma,r)$	Dominated	Dominant	Dominated
		$\lambda < \widehat{\lambda}(\sigma,r)$	Dominated	Dominated	Dominant
	CM format		Dominated	Dominant	\
	Dominant formats	$0 < r \le \widetilde{r}_1(\sigma)$ $0 < \lambda < \widetilde{\lambda}$ $\widetilde{r}_1(\sigma) < r \le \widetilde{r}_2(\sigma)$ $\lambda > \widetilde{\lambda}_4(\sigma,r)$ $\lambda < \widetilde{\lambda}_3(\sigma,r)$ $\widetilde{r}_2(\sigma) < r < \widetilde{r}(\sigma)$ $\lambda < \widetilde{\lambda}_3(\sigma,r)$	\	CD dominates	CD dominates
		$\widetilde{r}_1(\sigma) < r \le \widetilde{r}_2(\sigma)$ $\widetilde{\lambda}_3(\sigma,r) < \lambda < \widetilde{\lambda}_4(\sigma,r)$ $\widetilde{r}_2(\sigma) < r < \widetilde{r}(\sigma)$ $\widetilde{\lambda}_3(\sigma,r) < \lambda < \widetilde{\lambda}$ $\widetilde{r}(\sigma) < r < \widehat{r}(\sigma)$ $\widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda}$	\	CM dominates	CD dominates

Note: The detailed comparison results of CD format considering retailer risk-aversion are shown in the appendix.

risk-aversion degree is sufficient high, CM format can make the whole supply chain further profitable. Otherwise, CD format is the best choice for the whole supply chain. This by complementing the conventional understanding provides vital guidance for managers in selecting the appropriate contracting formats from the perspective of the whole supply chain.

Finally, our findings show that, by comparing the supply chain's performance under different strategies under CD and CM formats, the retailer's risk aversion behavior may improve the performance of the whole supply chain. In specific, under CD format, when the risk-aversion degree and marketing effort effect are relatively low, the retailer's risk-aversion behavior improves the performance level of the whole supply chain; otherwise, the whole supply chain achieves higher performance with the retailer's risk-neutral. However, under CM format (i.e., marketing cost-sharing game model), we find that when the risk-aversion degree is relatively low and the marketing effort effect is relatively high, the whole supply chain obtains higher performance with the retailer's risk-neutral; otherwise, the retailer's risk-aversion behavior enhances the performance level of the whole supply chain. Underpinned by this finding, we suggest that, from the perspective of the whole supply chain, managers should consider the key business factors, such as risk aversion behavior and manufacturing effort effect, to maximize supply chain performance.

8. Concluding remarks and future research

In this study, we investigate a green product supply chain where market demand depends on the product greening level selected by the manufacturer and the marketing effort chosen by the retailer. To meet the market demand and increase market competitiveness, the manufacturer invests in developing green technology to produce green products, and the retailer invests in marketing effort to promote these products. We specifically consider two widely-adopted contracting formats: contracting designing (CD) and contracting marketing (CM). We first discuss three contract strategies under CD format, namely, price-only, cost-sharing, and revenue-sharing game models. We then investigate the corresponding contracts under CM format and compare CD and CM formats to derive interesting implications for supply chains. Moreover, we extend our research in the basic model to a case where the retailer is risk averse, comparing the cost-sharing contract strategy under CD and CM formats and investigating the influence of retailer's risk-aversion on supply chain performance to derive several interesting implications.

8.1. Key findings

Through the study, propositions are proposed above which can provide managerial implications to operation managers. In particular, certain interesting findings are obtained and summarized as the below.

First, we reveal that, under CD format, the equilibrium wholesale price, marketing effort and retail price in Strategy PO are always higher than those in Strategy RS but are consistently lower than those in Strategy CS. *Second,* compared with Strategy PO, higher product greening levels are obtained in Strategies CS and RS. Determining which strategy can achieve the highest product greening level depends on the marketing effort effect. Interestingly, we demonstrate that product greening level improvement can benefit firms when the marketing effort effect is high or low. However, when the marketing effort effect is moderate, such an improvement does not necessarily lead to higher payoffs for firms. *Third,* the preferred strategy for the manufacturer and retailer is either Strategy RS or Strategy CS, and Strategy PO cannot be the dominant strategy under CD format. Specifically, when the marketing effort effect is weak, the manufacturer and retailer prefer Strategy RS. Conversely, Strategy CS is the dominant strategy for the manufacturer and retailer when the marketing effort effect is strong. *Fourth,* compared with CM format, we find that the whole supply chain is always better off under CD format. *Finally,* we extend our research to a case with retailer risk-aversion. The results derived in the basic model still hold under CD format in such a case. However, given the cost-sharing contract under CD and CM formats, we find that when the retailer's risk-aversion degree is sufficient low, or the retailer's risk-aversion degree is low and marketing effort effect is low or high, or the retailer's risk-aversion degree is high and the marketing effort effect is low, the whole supply chain profits more under CD format; otherwise, the whole supply chain attains higher performance under CM format. In addition, we illustrate the impact of retailer's risk-aversion on supply chain performance under CD and CM formats, and find that the retailer's risk aversion behavior may improve the performance of the whole supply chain in certain conditions.

8.2. Limitations and future research

Our study also exhibits limitations that may initiate future research. First, we assume that information (e.g., demand information and technology investment information) is symmetric. However, in practice, such information may be asymmetric among firms. Thus, incorporating such information asymmetry would be an interesting and worthwhile direction (Li et al., 2020b). Second, our study has focused on a typical situation in which the retailer has risk-averse behavior. In the future, it would be also interesting to investigate both firms' risk-averse behavior in such a supply chain.

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Appendix

Part A (Solution of equilibrium results under different strategies)

Strategy PO

We first solve the retailer's profit function. We substitute $D_{PO} = a - p_{PO} + \theta_{PO} + \lambda v_{PO}$ into Equation (1). The first-order condition yields $p_{PO} = \frac{2a+2w-w\lambda^2+2\theta}{4-\lambda^2}$ and $v_{PO} = \frac{\lambda(a-w+\theta)}{4-\lambda^2}$. We then plug $p_{PO} = \frac{2a+2w-w\lambda^2+2\theta}{4-\lambda^2}$ and $v_{PO} = \frac{\lambda(a-w+\theta)}{4-\lambda^2}$ into Equation (2), and can obtain $w_{PO} = \frac{a(-4+\lambda^2)+c(-3+\lambda^2)}{-7+2\lambda^2}$ and $\theta_{PO} = \frac{a-b}{7-2\lambda^2}$ by solving the first-order optimality condition. Substituting w_{PO} and θ_{PO} into $p_{PO} = \frac{2a+2w-w\lambda^2+2\theta}{4-\lambda^2}$ and $v_{PO} = \frac{\lambda(a-w+\theta)}{4-\lambda^2}$, we can obtain $p_{PO} = \frac{a(6-\lambda^2)+c(1-\lambda^2)}{7-2\lambda^2}$ and $v_{PO} = \frac{(a-c)\lambda}{7-2\lambda^2}$. In accordance with the above results, we can obtain $\pi_M^{PO} = \frac{(a-c)^2}{7-2\lambda^2}$ and $\pi_R^{PO} = \frac{(a-c)^2(4-\lambda^2)}{(7-2\lambda^2)^2}$. Furthermore, we demonstrate that when $0 < \lambda < \sqrt{\frac{7}{2}}$, the Hessian Matrix H meets the condition of $H > 0$ and the equilibrium results are non-negative.

Strategy CS

We substitute $D_{CS} = a - p_{CS} + \theta_{CS} + \lambda v_{CS}$ into Equation (3). The first-order condition yields $p_{CS} = \frac{2a+2w-w\lambda^2+2\theta}{4-\lambda^2}$ and $v_{CS} = \frac{\lambda(a-w+\theta)}{4-\lambda^2}$. We then plug p_{CS} and v_{CS}into π_M^{CS}, and can obtain $w_{CS} = \frac{a(-1+\delta)(-4+\lambda^2)+c[3-\lambda^2+\delta(-4+\lambda^2)]}{7-2\lambda^2+2\delta(-4+\lambda^2)]}$ and $\theta_{CS} = \frac{a-c}{7-8\delta-2\lambda^2+2\delta\lambda^2}$ by solving the first-order optimality condition. Substituting w_{CS} and θ_{CS} into $p_{CS} = \frac{2a+2w-w\lambda^2+2\theta}{4-\lambda^2}$ and $v_{CS} = \frac{\lambda(a-w+\theta)}{4-\lambda^2}$, we can obtain$p_{CS} = \frac{a(-1+\delta)(-6+\lambda^2)+c[1-\lambda^2+\delta(-2+\lambda^2)]}{7-2\lambda^2+2\delta(-4+\lambda^2)]}$ and $v_{CS} = \frac{(a-c)(1-\delta)\lambda}{7-2\lambda^2+2\delta(-4+\lambda^2)}$.

Substituting p_{CS}, θ_{CS}, v_{CS}, and w_{CS} into Equation (3), we can obtain $\delta = \frac{1}{4(4-\lambda^2)}$ by solving the first-order optimality condition of δ. Finally, substituting $\delta = \frac{1}{4(4-\lambda^2)}$ into the above expression, we can obtain$w_{CS} = \frac{15a+11c-4a\lambda^2-4c\lambda^2}{26-8\lambda^2}$, $p_{CS} = \frac{a(6-\lambda^2)(15-4\lambda^2)+c[32+5\lambda^2+4\lambda^4-6(4\lambda^2+3)]}{2(4-\lambda^2)(13-4\lambda^2)}$, $\theta_{CS} = \frac{2a-2c}{13-4\lambda^2}$, and $v_{CS} = \frac{\lambda(a-c)(15-4\lambda^2)}{2(4-\lambda^2)(13-4\lambda^2)}$. In accordance with the above results, we can obtain $\pi_M^{CS} = \frac{(a-c)^2(15-4\lambda^2)}{2(4-\lambda^2)(13-4\lambda^2)}$ and $\pi_R^{CS} = \frac{(a-c)^2(17-4\lambda^2)}{4(4-\lambda^2)(13-4\lambda^2)}$. Furthermore, we derive that when $0 < \lambda < \sqrt{\frac{13}{4}}$, the Hessian Matrix H meets the condition of $H > 0$ and the equilibrium results are non-negative in Strategy CS.

Strategy RS

We first solve the retailer's profit function. The first-order condition yields $p_{RS} = \frac{2a-2a\varphi+2w-w\lambda^2+2\theta-2\theta\varphi+\varphi w\lambda^2}{(1-\varphi)(4-\lambda^2+\varphi\lambda^2)}$ and $v_{RS} = \frac{(-a+a\varphi+w-\theta+\theta\varphi)\lambda}{4-\lambda^2+\varphi\lambda^2}$. We then plug p_{RS} and v_{RS}into π_M^{RS}, and can obtain $w_{RS} = \frac{(-1+\varphi)[-a(-1+\varphi)(4-\lambda^2)+c(3+(-1+\varphi)\lambda^2)]}{1+4(-2+\varphi)-2(-1+\varphi)\lambda^2}$ and $\theta_{RS} = \frac{a-c}{-7+4\varphi+2\lambda^2-2\varphi\lambda^2}$ by solving the first-order optimality condition. Substituting w_{RS} and θ_{RS} into $p_{RS} = \frac{2a-2a\varphi+2w-w\lambda^2+2\theta-2\theta\varphi+\varphi w\lambda^2}{(1-\varphi)(4-\lambda^2+\varphi\lambda^2)}$ and $v_{RS} = \frac{(-a+a\varphi+w-\theta+\theta\varphi)\lambda}{4-\lambda^2+\varphi\lambda^2}$, we can obtain$p_{RS} = \frac{c[-1-(-1+\varphi)\lambda^2]+a[2(-3+2\varphi)+(-1+\varphi)\lambda^2)]}{1+4(-2+\varphi)-2(-1+\varphi)\lambda^2}$ and $v_{RS} = \frac{(a-c)(-1+\varphi)\lambda}{1+4(-2+\varphi)-2(-1+\varphi)\lambda^2}$.

Substituting p_{RS}, θ_{RS}, v_{RS}, and w_{RS} into Equation (5), we can obtain $\varphi = \frac{2-\lambda^2}{8-\lambda^2}$ by solving the first-order optimality condition of φ. Finally, substituting $\varphi = \frac{2-\lambda^2}{8-\lambda^2}$ into the above expression, we can obtain$w_{RS} = \frac{6(8a+8c-2a\lambda^2-3c\lambda^2)}{(8-\lambda^2)(16-5\lambda^2)}$, $p_{RS} = \frac{8a(5-\lambda^2)+c[16+\lambda^2-8(\lambda^2+1)]}{3(16-5\lambda^2)}$, $\theta_{RS} = \frac{(a-c)(8-\lambda^2)}{3(16-5\lambda^2)}$, and $v_{RS} = \frac{2\lambda(a-c)}{16-5\lambda^2}$. In accordance with the above results, we can obtain $\pi_M^{RS} = \frac{(a-c)^2(8-\lambda^2)}{3(16-5\lambda^2)}$ and $\pi_R^{RS} = \frac{4(a-c)^2}{3(16-5\lambda^2)}$. Furthermore, we demonstrate that when $0 < \lambda < \sqrt{2}$, the Hessian Matrix H meets the condition of $H > 0$, the equilibrium results are non-negative, and the proportion of revenue sharing satisfies $0 < \varphi < 1$. That is, Strategy RS exists.

Strategy MCS

We first solve the retailer's profit function. The first-order condition yields $p_{MCS} = -\frac{2(1-\delta_{MCS})(a+w+\theta)-w\lambda^2}{-4(1-\delta_{MCS})+\lambda^2}$ and $v_{MCS} = -\frac{(a-w+\theta)\lambda}{-4(1-\delta_{MCS})+\lambda^2}$. We then plug p_{MCS} and v_{MCS}into π_M^{MCS}, and can obtain $w_{MCS} = \frac{-c(-1+\delta_{MCS})^2+4(a+c)(-1+\delta_{MCS})^2+\lambda^2[c(-1+\delta_{MCS})+a(-1+2\delta_{MCS})]}{7(-1+\delta_{MCS})^2+(-2+3\delta_{MCS})\lambda^2}$ and $\theta_{MCS} = \frac{(a-c)(-1+\delta_{MCS})^2}{7+7\delta_{MCS}^2-2\lambda^2+\delta_{MCS}(-14+3\lambda^2)}$ by solving the first-order optimality condition. Substituting w_{MCS} and θ_{MCS} into $p_{MCS} = -\frac{2(1-\delta_{MCS})(a+w+\theta)-w\lambda^2}{-4(1-\delta_{MCS})+\lambda^2}$ and $v_{MCS} = -\frac{(a-w+\theta)\lambda}{-4(1-\delta_{MCS})+\lambda^2}$, we can obtain$p_{MCS} = \frac{c(-1+\delta_{MCS})(-1+\delta_{MCS}+\lambda^2)+a[6(-1+\delta_{MCS})^2+\lambda^2(-1+2\delta_{MCS})]}{7(-1+\delta_{MCS})^2+(-2+3\delta_{MCS})\lambda^2}$ and $v_{MCS} = \frac{\lambda(-1+\delta_{MCS})(a-c)}{7(-1+\delta_{MCS})^2+(-2+3\delta_{MCS})\lambda^2}$.

Substituting p_{MCS}, θ_{MCS}, v_{MCS}, and w_{MCS} into Equation (8), we can obtain $\delta_{MCS} = \frac{1}{3}$ by solving the first-order optimality condition of δ_{MCS}. Finally, substituting $\delta_{MCS} = \frac{1}{3}$ into the above expression, we can obtain$w_{MCS} = \frac{a(16-3\lambda^2)+2c(6-3\lambda^2)}{28-9\lambda^2}$, $p_{MCS} = \frac{3a(8-\lambda^2)+2c(2-3\lambda^2)}{28-9\lambda^2}$, $\theta_{MCS} = \frac{4(a-c)}{28-9\lambda^2}$, and $v_{MCS} = \frac{6\lambda(a-c)}{28-9\lambda^2}$. According to the above results, we can obtain that the profits of manufacturer, retailer and supply chain are $\pi_M^{MCS} = \frac{4(a-c)^2}{28-9\lambda^2}$, $\pi_R^{MCS} = \frac{8(a-c)^2(8-3\lambda^2)}{(-28+9\lambda^2)^2}$ and

$\pi_{SC}^{MCS} = \frac{4(a-c)^2(44-15\lambda^2)}{(-28+9\lambda^2)^2}$. Furthermore, by calculating, we find that when $0 < \lambda < \sqrt{\frac{8}{3}}$, the Hessian matrix is negative-definite and the equilibrium results are non-negative. Moreover, based on the analysis results in Strategies PO, CS and RS, we assume that $0 < \lambda < \widetilde{\lambda} < Min\left\{\sqrt{\frac{7}{2}}, \sqrt{\frac{13}{4}}, \sqrt{2}, \sqrt{\frac{8}{3}}\right\} = \sqrt{2}$ in our basic model.

Retailer risk aversion

When the downstream retailer is risk averse, the solution of equilibrium results under different strategies are similar to that basic model; hence, we omit the detail process for brevity. Moreover, similar to the basic model, to obtain the channel members' optimal decisions and guarantee the non-negativity of the optimal solutions, our study focuses on the case of $0 < r \le \widetilde{r}(\sigma) = \frac{-3+2\sqrt{3}}{6\sigma^2}$ and $0 < \lambda < \widetilde{\lambda} = \sqrt{2}$, or $\frac{-3+2\sqrt{3}}{6\sigma^2} = \widetilde{r}(\sigma) < r < \widehat{r}(\sigma) = \frac{1}{6\sigma^2}$ and $\frac{1}{2}\sqrt{\frac{-1+12r\sigma^2+12r^2\sigma^4}{r\sigma^2}} = \widehat{\lambda}(\sigma, r) < \lambda < \widetilde{\lambda} = \sqrt{2}$ in the extension.

Part B (Proof)

Proof of Corollary 1

Proof: By calculating the first derivative of wholesale price to λ, we have $\frac{\partial w_{PO}}{\partial \lambda} = \frac{2\lambda(a-c)}{(7-2\lambda^2)^2} > 0$. By calculating the first derivative of retail price to λ, $\frac{\partial p_{PO}}{\partial \lambda} = \frac{10\lambda(a-bc)}{(7-2\lambda^2)^2} > 0$. By calculating the first derivative of greening level to λ, $\frac{\partial \theta_{PO}}{\partial \lambda} = \frac{4\lambda(a-bc)}{(7-2\lambda^2)^2} > 0$. By calculating the first derivative of marketing effort to λ,$\frac{\partial v_{PO}}{\partial \lambda} = \frac{(a-c)(7+2\lambda^2)}{(7-2\lambda^2)^2} > 0$. By calculating the first derivative of market demand to λ, $\frac{\partial D_{PO}}{\partial \lambda} = \frac{8\lambda(a-c)}{(7-2\lambda^2)^2} > 0$. Moreover, by calculating the first derivative of manufacturer's and retailer's profit to λ, we have $\frac{\partial \pi_R^{PO}}{\partial \lambda} = \frac{2\lambda(a-c)^2(-9+2\lambda^2)}{(-7+2\lambda^2)^3} > 0$ and $\frac{\partial \pi_M^{PO}}{\partial \lambda} = \frac{4\lambda(a-c)^2}{(7-2\lambda^2)^2} > 0$.

Proof of Corollary 2.

Proof: By calculating the first derivative of wholesale price to λ, we have $\frac{\partial w_{CS}}{\partial \lambda} = \frac{8\lambda(a-c)}{(13-4\lambda^2)^2} > 0$. By calculating the first derivative of retail price to λ, we have $\frac{\partial p_{CS}}{\partial \lambda} = \frac{2(a-c)\lambda(291-152\lambda^2+20\lambda^4)}{(52-29\lambda^2+4\lambda^4)^2} > 0$. By calculating the first derivative of greening level to λ, we have $\frac{\partial \theta_{CS}}{\partial \lambda} = \frac{16\lambda(a-c)}{(13-4\lambda^2)^2} > 0$. By calculating the first derivative of marketing effort to λ, we have $\frac{\partial v_{CS}}{\partial \lambda} = \frac{(a-c)(780-189\lambda^2-64\lambda^4+16\lambda^6)}{2(52-29\lambda^2+4\lambda^4)^2} > 0$. By calculating the first derivative of market demand to λ, we have $\frac{\partial D_{CS}}{\partial \lambda} = \frac{2\lambda(a-c)(227+16\lambda^4-120\lambda^2)}{(52-29\lambda^2+4\lambda^4)^2} > 0$. Moreover, by calculating the first derivative of manufacturer's and retailer's profit to λ, we have $\frac{\partial \pi_M^{CS}}{\partial \lambda} = \frac{\lambda(a-c)^2(227+16\lambda^4-120\lambda^2)}{(52-29\lambda^2+4\lambda^4)^2} > 0$ and $\frac{\partial \pi_R^{CS}}{\partial \lambda} = \frac{\lambda(a-c)^2(285+16\lambda^4-136\lambda^2)}{2(52-29\lambda^2+4\lambda^4)^2} > 0$.

Proof of Corollary 3.

Proof: By calculating the first derivative of wholesale price to λ, we have $\frac{\partial w_{RS}}{\partial \lambda} = \frac{12\lambda[2a(96-40\lambda^2+5\lambda^4)+c(64-80\lambda^2+5\lambda^4)]}{(16-5\lambda^2)^2(-8+\lambda^2)^2} > 0$. By calculating the first derivative of retail price to λ, we have $\frac{\partial p_{RS}}{\partial \lambda} = \frac{48\lambda(a-c)}{(16-5\lambda^2)^2} > 0$. By calculating the first derivative of greening level to λ, we have $\frac{\partial \theta_{RS}}{\partial \lambda} = \frac{16(a-c)\lambda}{(16-5\lambda^2)^2} > 0$. By calculating the first derivative of marketing effort to λ, we have $\frac{\partial v_{RS}}{\partial \lambda} = \frac{2(a-c)(16+5\lambda^2)}{(16-5\lambda^2)^2} > 0$. By calculating the first derivative of market demand to λ, we have $\frac{\partial D_{RS}}{\partial \lambda} = \frac{32\lambda(a-c)}{(16-5\lambda^2)^2} > 0$. Moreover, by calculating the first derivative of manufacturer's and retailer's profit to λ, we have $\frac{\partial \pi_R^{RS}}{\partial \lambda} = \frac{40\lambda(a-c)^2}{3(16-5\lambda^2)^2} > 0$, $\frac{\partial \pi_M^{RS}}{\partial \lambda} = \frac{16\lambda(a-c)^2}{(16-5\lambda^2)^2} > 0$.

Proof of Proposition 1.

Proof: According to the equilibrium greening level in Strategies CS and PO in Table 3, we have $\theta_{CS} - \theta_{PO} = \frac{a-c}{(13-4\lambda^2)(7-2\lambda^2)}$. Given that $0 < \lambda < \sqrt{2}$, the denominator is greater than zero. Thus, $\theta_{CS} > \theta_{PO}$ is firmly established.

According to the equilibrium greening level in Strategies CS and RS in Table 3, we have $\theta_{CS} - \theta_{RS} = -\frac{(a-c)(8-15\lambda^2+4\lambda^4)}{624-387\lambda^2+60\lambda^4}$. Let $G(\lambda) = -\frac{(8-15\lambda^2+4\lambda^4)}{624-387\lambda^2+60\lambda^4}$. We derive that when $0 < \lambda < \sqrt{2}$, a threshold $\widetilde{\lambda}_1 = \frac{1}{2}\sqrt{\frac{1}{2}(15-\sqrt{97})}$exists. When,$0 < \lambda < \widetilde{\lambda}_1$ we have.$G(\lambda, \tau) < 0$ When,$\lambda > \widetilde{\lambda}_1$ we have.$G(\lambda, \tau) > 0$

According to the equilibrium greening level in Strategies RS and PO in Table 3, we have $\theta_{RS} - \theta_{PO} = \frac{2(a-c)(\lambda^2-1)^2}{3(16-5\lambda^2)(7-2\lambda^2)}$. Given that $0 < \lambda < \sqrt{2}$, the denominator and numerator are greater than zero. Hence, $\theta_{RS} > \theta_{PO}$ is firmly established.

Proof of Proposition 2.

Proof: According to the equilibrium wholesale price in Strategies CS and PO in Table 3, we have $w_{CS} - w_{PO} = \frac{a-c}{2(13-4\lambda^2)(7-2\lambda^2)}$. Given that $0 < \lambda < \sqrt{2}$, the denominator is greater than zero. Thus, $w_{PO} < w_{CS}$ is firmly established.

According to the equilibrium wholesale price in Strategies RS and PO in Table 3, we have $w_{RS} - w_{PO} = \frac{(2-\lambda^2)[a(88-42\lambda^2+5\lambda^4)+c(24-25\lambda^2+5\lambda^4)]}{(-16+5\lambda^2)(-8+\lambda^2)(-7+2\lambda^2)}$. Given that $0 < \lambda < \sqrt{2}$, the numerator is greater than zero, while the denominator is less than zero. Therefore, $w_{PO} > w_{RS}$ is firmly established.

Proof of Proposition 3.

Proof: According to the equilibrium marketing effort in Strategies CS and PO in Table 3, we have $v_{CS} - v_{PO} = \frac{(-a+c)\lambda}{2(-364+307\lambda^2-86\lambda^4-8\lambda^6)}$. Obviously, given that $0 < \lambda^2 < 2$, the denominator and numerator are less than zero, and thus $v_{CS} > v_{PO}$ is firmly established.

According to the equilibrium marketing effort in Strategies RS and PO in Table 3, we have $v_{RS} - v_{PO} = \frac{(a-c)(\lambda^2-2)}{(112-67\lambda^2+10\lambda^4)}$. Obviously, given that $0 < \lambda^2 < 2$ holds, the denominator is greater than zero while the numerator is less than zero. Thus, $v_{PO} > v_{RS}$ is firmly established.

Proof of Proposition 4.

Proof: According to the equilibrium retail price in Strategies CS and PO in Table 3, we have $p_{CS} - p_{RS} = -\frac{(a-c)(160-70\lambda^2-7\lambda^4+4\lambda^6)}{6(-16+5\lambda^2)(-13+4\lambda^2)(-4+\lambda^2)}$. Given that $0 <$

$\lambda^2 < 2$, the numerator is greater than zero. Obviously, the numerator is less than zero. Therefore, $p_{CS} > p_{RS}$ is firmly established.

According to the equilibrium retail price in Strategies RS and PO in Table 3, we have $p_{RS} - p_{PO} = \frac{(a-c)(-8+2\lambda^2+\lambda^4)}{336-201\lambda^2+30\lambda^4}$. Obviously, given that $0 < \lambda^2 < 2$ holds, the denominator is greater than zero while the numerator is less than zero. Thus, $p_{PO} > p_{RS}$ is firmly established.

Proof of Proposition 5.

Proof: According to the manufacturer's profit in Strategies CS and PO in Table 3, we have $\pi_M^{CS} - \pi_M^{PO} = \frac{(a-c)^2}{2(364-307\lambda^2+86\lambda^4-8\lambda^6)}$. Obviously, given that $0 < \lambda^2 < 2$, the denominator is are greater than zero, and thus $\pi_M^{CS} > \pi_M^{PO}$ is firmly established.

According to the manufacturer's profit in Strategies CS and RS in Table 3, we have $\pi_M^{CS} - \pi_M^{RS} = -\frac{(a-c)^2(-112+151\lambda^2-62\lambda^4+8\lambda^6)}{6(-16+5\lambda^2)(-4+\lambda^2)(-13+4\lambda^2)}$. Let $\Theta(\lambda) = -\frac{(a-c)^2}{6(-16+5\lambda^2)(-4+\lambda^2)(-13+4\lambda^2)}$. Obviously, $\Theta(\lambda) > 0$ holds. Let $H(\lambda) = (-112 + 151\lambda^2 - 62\lambda^4 + 8\lambda^6)$. We demonstrate that when $0 < \lambda^2 < 2$, the threshold $\widetilde{\lambda}_2 = \frac{1}{4}(-1+\sqrt{33})$ exists. Moreover, when $0 < \lambda < \widetilde{\lambda}_2$, we have $H(\lambda) < 0$. Conversely, $H(\lambda) > 0$ when $\lambda > \widetilde{\lambda}_2$. Therefore, we can demonstrate that $\pi_M^{RS} > \pi_M^{CS}$ when $0 < \lambda < \widetilde{\lambda}_2$; otherwise, $\pi_M^{RS} < \pi_M^{CS}$.

According to the manufacturer's profit in Strategies RS and PO in Table 3, we have $\pi_M^{RS} - \pi_M^{PO} = \frac{2(a-c)^2(\lambda^2-2)^2}{336-201\lambda^2+30\lambda^4}$. Given that $0 < \lambda^2 < 2$, the denominator is greater than zero. Thus, $\pi_M^{RS} > \pi_M^{PO}$ is firmly established.

Proof of Proposition 6.

Proof: According to the retailer's profit in Strategies CS and PO in Table 3, we have $\pi_R^{CS} - \pi_R^{PO} = \frac{(a-c)^2}{4(4-\lambda^2)(13-4\lambda^2)(7-2\lambda^2)}$. Obviously, the denominator and numerator are greater than zero. Thus, $\pi_R^{CS} > \pi_R^{PO}$ is firmly established.

According to the retailer's profit in Strategies CS and RS in Table 3, we have $\pi_R^{CS} - \pi_R^{RS} = \frac{(a-c)^2(16-17\lambda^2+4\lambda^4)}{12(-16+5\lambda^2)(-4+\lambda^2)(-13+4\lambda^2)}$. Let $D(\lambda) = \frac{(a-c)^2}{12(-16+5\lambda^2)(-4+\lambda^2)(-13+4\lambda^2)}$. Obviously, $D(\lambda) > 0$ holds. Let $T(\lambda) = 16 - 17\lambda^2 + 4\lambda^4$. We can derive that when $0 < \lambda^2 < 2$, the threshold $\widetilde{\lambda}_2 = \frac{1}{4}(-1+\sqrt{33})$ exists. Moreover, we have $T(\lambda) < 0$when $0 < \lambda < \widetilde{\lambda}_2$. On the contrary, $T(\lambda) > 0$ when $\lambda > \widetilde{\lambda}_2$. Therefore, we can derive that $\pi_R^{RS} > \pi_R^{CS}$ when $0 < \lambda < \widetilde{\lambda}_2$; otherwise, $\pi_R^{RS} < \pi_R^{CS}$.

According to the retailer's profit in Strategies RS and PO in Table 3, we have $\pi_R^{RS} - \pi_R^{PO} = \frac{(a-c)^2(\lambda^2-2)^2}{3(15-4\lambda^2)(7-2\lambda^2)}$. Given that $0 < \lambda^2 < 2$, the denominator and numerator are greater than zero, and thus $\pi_R^{RS} > \pi_R^{PO}$ is firmly established.

Proof of Proposition 7.

Proof: According to the profit of whole supply chain in Tables 3 and 4, we have $\pi_{SC}^{MCS} - \pi_{SC}^{CS} = \frac{(a-c)^2(-240+200\lambda^2-79\lambda^4+12\lambda^6)}{4(28-9\lambda^2)^2(52-29\lambda^2+4\lambda^4)}$. Given that $0 < \lambda^2 < 2$, the denominator is greater than zero. Let $E = -240 + 200\lambda^2 - 79\lambda^4 + 12\lambda^6$ and $y = \lambda^2$, and then $F = \frac{\partial E}{\partial y} = 200 - 158y + 36y^2$ and $G = \frac{\partial F}{\partial y} = -158 + 72y < 0$. We can find that F decreases with y. Consequently, we can derive that $MinF|_{y\to 2} = 28 > 0$. Thus, F increases with y, and then we can derive that $MaxE|_{y\to 2} = -60 < 0$. Thus, $\pi_{SC}^{MCS} < \pi_{SC}^{CS}$ is firmly established.

Proof of Proposition 8.

Proof. In accordance with cost-sharing contract with retailer's risk-aversion under CD and CM format in Table 5, we have $U_{SC}^{R-MCS} - U_{SC}^{R-CS} = \frac{1}{4}(a-c)^2\left[\frac{-47-108r\sigma^2-60r^2\sigma^4+4\lambda^2(3+4r\sigma^2)}{(-13+4\lambda^2-12r\sigma^2)(-4+\lambda^2-4r\sigma^2)} - \frac{16(1+2r\sigma^2)^2[-4(11+24r\sigma^2+12r^2\sigma^4)+\lambda^2(15+32r\sigma^2+16r^2\sigma^4)]}{3+3+4r\sigma^2)(3+3+4r\sigma^2)(3+3+4r\sigma^2)^2-4(7+20r\sigma^2+12r^2\sigma^4)]^2}\right]$. Let $\Psi(r,\lambda) = \frac{-47-108r\sigma^2-60r^2\sigma^4+4\lambda^2(3+4r\sigma^2)}{(-13+4\lambda^2-12r\sigma^2)(-4+\lambda^2-4r\sigma^2)} - \frac{16(1+2r\sigma^2)^2[-4(11+24r\sigma^2+12r^2\sigma^4)+\lambda^2(15+32r\sigma^2+16r^2\sigma^4)]}{3+3+4r\sigma^2)(3+3+4r\sigma^2)(3+3+4r\sigma^2)^2-4(7+20r\sigma^2+12r^2\sigma^4)]^2}$.

We can derive that $\Psi(r,\lambda)$ is always greater than zero when $\frac{-3+2\sqrt{3}}{6\sigma^2} = \widetilde{r}(\sigma) < r < \widehat{r}(\sigma) = \frac{1}{6\sigma^2}$ and $\frac{1}{2}\sqrt{\frac{-1+12r\sigma^2+12r^2\sigma^4}{r\sigma^2}} = \widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda} = \sqrt{2}$. However, when $0 < r \le \widetilde{r}(\sigma) = \frac{-3+2\sqrt{3}}{6\sigma^2}$, $0 < \lambda < \widetilde{\lambda} = \sqrt{2}$, we can derive that the thresholds of $\widetilde{\lambda}_3(\sigma,r)$ and $\widetilde{\lambda}_4(\sigma,r)$ exist. When $\widetilde{\lambda}_3(\sigma,r) < \lambda < \widetilde{\lambda}_4(\sigma,r)$, $\Psi(r,\lambda) > 0$ is established. Furthermore, we can derive that the thresholds of $\widetilde{r}_1(\sigma)$ and $\widetilde{r}_2(\sigma)$ exist. When $0 < r < \widetilde{r}_1(\sigma)$, the thresholds of $\widetilde{\lambda}_3(\sigma,r)$ and $\widetilde{\lambda}_4(\sigma,r)$ are less than zero. Moreover, the threshold of $\widetilde{\lambda}_4(\sigma,r)$ is greater than $\widetilde{\lambda}$ when $\widetilde{r}_2(\sigma) < r < \widetilde{r}(\sigma)$. Thus, $U_{SC}^{MCS} > U_{SC}^{CS}$ is established when $\widetilde{r}_1(\sigma) < r \le \widetilde{r}_2(\sigma)$ and $\widetilde{\lambda}_3(\sigma,r) < \lambda < \widetilde{\lambda}_4(\sigma,r)$, $\widetilde{r}_2(\sigma) < r < \widetilde{r}(\sigma)$ and $\widetilde{\lambda}_3(\sigma,r) < \lambda < \widetilde{\lambda}$ or $\widetilde{r}(\sigma) < r < \widehat{r}(\sigma)$ and $\widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda}$; otherwise, $U_{SC}^{MCS} < U_{SC}^{CS}$.

Proof of Proposition 9

Proof. In accordance with revenue-sharing game model with retailer's risk-aversion and risk-neutral under CD format, we have $U_{SC}^{R-RS} - U_{SC}^{RS} = (a-c)^2\left[\frac{3(-12+\lambda^2-12r\sigma^2)(16-5\lambda^2)+3[5\lambda^2+4(-4-3r\sigma^2)](12-\lambda^2)}{9(16-5\lambda^2)[5\lambda^2+4(-4-3r\sigma^2)]}\right]$. Let $\xi(\sigma, r, \lambda) = 3(-12 + \lambda^2 - 12r\sigma^2)(16 - 5\lambda^2) + 3[5\lambda^2 + 4(-4 - 3r\sigma^2)](12 - \lambda^2)$. By calculating $\xi(\sigma,r,\lambda)$, we can derive that the threshold $\widetilde{\lambda}_7(\sigma,r) = 1$ exists. Moreover, we demonstrate that the threshold $\widetilde{\lambda}_7(\sigma,r)$ is always greater than zero and less than $\widetilde{\lambda}$ when $0 < r \le \widetilde{r}(\sigma) = \frac{-3+2\sqrt{3}}{6\sigma^2}$. When $\frac{-3+2\sqrt{3}}{6\sigma^2} = \widetilde{r}(\sigma) < r < \widehat{r}(\sigma) = \frac{1}{6\sigma^2}$ and $\frac{1}{2}\sqrt{\frac{-1+12r\sigma^2+12r^2\sigma^4}{r\sigma^2}} = \widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda}$, we prove that $\widetilde{\lambda}_7(\sigma,r)$ is not always lie in a finite interval. In specific, $\widetilde{\lambda}_7(\sigma,r)$ is less than $\widehat{\lambda}(\sigma,r)$ when $\widehat{r}_3(\sigma) < r < \widehat{r}(\sigma)$. Therefore, we have $\xi(\sigma,r,\lambda) > 0$ when $0 < r \le \widetilde{r}(\sigma)$ and $0 < \lambda < \widetilde{\lambda}_7(\sigma,r)$, or $\widetilde{r}(\sigma) < r \le \widehat{r}_3(\sigma)$ and $\widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda}_7(\sigma,r)$. Otherwise, $\xi(\sigma,r,\lambda) < 0$. Therefore, we can obtain that the supply chain obtains higher performance with retailer's risk aversion when the risk-aversion degree and marketing effort effect are relatively low; otherwise, the supply chain achieves higher performance with retailer's risk neutral. The proof process and results of price-only game model and cost-sharing game model with retailer's risk-aversion and risk-neutral under CD format is analogous to that of revenue-sharing game model. Specifically, for the price only game model, we demonstrate that when $0 < r \le \widetilde{r}(\sigma)$ and $0 < \lambda < \widetilde{\lambda}_5(\sigma,r)$, or $\widetilde{r}(\sigma) < r \le \widehat{r}_1(\sigma)$ and $\widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda}_5(\sigma,r)$, the supply chain achieves higher performance with retailer's risk aversion; otherwise, the supply chain attains higher performance with retailer's risk neutral. In terms of cost-sharing game model under CD format, we demonstrate that when $0 < r \le \widetilde{r}(\sigma)$ and $0 < \lambda < \widetilde{\lambda}_6(\sigma,r)$, or $\widetilde{r}(\sigma) < r \le \widehat{r}_2(\sigma)$ and $\widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda}_6(\sigma,r)$, the supply chain attains higher performance with retailer's risk aversion; otherwise, the supply chain obtains higher performance with retailer's risk neutral. In summary, we can demonstrate that the supply chain benefits more with retailer's risk aversion under CD format when the risk-aversion degree and marketing effort effect are relatively low; otherwise, the whole supply chain attains higher performance with retailer's risk neutral.

In accordance with marketing cost-sharing game model with retailer's risk-aversion and risk-neutral under CM format, we have $U_{SC}^{R-MCS} - U_{SC}^{MCS} = (a-c)^2\left[\frac{-4(-28+9\lambda^2)^2(1+2r\sigma^2)^2[4(-11-24r\sigma^2-12r^2\sigma^4)+\lambda^2(15+32r\sigma^2+16r^2\sigma^4)]-4(44-15\lambda^2)3+4r\sigma^2)(3+4r\sigma^2)(3+4r\sigma^2)^2]^2}{(-28+9\lambda^2)^2 3+4r\sigma^2)(3+4r\sigma^2)(3+4r\sigma^2)^2]^2}\right.$. Let $\xi_1(\sigma,r,\lambda) = -4(-28+9\lambda^2)^2(1+2r\sigma^2)^2[4(-11-24r\sigma^2-12r^2\sigma^4)+\lambda^2(15+32r\sigma^2+16r^2\sigma^4)]- 4(44-15\lambda^2)3+4r\sigma^2)(3+4r\sigma^2)(3+4r\sigma^2)^2]^2$. By calculating $\xi_1(\sigma,r,\lambda)$, we derive that the threshold $\widetilde{\lambda}_8(\sigma,r)$ exists. Moreover, we prove that the threshold $\widetilde{\lambda}_8(\sigma,r)$ is always greater than zero and less than $\widetilde{\lambda}$ when $0 < r \le \widetilde{r}(\sigma)$. When $\widetilde{r}(\sigma) < r < \widehat{r}(\sigma)$ and $\widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda}$, we derive that $\widetilde{\lambda}_8(\sigma,r)$ is not always lie in a finite interval. In specific, $\widetilde{\lambda}_8(\sigma,r)$ is greater than $\widetilde{\lambda}$ when $\widehat{r}_4(\sigma) < r < \widehat{r}(\sigma)$. Thus, we have $\xi_1(\sigma,r,\lambda) < 0$ when $0 < r \le \widetilde{r}(\sigma)$ and $0 < \lambda < \widetilde{\lambda}_8(\sigma,r)$, or $\widetilde{r}(\sigma) < r \le \widehat{r}_4(\sigma)$ and $\widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda}_8(\sigma,r)$. Otherwise, $\xi_1(\sigma,r,\lambda) > 0$.

Part C (Comparison results of CD format with retailer's risk-aversion)

Table C1
Equilibrium results with the retailer's risk aversion in three different strategies

Equilibrium result	Strategy R–PO	Strategy R–CS	Strategy R-RS
w_i	$\frac{a(-4+\lambda^2-4r\sigma^2)+c(-3+\lambda^2-2r\sigma^2)}{-7+2\lambda^2-6r\sigma^2}$	$\frac{a(-15+4\lambda^2-14r\sigma^2)+c(-11+4\lambda^2-10r\sigma^2)}{-26+8\lambda^2-24r\sigma^2}$	$-\frac{6[2a(-4+\lambda^2-4r\sigma^2)+c(-8+3\lambda^2-4r\sigma^2)]}{(8-\lambda^2)(16-5\lambda^2+3r\sigma^2)}$
p_i	$\frac{a(-6+\lambda^2-4r\sigma^2)+c(-1+\lambda^2-2r\sigma^2)}{-7+2\lambda^2-6r\sigma^2}$	$\frac{a(-15+4\lambda^2-14r\sigma^2)(-6+\lambda^2-4r\sigma^2)+c[14+4\lambda^2+56r\sigma^2+40r^2\sigma^4+\lambda^2(-19-26r\sigma^2)]}{(-26+8\lambda^2-24r\sigma^2)(-4+\lambda^2-4r\sigma^2)}$	$-\frac{-8a(-5+\lambda^2-3r\sigma^2)+c[-7\lambda^2-4(-2-3r\sigma^2)]}{3[5\lambda^2+4(-4-3r\sigma^2)]}$
θ_i	$\frac{a-c+2ar\sigma^2-2cr\sigma^2}{7-2\lambda^2+6r\sigma^2}$	$\frac{2(a-c)(1+r\sigma^2)}{13-4\lambda^2+12r\sigma^2}$	$\frac{(a-c)(8-\lambda^2+12r\sigma^2)}{3(16-5\lambda^2+12r\sigma^2)}$
v_i	$\frac{(a-c)\lambda}{7-2\lambda^2+6r\sigma^2}$	$\frac{(a-c)(-15+4\lambda^2-14r\sigma^2)}{2(13-4\lambda^2+12r\sigma^2)(-4+\lambda^2-4r\sigma^2)}$	$\frac{2\lambda(a-c)}{16-5\lambda^2+3r\sigma^2}$
δ	\	$\frac{1+4r\sigma^2[\lambda^2-3(1+r\sigma^2)]}{4(4-\lambda^2+4r\sigma^2)(1+r\sigma^2)}$	\
φ	\	$\frac{(a-c)^2[-47-108r\sigma^2-60r^2\sigma^4+4\lambda^2(3+4r\sigma^2)]}{4(13-4\lambda^2+12r\sigma^2)(-4+\lambda^2-4r\sigma^2)}$	$\frac{2-\lambda^2}{8-\lambda^2}$
U_M^i	$\frac{(a-c)^2(1+2r\sigma^2)}{7-2\lambda^2+6r\sigma^2}$	$\frac{a(-15+4\lambda^2-14r\sigma^2)+c(-11+4\lambda^2-10r\sigma^2)}{-26+8\lambda^2-24r\sigma^2}$	$\frac{(a-c)^2(8-\lambda^2+12r\sigma^2)}{3(16-5\lambda^2+12r\sigma^2)}$
U_R^i	$\frac{(a-c)^2(4-\lambda^2+4r\sigma^2)}{(7-2\lambda^2+6r\sigma^2)^2}$	$\frac{a(-15+4\lambda^2-14r\sigma^2)(-6+\lambda^2-4r\sigma^2)+c[14+4\lambda^2+56r\sigma^2+40r^2\sigma^4+\lambda^2(-19-26r\sigma^2)]}{(-26+8\lambda^2-24r\sigma^2)(-4+\lambda^2-4r\sigma^2)}$	$\frac{4(a-c)^2}{3(16-5\lambda^2+3r\sigma^2)}$

Proof. In accordance with the retailer's utilities in Strategies R–CS and R-RS, we have $U_R^{R-CS} - U_R^{R-RS} = \frac{1}{12}(a-c)^2\left[-\frac{16}{16-5\lambda^2+12r\sigma^2}+\frac{3(17-4\lambda^2+20r\sigma^2+4r^2\sigma^4)}{(-13+4\lambda^2-12r\sigma^2)(-4+\lambda^2-4r\sigma^2)}\right]$. Let $\mathbb{N}(r,\lambda) = -\frac{16}{16-5\lambda^2+12r\sigma^2}+\frac{3(17-4\lambda^2+20r\sigma^2+4r^2\sigma^4)}{(-13+4\lambda^2-12r\sigma^2)(-4+\lambda^2-4r\sigma^2)}$. By solving $\mathbb{N}(r,\lambda)$, we can derive that the roots of $\widehat{\lambda}(\sigma,r) = \frac{\sqrt{17+4r\sigma^2-60r^2\sigma^4-33\sqrt{33+84r\sigma^2+100r^2\sigma^4}+6r\sigma^2\sqrt{33+84r\sigma^2+100r^2\sigma^4}}}{2\sqrt{2}}$, $\bar{\lambda}(\sigma,r) = -\frac{\sqrt{17+4r\sigma^2-60r^2\sigma^4+33\sqrt{33+84r\sigma^2+100r^2\sigma^4}-6r\sigma^2\sqrt{33+84r\sigma^2+100r^2\sigma^4}}}{2\sqrt{2}}$, $\breve{\lambda}(\sigma,r) = \frac{\sqrt{17+4r\sigma^2-60r^2\sigma^4+33\sqrt{33+84r\sigma^2+100r^2\sigma^4}-6r\sigma^2\sqrt{33+84r\sigma^2+100r^2\sigma^4}}}{2\sqrt{2}}$ and $\widehat{\lambda}(\sigma,r) = -\frac{\sqrt{17+4r\sigma^2-60r^2\sigma^4-33\sqrt{33+84r\sigma^2+100r^2\sigma^4}+6r\sigma^2\sqrt{33+84r\sigma^2+100r^2\sigma^4}}}{2\sqrt{2}}$ exist. Moreover, we can derive that the roots of $\bar{\lambda}(\sigma,r)$ and $\widehat{\lambda}(\sigma,r)$ are less than zero and the root of $\breve{\lambda}(\sigma,r)$ is greater than $\widetilde{\lambda}$ when $0 < r \le \widetilde{r}(\sigma) = \frac{-3+2\sqrt{3}}{6\sigma^2}$ and $0 < \lambda < \widetilde{\lambda} = \sqrt{2}$, or $\frac{-3+2\sqrt{3}}{6\sigma^2} = \widetilde{r}(\sigma) < r < \widehat{r}(\sigma) = \frac{1}{6\sigma^2}$ and $\frac{1}{2}\sqrt{\frac{-1+12r\sigma^2+12r^2\sigma^4}{r\sigma^2}} = \widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda} = \sqrt{2}$. We further derive that $\mathbb{N}(r,\lambda) > 0$ when $\lambda > \widehat{\lambda}(\sigma,r) = \frac{\sqrt{17+4r\sigma^2-60r^2\sigma^4-33\sqrt{33+84r\sigma^2+100r^2\sigma^4}+6r\sigma^2\sqrt{33+84r\sigma^2+100r^2\sigma^4}}}{2\sqrt{2}}$. When $\lambda < \widehat{\lambda}(\sigma,r) = \frac{\sqrt{17+4r\sigma^2-60r^2\sigma^4-33\sqrt{33+84r\sigma^2+100r^2\sigma^4}+6r\sigma^2\sqrt{33+84r\sigma^2+100r^2\sigma^4}}}{2\sqrt{2}}$, we derive that $\mathbb{N}(r,\lambda) < 0$. Thus, we can obtain that $U_R^{R-CS} < U_R^{R-RS}$ is established when $\lambda < \widehat{\lambda}(\sigma,r)$; otherwise, $U_R^{R-CS} > U_R^{R-RS}$ is established.

In accordance with the retailer's utilities in Strategies R–CS and R–PO, we have $U_R^{R-CS} - U_R^{R-PO} = \frac{(a-c)^2[1+4r(-3+\lambda^2)\sigma^2-12r^2\sigma^4]^2}{4(-13+4\lambda^2-12r\sigma^2)(-4+\lambda^2-4r\sigma^2)(7-2\lambda^2+6r\sigma^2)}$. Obviously, when $0 < r \le \widetilde{r}(\sigma) = \frac{-3+2\sqrt{3}}{6\sigma^2}$ and $0 < \lambda < \widetilde{\lambda} = \sqrt{2}$, or $\frac{-3+2\sqrt{3}}{6\sigma^2} = \widetilde{r}(\sigma) < r < \widehat{r}(\sigma) = \frac{1}{6\sigma^2}$, $\frac{1}{2}\sqrt{\frac{-1+12r\sigma^2+12r^2\sigma^4}{r\sigma^2}} = \widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda} = \sqrt{2}$, $7-2\lambda^2+6r\sigma^2 > 0$ and $5\lambda^2-4(4+3r\sigma^2) < 0$ is firmly established. Therefore, $U_R^{R-CS} > U_R^{R-PO}$ is firmly established.

In accordance with the retailer's utilities in Strategy R-RS and R–PO, we have $U_R^{R-RS} - U_R^{R-PO} = -\frac{(a-c)^2(-3+\lambda^2)^2}{3(7-2\lambda^2+6r\sigma^2)[5\lambda^2-4(4+3r\sigma^2)]}$. Obviously, when $0 < r \le \widetilde{r}(\sigma) = \frac{-3+2\sqrt{3}}{6\sigma^2}$ and $0 < \lambda < \widetilde{\lambda} = \sqrt{2}$, or $\frac{-3+2\sqrt{3}}{6\sigma^2} = \widetilde{r}(\sigma) < r < \widehat{r}(\sigma) = \frac{1}{6\sigma^2}$, $\frac{1}{2}\sqrt{\frac{-1+12r\sigma^2+12r^2\sigma^4}{r\sigma^2}} = \widehat{\lambda}(\sigma,r) < \lambda < \widetilde{\lambda} = \sqrt{2}$, $7-2\lambda^2+6r\sigma^2 > 0$ and $5\lambda^2-4(4+3r\sigma^2) < 0$ is firmly established. Thus, $U_R^{R-RS} > U_R^{R-PO}$ is firmly established.

The manufacturer's equilibrium results in Strategies R-RS, R–CS and R–PO are similar to that of retailer; hence, we omit the detailed process for brevity. That is, compared with Strategy R–PO, the manufacturer's profit is always better off in Strategies R-RS and R–CS. Moreover, when the marketing effort is high, the manufacturer profits most in Strategy R–CS. On the contrary, the manufacturer profits most in Strategy R-RS when the marketing effort is low. By analyzing the equilibrium results, we find that Strategy R–CS is the dominant strategy for the manufacturer and retailer when $\lambda < \widehat{\lambda}(\sigma,r) = \frac{\sqrt{17+4r\sigma^2-60r^2\sigma^4-33\sqrt{33+84r\sigma^2+100r^2\sigma^4}+6r\sigma^2\sqrt{33+84r\sigma^2+100r^2\sigma^4}}}{2\sqrt{2}}$. When $\lambda > \widehat{\lambda}(\sigma,r) = \frac{\sqrt{17+4r\sigma^2-60r^2\sigma^4-33\sqrt{33+84r\sigma^2+100r^2\sigma^4}+6r\sigma^2\sqrt{33+84r\sigma^2+100r^2\sigma^4}}}{2\sqrt{2}}$, Strategy R-RS is the dominant strategy for the manufacturer and retailer.

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