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MANUFACTURER'S COOPERATION STRATEGIES OF CLOSED-LOOP SUPPLY CHAIN CONSIDERING RECYCLING ADVERTISING

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Abstract. Online recycling shows great potential to significantly boost recoverable quantity and attract advertising investment. This study focuses on exploring how retail and recycling advertising affects the manufacturer's cooperation strategy in a closed-loop supply chain (CLSC). The CLSC model consisting of a manufacturer, an online recycling platform with recycling advertising, and a retailer with retail advertising considers four cooperation strategies by a manufacturer: no cooperation, cooperation with only the retailer, cooperation with only the online recycling platform, and cooperation with the online recycling platform and the retailer. After comparing four strategies, it is found that the manufacturer collaborates with the retailer, or the online recycling platform based on retail and recycling advertising coefficients. Furthermore, cooperation between the manufacturer and the retailer increases retail advertising and sales, which incentivizes the manufacturer to collaborate with the retailer. Collaboration between the manufacturer and the online recycling platform will increase both recycling advertising and quantity, which incentivizes the manufacturer to collaborate with the online recycling platform. These results would encourage more manufacturers to improve their operational efficiency through cooperation with online recycling platforms because the online recycling platforms conveniently utilize recycling advertising to increase the quantity of used products recycled, which in turn contributes to environmental sustainability.

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1. Introduction

Climate change due to increasing human population and industrialization is affecting every country in the world [44]. Human survival is now at risk due to the worsening air quality and greenhouse effect caused by increased carbon emissions [4, 28]. Hence, more and more manufacturing enterprises are now strategically promoting closed-loop supply chain (CLSC) management to obtain socio-economic benefits [35]. On the one hand, CLSC management can significantly improve resource utilization and reduce production cost. Xerox's regeneration strategy, for example, saves 45% to 60% of its manufacturing cost [1]. On the other hand, remanufacturing helps reduce carbon emissions and protects the environment [18]. For example, remanufacturing by Apple reduced its carbon emissions per dollar income by 15.4%.

Keywords. Cooperation strategy, recycling advertising, retail advertising, closed-loop supply chain.

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Both theory and empirical analysis have shown that manufacturers can improve individual and channel profitability by forming strategic alliances with other CLSC members [33, 48].To improve their competitiveness and operational efficiency, manufacturers cooperate with retailers or recyclers [43]. For instance, Xerox, Eastman Kodak, and Changhong cooperate with retailers to strengthen their forward logistics and increase profits [38, 43]. Others, such as General Motors, Nike, Tesla, and Dell collaborate with recyclers to improve their recycling capabilities for economic and social benefits [13, 25, 29, 41]. Although some scholars have examined how manufacturer's cooperation strategies affect CLSC performance [41, 48], they have not extended their discussion to the CLSC that considers the recycling advertising investment of online recycling platforms. The literature indicates that advertising has a meaningful impact on cooperation between supply chain members [26]. However, studies on CLSC associated with advertising have focused only on pricing strategies and coordination, while the interaction between online recycling platforms' recycling advertising and CLSC cooperation strategies have rarely been quantitatively examined, even though some online recycling platforms have begun to invest in recycling advertising.

The ubiquity of the internet has significantly increased the available channels of renewable material supply [14] and many online recycling platforms, like the European Recycling Platform, Aihuishou.com, Zhengerpin.com, and ecoATM [10, 36] have come up as a result of that. Due to the convenience of online recycling [13, 34], some manufacturers have begun to cooperate with online recycling platforms. For example, in April 2018, Huawei cooperated with Aihuishou.com to facilitate recycling services for Chinese users [15]. Aihuishou.com also collaborates with other manufacturers, like Xiaomi, Apple, and others [2]. As "online recycling" accounts for a negligible portion of total waste recycling, as it is a relatively new method of recycling [40], online recycling platforms need to step up their awareness campaigns [9]. Hence, many online recycling platforms use recycling advertising to drive traffic to their platforms and increase recoverable quantity [23]. For example, Aihuishou.com has begun investing in recycling advertising to raise consumer awareness of online recycling platforms [11].

Based on the above observation, the following questions need to be answered when there is recycling and retail advertising in the CLSC: (1) how do retail and recycling advertising affect manufacturer's cooperative strategies? (2) what are the effects of retail and recycling advertising on the different variables involved in the cooperative strategies? and (3) how do cooperative strategies affect these variables in the presence of retail and recycling advertising in the supply chain? To our knowledge, research on these topics is limited. The primary objective of our study is to investigate the impact of recycling advertising on CLSC cooperation strategy and decision-making of individual members by examining the questions. To address the research questions above, we assume a CLSC system that comprises a manufacturer, a retailer, and an online recycling platform. In contrast to previous studies, this study examines both retail and recycling advertising. We build four Stackelberg models: (1) no cooperation (N), (2) the manufacturer and the retailer cooperation (MR), (3) the manufacturer and the online recycling platform cooperation (MO), and (4) the manufacturer cooperation with the retailer and the online recycling platform (MRO).

The following are the primary contributions of this study. To our knowledge, this is the first study that examines how recycling and retail advertising affect manufacturer cooperation strategies. It makes specific reference to the strategic choices of manufacturer alliances and advertising on online recycling platforms, both of which have important managerial implications. While there has been some research on the effect of advertising on the supply chain, the majority of those studies have focused on retail advertising, with only a few studies on recycling advertising by online recyclers. Our findings will add to the body of knowledge on advertising and help improve industrial practice.

Our analysis consists of seven sections. Section 1 describes relevant topics. Section 2 reviews relevant literature. Section 3 problem descriptions and notations. Section 4 presents the model description and solves the model. Section 5 compares the decision variables and profits of CLSC. Section 6 analyzes the effects of parameters on decision variables and cooperation strategies. Section 7 provides the conclusions, managerial insights, and shortcomings of this study.

2. Literature review

This study builds on and contributes to two research streams: (1) the literature on cooperative strategy in CLSC and (2) the literature on advertising in CLSC.

2.1. Cooperative strategy in CLSC

Because collaboration can increase supply chain efficiency and competitiveness, manufacturers are now strategically deploying it [30]. In recent years, many studies have discussed how manufacturers choose their cooperation strategies in supply chains. Mahdiraji *et al.* [30], Taleizadeh *et al.* [39], Guan *et al.* [12], and Zhao *et al.* [47] looked at the issues of cooperation strategy in forwarding supply chains and discovered that collaboration between manufacturers and retailers facilitates supply chain management. However, these studies have focused exclusively on the collaboration between manufacturers and retailers and left out collaboration between manufacturers and recyclers. Our study discusses both forward and reverse supply chain collaboration.

Several additional studies examined the cooperative strategy of CLSC. Specifically, Asl-Najafi *et al.* [5] examined the effect of product life cycle on CLSC coordination. Zhao *et al.* [46] examined decision-making and coordination in a CLSC concerning component reuse. They discovered that reuse benefits only recycled component suppliers for low-price-elasticity products and manufacturers can use wholesale price contracts to improve supply chain coordination. However, the above research does not analyze cooperation strategy from the manufacturer's perspective. Ma *et al.* [29] investigated the influence of collaboration strategy on CLSC decision-making. They discovered manufacturers were amenable to collaborating with retailers and recyclers. Alamdar *et al.* [3] investigated optimal decision-making in a fuzzy three-level CLSC. The findings confirmed that collaboration between manufacturers and retailers benefited consumers, while collaboration between manufacturers and recyclers resulted in increased recovery. Wei *et al.* [41] extended this work by examining the effect of competition on the optimal decisions and cooperation strategies of CLSC when recycling channels were competitive. They confirmed that the competition coefficient of the recycling channel affected the manufacturer's willingness. Additionally, some research has been conducted on the effects of equity concerns and irrational decision-making on CLSC cooperative coordination strategies. In particular, Zheng *et al.* [48] constructed a three-level CLSC. The study found that when retailers considered fairness concerns, cooperation among supply chain members was beneficial to maximize the overall profit of the supply chain. In a two-stage CLSC consisting of a manufacturer and a retailer, Jian *et al.* [17] discussed the impact of manufacturer's fairness concerns on centralized and decentralized decision-making in CLSC. Their study proposed an allocation scheme that effectively addressed CLSC coordination, fostering cooperation and achieving collective and individual rationalities. Bera and Giri [6] examined the decentralized behavior of entities in a green supply chain, with a specific focus on government intervention and the evolutionary game between retailers and the manufacturer.

Although scholars have examined the factors that affect cooperation strategies and the impact of cooperation on CLSC performance, no study has examined the effect of advertising on the cooperation strategy and decision making of the supply chain members in the CLSC. It should be noted that advertising has a significant effect on the cooperation of supply chain members. This study further expands on the existing research models to examine how recycling and retail advertising affect cooperation strategies.

2.2. Advertising in CLSC

Another stream of literature closely related to our study is advertising. Studies have shown that advertising increases customer stickiness and brand loyalty, influences brand switching and channel substitution [32], establishes store image, and increases store traffic. Following these studies, many scholars have explored the impact of advertising on the supply chain. In particular, Karray [19], Karray *et al.* [20] and Mirzaei *et al.* [32] studied the issue of cooperative diffusion in supply chains. Li *et al.* [26] expanded this work by examining the cooperative advertising strategy used in the O2O supply chain. The findings indicated that compared to unilateral cooperative advertising, the bilateral cooperative advertising model can benefit the entire supply chain. However, in the bilateral cooperative advertising model, the agent's profit is lost because it is required to share a portion of the offline advertising expenses without receiving compensation. Zhang *et al.* [45] examined the impact of advertising collaboration on a supply chain comprised of a manufacturer and a retailer. They confirmed that cost-sharing and revenue-sharing contracts for advertising were advantageous for coordinating the dual-channel supply chain system. Stallone *et al.* [37] investigated the applications of blockchain technology in digital advertising, focusing on its potential for improving supply chain transparency and addressing fraud. They developed a framework to classify innovations in this area and examined ten relevant use cases. The findings highlight the importance of contextual innovations, such as rewarding web users and content creators, and emphasize the need for better understanding of boundary innovations to enhance advertising supply chain transparency. None of these studies, however, examined the effect of advertising on CLSC.

There has been some literature on advertising from the perspective of CLSC, *e.g.*, Xie *et al.* [42], and Li *et al.* [24]. For instance, Xie *et al.* [42] studied the coordination contract considering cooperative advertising in a dual-channel CLCS. They established a recovery income distribution mechanism based on the relationship between the recovery rate and the recovery income distribution rate. In addition, Li *et al.* [24]constructed a direct selling CLCS consisting of a manufacturer, a remanufacturer, and two advertising agents and analyzed the impact of advertising on supply chain members' decisions and profits. Furthermore, some literature regarded advertising as a marketing strategy to investigate the impact of advertising on profit and CLSC decisions. For instance, Chen *et al.* [7] thought pricing strategy and advertising decisions were two marketing strategies. From the perspective of economic and social benefits, they analyzed and compared the impact of these two marketing strategies on CLSC. The results showed that the advertising elasticity of market demand was a crucial factor affecting manufacturer profits and social welfare. Li *et al.* [27] investigated the advertising decision of a direct-selling CLSC and examined the impact of advertising parameters on the equilibrium decision and profit. The results showed that advertising demand elasticity was positively correlated with equilibrium decision-making, and this study provided management enlightenment for direct selling CLSC enterprises. Khorshidvand *et al.* [21] extended this work and combined pricing, greening, and advertising decisions, trying to propose a hybrid modeling method of green sustainable closed-loop supply. Furthermore, Khorshidvand *et al.* [22] proposed a novel two-stage model based on price, green, and advertising decisions to optimize the economy, environment, and society, as well as obtain optimal prices for new and recycled products. Meng and Gamlin [31] proposed figuratively dirty ads activated moral cleansing goals and increased recycling, while literal dirty ads did not have the same effect. This supports goal activation over semantic priming. The influence of figuratively dirty ads on recycling was stronger for individuals with a higher moral identity.

Although advertising plays a crucial role in the decision-making on CLSC members, existing literature primarily focuses on the impact of advertising on supply chain pricing and quantity decisions. Research on advertising in CLSC is mainly concentrated on pricing strategies and coordination, with no studies investigating how advertising influences the cooperative strategies of supply chain members. To fill this gap, this study examines how recycling and retail advertising affect the cooperation strategies of manufacturers in the presence of both retail and recycling advertising within the supply chain. Furthermore, current articles mainly address advertisements in the forward sales domain, which aim to promote manufacturers and retailers to increase retail volume. There is a scarcity of literature on advertising in the recycling domain, where the primary objective of recycling advertisements is to promote recycling platforms and methods to boost recycling volume. In contrast to previous studies, this paper simultaneously considers the phenomena and effects of both recycling and retail advertising.

3. Problem descriptions and notations

This study considers a three-level CLSC consisting of a manufacturer, a retailer, and an online recycling platform. In the retail channel, the manufacturer manufactures a new product using raw materials or used products and is responsible for setting wholesale price that is paid when selling to the retailer. The retailer sets the retail price and uses retail advertising to stimulate market demand. In the collecting channels, the manufacturer sets transfer price and entrusts the online recycling platform with recycling of old products to

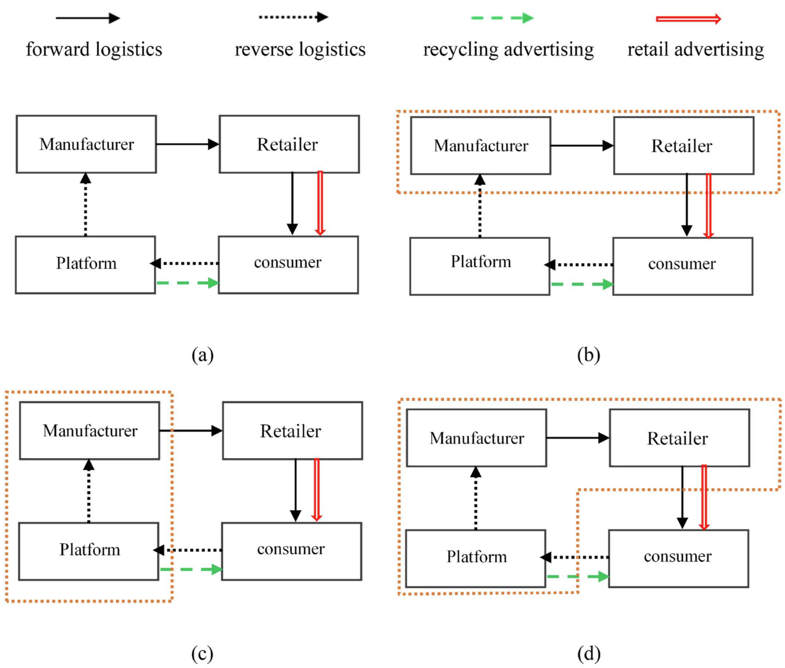

FIGURE 1. Four cooperative models of the manufacturer. (a) Model N. (b) Model MR. (c) Model MO. (d) Model MRO.

save on production cost. To increase the quantity of recyclables, the online recycling platform sets recycling price and uses recycling advertising to promote itself to consumers.

The primary goal of this study is to understand how recycling and retail advertising affect cooperation strategy. Hence, we build four models as shown in Figure 1: (1) no cooperation (N), (2) the manufacturer and the retailer cooperation (MR), (3) the manufacturer and the online recycling platform cooperation (MO), and (4) the manufacturer cooperation with the retailer and the online recycling platform (MRO).

The following table illustrates the parameters and decision variables used in this article.

In this study, the manufacturer is the market leader, and the retailer and the recycler are the followers in a Stackelberg game. Consumers have the same level of acceptance of products made of new or recycled materials. In other words, there is no difference between a new product and a remanufactured product in the minds of the consumers. Additionally, to make the analysis tractable, this study makes the following assumptions:

Assumption 3.1. *Referring to Chen et al. [7] and Khorshidvand et al. [21], the retailer's retail advertising behavior and retail price affect the market demand for products. So, the market demand function is:*

$$q = \alpha - \beta p + zg. \tag{1}$$

Where, α represents the market capacities, $\alpha > 0$, p represents the retail price of the product, β represents coefficient of price on market demand, g represents retail advertising effort of the retailer, z represents coefficient of price on market demand. $\alpha > \beta p$ ensures that under any circumstance the market demand is non-negative [8].

Assumption 3.2. *Recycling advertising and recycling price plays an important role in contributing to the supply of returned items [24]. Thus, the recoverable quantity function is given by*

$$Q = a + fr + hA. \tag{2}$$

Table 1. Parameters and decision variables.

Parameters	Implication
ω	The wholesale price of unit product
Δ	Cost savings from using old products, $\Delta = c_M - c_r$
C_m	Unit cost for a manufacturer to produce products using new manufacturing materials
C_γ	Unit cost for a manufacturer to produce products using recycled old products
b	The unit price paid by the manufacturer to Online recycling platforms, transfer price
p	Retail price of unit product
q	Market demand, $q = \alpha - \beta p + zg$
α	Market capacities
β	Coefficient of price on market demand
z	Coefficient of retail advertisement on market demand
g	Retail advertising effort of the retailer
Q	Recoverable quantity, $Q = a + fr + hA$
a	Initial recoverable quantity
r	Recycling price paid by the online recycling platform to consumers
A	Recycling advertising effort of the online recycling platform
f	Coefficient of recycling price on recoverable quantity
h	Coefficient of recycling advertising on recoverable quantity
CR	Advertising cost of the retailer, $\text{CR} = \frac{1}{2}kg^2$
CO	Advertising cost of the online recycling platform, $\text{CO} = \frac{1}{2}kA^2$
k	Recycler advertising cost factor
π	The profits of X, where $X = \{M, O, R, S\}$ represent the manufacturer, the online recycling platform, the retailer, and the CLSC system.

Where, a represents the initial recoverable quantity, $a > 0$, r represents the recycling price, f represents coefficient of recycling price on recoverable quantity, A represents recycling advertising effort of the online recycling platform, h represents coefficient of recycling advertising on recoverable quantity.

Assumption 3.3. *The advertising cost is a quadratic function of the advertising effort [21]. Thus, the advertising cost function of the retailer and the online recycling platform is given by:*

$$CR = \frac{1}{2}kg^2 \tag{3}$$

$$CO = \frac{1}{2}kA^2. \tag{4}$$

Where, k represents the recycler advertising cost factor.

Subsequently, we derive the profit as follows. The profit function of the manufacturer (π_M) consists of the revenue from selling products to retailers and the profit from savings in remanufacturing. The profit function of the online recycling platform (π_O) is equal to the revenue from selling products to manufacturers minus the cost of advertising to retailers. The profit function of the retailer (π_R) is the revenue from selling products to consumers minus the cost of advertising for recycling.

$$\pi_M = (\omega - c_M)(\alpha - \beta p + zg) + (\Delta - b)(a + fr + hA) \tag{5}$$

$$\pi_O = (b - r)(a + fr + hA) - \frac{1}{2}kA^2 \tag{6}$$

$$\pi_R = (p - \omega)(\alpha - \beta p + zg) - \frac{1}{2}kg^2. \tag{7}$$

4. Cooperative models in CLSC

This section mainly analyzes the decision orders of four cooperation strategies in CLSC, namely, Model N, Model MR, Model MO, and Model MRO, and obtains the equilibrium results and supply chain profits (see Tab. 2) of the four models. All the solving processes can be seen in Appendix A.

4.1. Model N: no cooperation

In Model N (as shown in Fig. 1a), the manufacturer neither cooperates with the retailer nor the online recycling platform. In this scenario, the manufacturer, the retailer, and the online recycling platform all aim to maximize their interests. The game order is: first, the manufacturer decides wholesale price ϖ and transfer price b; then the online recycling platform determines recycling price r and recycling advertising effort A; finally, the retailer decides retail price p and retail advertising effort g. Thus, the objective function is

$$\operatorname*{Max}_{\omega,b} \pi_M = (\omega - c_M)(\alpha - \beta p + zg) + (\Delta - b)(a + fr + hA) \tag{8}$$

$$\text{s.t.} \begin{cases} \operatorname*{Max}_{r,A} \pi_C = (b - r)(a + fr + hA) - \frac{1}{2}kA^2 \\ \operatorname*{Max}_{p,g} \pi_R = (p - \omega)(\alpha - \beta p + zg) - \frac{1}{2}kg^2. \end{cases} \tag{9}$$

4.2. Model MR: cooperation between the manufacturer and the retailer

Manufacturers such as BMW, Changhong, and Haier form alliances with retailers. Under this cooperation model (MR, as shown in Fig. 1b), the alliance members regard the maximum overall profit as the goal. The order of the game is as follows: first, the cooperative alliance sets product price p, retail advertising effort g, and transfer price b; subsequently, the online recycling platform determines recycling price r and recycling advertising effort A. This problem is transformed into the following model:

$$\operatorname*{Max}_{p,b,g} \pi_{M+R} = (p - c_m)(\alpha - \beta p + zg) + (\Delta - b)(a + fr + hA) - \frac{1}{2}kg^2 \tag{10}$$

$$\text{s.t. } \operatorname*{Max}_{r,A} = (b - r)(a + fr + hA) - \frac{1}{2}kA^2. \tag{11}$$

4.3. Model MO: cooperation between the manufacturer and the online recycling platform

To facilitate recycling, some manufacturers, such as OPPO and Vivo, work with online recycling platforms. Under this cooperation model (MO, as shown in Fig. 1c), the alliance members regard the maximum overall profit as the goal. The game order is as follows: first, the cooperative alliance determines recycling price r, recycling advertising effort A, and wholesale price ϖ; subsequently, the retailer sets retail price p and retail advertising effort g. This problem is transformed into the following model:

$$\operatorname*{Max}_{\varpi,r,A} \pi_{M+C}^{MC} = (\varpi - c_m)(\alpha - \beta p - zg) + (\Delta - r)(a + fr + hA) - \frac{1}{2}kA^2 \tag{12}$$

$$\text{s.t. Friday, March 15, 2024 at 2:48 pm } \operatorname*{Max}_{p,g} \pi_R = (p - \varpi)(\alpha - \beta p + zg) - \frac{1}{2}kg^2. \tag{13}$$

Table 2. equilibrium results of four models.

	Model N	Model MR	Model MO	MRO
ϖ	$\frac{\alpha}{2\beta}+\frac{c_m}{2}$	NA	$\frac{\alpha}{2\beta}+\frac{c_m}{2}$	NA
b	$-\frac{a-\Delta f}{2f}$	$-\frac{a-\Delta f}{2f}$	NA	NA
p	$\frac{k\alpha+X_1}{2k\beta-z^2}$	$\frac{-c_M z^2+k\alpha+c_M k\beta}{2k\beta-z^2}$	$\frac{k\alpha+X_1}{2k\beta-z^2}$	$\frac{-c_M z^2+k\alpha+c_M k\beta}{2k\beta-z^2}$
g	$\frac{z\left(\frac{\alpha}{2}-\frac{c_M y}{2}\right)}{2ky-z^2}$	$\frac{z(\alpha-c_M y)}{2k\beta-z^2}$	$\frac{z\left(\frac{\alpha}{2}-\frac{c_M y}{2}\right)}{2ky-z^2}$	$\frac{z(\alpha-c_M y)}{2k\beta-z^2}$
q	$\frac{k\beta X_2}{2\left(2k\beta-z^2\right)}$	$\frac{k\beta X_2}{2k\beta-z^2}$	$\frac{k\beta X_2}{2\left(2k\beta-z^2\right)}$	$\frac{k\beta X_2}{2k\beta-z^2}$
A	$\frac{h\left(\frac{a}{2}+\frac{\Delta f}{2}\right)}{2fk-h^2}$	$\frac{h\left(\frac{a}{2}+\frac{\Delta f}{2}\right)}{2fk-h^2}$	$\frac{h(a+\Delta f)}{2fk-h^2}$	$\frac{h(a+\Delta f)}{2fk-h^2}$
r	$\frac{ak+X_3}{2fk-h^2}$	$\frac{ak+X_3}{2fk-h^2}$	$-\frac{\Delta h^2+ak-\Delta fk}{2fk-h^2}$	$-\frac{\Delta h^2+ak-\Delta fk}{2fk-h^2}$
Q	$\frac{fk(a+\Delta f)}{2\left(2fk-h^2\right)}$	$\frac{fk(a+\Delta f)}{2\left(2fk-h^2\right)}$	$\frac{fk(a+\Delta f)}{2fk-h^2}$	$\frac{fk(a+\Delta f)}{2fk-h^2}$
π_R	$\frac{kX_5}{8}$		$\frac{kX_5}{8}$	
π_M	$\frac{kX_4}{4}+\frac{kX_5}{4}$	$\frac{kX_4}{4}+\frac{kX_5}{2}$	$\frac{kX_5}{4}+\frac{kX_4}{2}$	$\frac{kX_5}{2}+\frac{kX_4}{2}$
π_C	$\frac{kX_4}{8}$	$\frac{kX_4}{8}$		
π_S	$\frac{3kX_5}{8}+\frac{3kX_4}{8}$	$\frac{kX_5}{2}+\frac{3kX_4}{8}$	$\frac{3kX_5}{8}+\frac{kX_4}{2}$	$\frac{kX_5}{2}+\frac{kX_4}{2}$

4.4. Model MRO: the manufacturer cooperates with the retailer and the online recycling platform.

Some manufacturers have partnered with both retailers and online recycling platforms, such as Xiaomi and Huawei. In this scenario, the cooperative alliance aims to maximize the profit of the entire supply chain. The problem is transformed into the following model:

$$\operatorname*{Max}_{p,g,A,R} \pi_{MCR} = (p-c_m)(\alpha-\beta p+zg)+(\Delta-r)(a+fr+hA)-\frac{1}{2}kA^2-\frac{1}{2}kg^2. \tag{14}$$

The equilibrium results of the four models (see Tab. 2) are obtained by the reverse recursive method. The proof is furnished in Appendix A.
where, $X_1=\frac{k(\alpha+c_m\beta)}{2}-\frac{z^2(\alpha+c_m\beta)}{2\beta}$, $X_2=\alpha-c_m\beta$, $X_3=\left(k-\frac{h^2}{f}\right)\left(\frac{a}{2}-\frac{\Delta f}{2}\right)$, $X_4=\frac{(a+\Delta f)^2}{(2fk-h^2)}$, $X_5=\frac{(\alpha-c_m\beta)^2}{(2k\beta-z^2)}$.

5. Comparisons of the four cooperative models

This section mainly analyzes the equilibrium results of the four cooperation models presented in Table 2. Firstly, it analyzes the impact of cooperative strategies on the equilibrium results. Next, it examines the interaction between recycling advertising and the manufacturer's cooperative strategies. Finally, it examines the impact of cooperative strategies and recycling advertising on supply chain profits. The proof is furnished in Appendix B.

Proposition 5.1.

(1) In models N and MO, the order of wholesale price is given as: $\varpi_N=\varpi_{MC}$.
(2) In models N and MR, the order of transfer price is given as: $b_N=b_{MR}$.

Proposition 5.1 (1) states that wholesale price (ϖ) in models N and MO is equal. This is entirely reasonable; the manufacturer's unit profit is obtained by subtracting the unit cost from the wholesale price, whereas the retailer's unit profit is obtained by subtracting the wholesale price from the retail price. If the wholesale price is too low, the manufacturer's profits would suffer, and if the wholesale price is too high, the retailer's unit profit would suffer, causing the retailer to reduce purchases, in turn reducing the manufacturer's profit. To maintain a balance between price and quantity while maximizing profit, the wholesale price for models N and MO is set at $\frac{\alpha}{2\beta} + \frac{1}{2}c_m$. This means that wholesale prices are stable for the different cooperative models. This conclusion will help manufacturers choose a reasonable wholesale price.

Proposition 5.1 (2) states that transfer price (b) in models N and MO is equal. This conclusion is consistent with existing literature such as Ma *et al.* [29] and Wei *et al.* [41]. This is understandable; on the one hand, the online recycling platform is motivated to recycle used products by the marginal revenue ($b - C$). If the transfer price is low (b), the online recycling platform will become less profitable, reducing its incentive to recycle products. On the other hand, the manufacturer is motivated to obtain used products from recyclers for remanufacturing by the cost savings associated with remanufacturing ($\Delta - b$). If the transfer price (b) is too high, the manufacturer will become less profitable, reducing the manufacturer's incentive to engage in remanufacturing. To balance the manufacturer's income and the recycler's income, in models N and MO, the optimal transfer payment price is set at $\frac{\Delta}{2}$. This means that the transfer price is consistent across cooperative models. This recommendation will assist the manufacturer in determining the appropriate transfer price. In addition, the results show that the advertising coefficient has no effect on the wholesale price or the transfer price.

Proposition 5.2. *Retail price (p) in the four models satisfies the following conditions:*

(1) If $z < \sqrt{k\beta}$, $p_N = p_{MO} > p_{MR} = p_{MRO}$
(2) If $z > \sqrt{k\beta}$, $p_{MR} = p_{MRO} > p_N = p_{MO}$.

Proposition 5.2 states that, regardless of the advertising coefficient, the optimal retail price when the manufacturer cooperates with the online recycling platform will be the same as that when the manufacturer does not cooperate with the online recycling platform (*i.e.*, $p_N = p_{MO}$, $p_{MR} = p_{MRO}$). This implies that the manufacturer's relationship with the recycler has no effect on the retail price. This is well understood; this study assumes that retail price and retail advertising have the maximum impact on sales, while recycling price and recycling advertising have the maximum impact on recoverable quantity. The positive supply chain has a negligible impact on the reverse supply chain, so whether the manufacturer works with the recycler or not has no bearing on the positive supply chain's decision to set the retail price.

If the influence of retail advertising on sales (z) is negligible, the optimal retail price when the manufacturer collaborates with the retailer (MR, MRO) will be lower than the optimal retail price when the manufacturer does not collaborate with the retailer (N, MO). This is because when the manufacturer collaborates with the retailer, the cooperative alliance formed by the manufacturer and the retailer can avoid double marginalization, thereby benefiting all alliance members.

If the influence of retail advertising on sales(z) is significant when the manufacturer cooperates with the retailer (MR, MRO), the optimal retail price will be higher than when the manufacturer does not cooperate with the retailer (N, MO). This is an unexpected outcome. In particular, retail advertising has a greater impact on sales than retail price, and each increase in unit price has a negligible effect on sales. When the manufacturer cooperates with the retailer, the alliance's profit function is $(p-c_m)(\alpha-\beta p+zg)+(\Delta-b)(a+fr+hA)-\frac{1}{2}kg^2$, which means that increasing price results in significant revenue growth while decreasing sales slightly, giving the alliance a stronger incentive to increase the price.

Proposition 5.2 states that the manufacturer's cooperation strategies have an effect on the optimal retail price and this effect is also dependent on the coefficient of retail advertising on sales. Proposition 5.2 also yields some intriguing results. If retail advertising has a significant effect on sales (z), the collaboration between the manufacturer and the retailer could result in an increase in the retail price, which will not be beneficial for consumers.

Proposition 5.3. *Product demand (q) and retail advertising effort (g) of the retailer in the four models satisfy:*

(1) $q_{MR} = q_{MRO} > q_N = q_{MO}$
(2) $g_{MR} = g_{MRO} > g_N = g_{MO}$.

Proposition 5.3 demonstrates that under the four models, recycling and retail advertising coefficients have no effect on the order of sales quantity and retail advertising effort levels. Specifically, when the manufacturer collaborates with the retailer (MR, MRO), the sales and the level of retail advertising effort are higher than when the manufacturer does not collaborate with the retailer (N, MO). When the manufacturer and the retailer do not cooperate, the retailer will purchase a fewer products than the upstream manufacturer's optimal quantity. When the manufacturer and the retailer collaborate, both parties have the same goal, effectively avoiding a conflict of interest. Both parties seek to maximize the alliance's profits in this case. To improve profits, the alliance will increase sales. Furthermore, since the sales function is $q = \alpha - \beta p + zg$, the alliance members have a great incentive to increase the level of retail advertising effort to increase sales.

Proposition 5.4. *Recycling price (r) in the four models satisfies the following conditions:*

(1) If $h < \sqrt{kf}$, $r_{MO} = r_{MRO} > r_N = r_{MR}$
(2) If $h > \sqrt{kf}$, $r_{MO} = r_{MRO} < r_N = r_{MR}$.

Proposition 5.4 states that, regardless of the advertising coefficient, the optimal recycling price when the manufacturer cooperates with the retailer will be the same as the optimal recycling price when the manufacturer does not cooperate with the retailer (*i.e.*, $r_{MO} = r_{MRO}$, $r_N = r_{MR}$). In contrast to Ma *et al.* [29], this study concludes that collaboration with the retailer benefits only the positive supply chain and has no effect on recoverable quantity. This is because this study introduces recycling advertising into CLSC and examines its effect on recoverable quantity. Ma *et al.* [29] assume that $Q = (\alpha - \beta P)\tau$, where recoverable quantity is influenced by consumer market demand. And this paper assumes that $Q = a + fr + hA$, where recoverable quantity is primarily determined by the recycling advertising and recycling price. Thus, increased demand generated through collaboration with the retailer does not result in increased recoverable quantity.

If the influence of recycling advertising on the quantity recovered (h) is negligible, the optimal recycling price when the manufacturer cooperates with the online recycling platform (MO, MRO) will be lower than the optimal recycling price when the manufacturer does not cooperate with the online recycling platform (N, MR). This is because when the manufacturer collaborates with the recycler, the cooperative alliance formed by the two can internalize the cost savings associated with remanufacturing. As a result, the members of the alliance have more incentive to increase the recycling price in order to increase the recoverable quantity.

If the influence of recycling advertising on recoverable quantity (h) is significant, the optimal recycling price when the manufacturer cooperates with the online recycling platform (MO, MRO) will be higher than the optimal recycling price when the manufacturer does not cooperate with the online recycling platform (N, MR). This result is well understood; when recycling advertising has a greater impact on recoverable quantity, the alliance between the manufacturer and the recycler will rely primarily on recycling advertising to increase the recoverable quantity. While increasing the recycling price can increase recoverable quantity, the increase in recoverable quantity is insufficient to offset the increased cost of recycling caused by the increased recycling price. As a result, the alliance members would significantly reduce the recycling price.

Proposition 5.4 states that cooperation strategies affect the optimal recycling price and that this effect is also dependent on the coefficient of recycling advertising on recoverable quantity.

Proposition 5.5. *Recycling advertising effort of the online recycling platform A and recoverable quantity Q in the four models satisfy:*

(1) $A_{MO} = A_{MRO} > A_N = A_{MR}$
(2) $Q_{MO} = Q_{MRO} > Q_N = Q_{MR}$.

Proposition 5.5 states that when the manufacturer cooperates with the recycler (MO, MRO), the recycling advertising effort A and the recoverable quantity Q are the largest. When the manufacturer does not cooperate with the recycler (N, MR), the recycling advertising effort A and the recoverable quantity Q are the lowest. This is because when the manufacturer collaborates with the recycler, the savings associated with remanufacturing can be internalized. As a result, the alliance members are more receptive to increasing recycling advertising to boost recoverable quantity. Proposition 5.5 implies that cooperation between the manufacturer and the recycler should be encouraged.

Proposition 5.6. *The manufacturer has an incentive to cooperate with the retailer* $\pi_{M+\mathrm{R}}^{MR} > \pi_M^N + \pi_R^N$.

Proposition 5.6 indicates that the manufacturer wishes to collaborate with the retailer. This conclusion is consistent with the findings of Li *et al.* [25] and Wei *et al.* [41], which indicates that collaboration between the manufacturer and the retailer benefits manufacturer's profits. This is because, through collaboration between the manufacturer and the retailer, double marginalization can be effectively eliminated. The alliance members will increase investment in retail advertising and sales (see Prop. 5.3) to maximize profits and create a win-win situation. As a result, the manufacturer and the retailer should develop positive working relationships. Numerous observations within the industry corroborate this conclusion as well. In practice, manufacturers such as Xerox, Eastman Kodak, and Changhong will form alliances with retailers.

Proposition 5.7. *The manufacturer has an incentive to cooperate with the online recycling platform* $\pi_{M+\mathrm{O}}^{MO} > \pi_M^N + \pi_O^N$.

Proposition 5.7 indicates that the manufacturer wishes to collaborate with the online recycling platform. It is well known that the negative effects of double marginalization are evident when the manufacturer and the recycler aim to maximize their respective interests. Collaborations between the manufacturer and the recycler can help internalize the cost of remanufacturing ($b(a + fr + hA)$) and increase the recoverable quantity (see Prop. 5.5). Numerous industry observations corroborate this conclusion, as a number of well-known manufacturers, including Apple, Huawei, OPPO, and VIVO, have partnered with online recycling platforms.

Proposition 5.8. *Effect of recycling advertising coefficient on cooperation strategies.*

(1) When the coefficient of recycling advertising on recoverable quantity h is small, that is $\mathrm{h} < \mathrm{h}_o$ $h_0 = \frac{\sqrt{2kM^2fy^2-4kMfxy-2kN^2f^2y+N^2f^2z^2-4kNafy+2Nafz^2-2ka^2y+a^2z^2+2kfx^2}}{x-My}$, *the manufacturer tends to cooperate with the retailer, where* $\pi_{M+\mathrm{O}}^{MO} - \pi_M^N - \pi_O^N < \pi_{M+\mathrm{R}}^{MR} - \pi_M^N - \pi_R^N$.

(2) When the coefficient of recycling advertising on recoverable quantity h is small, that is $\mathrm{h} \geq \mathrm{h}_o$*, the manufacturer tends to cooperate with the online recycling platform, where* $\pi_{M+\mathrm{O}}^{MO} - \pi_M^N - \pi_O^N > \pi_{M+\mathrm{R}}^{MR} - \pi_M^N - \pi_R^N$.

Proposition 5.8 states that the manufacturer's motivation to cooperate only with the recycler (MO) or only with the retailer (MR) is affected by the coefficient of advertising on the recoverable quantity.

When the coefficient of recycling advertising on recoverable quantity is minimal, the manufacturer prefers to work with the retailer. When recycling advertising has a sizable impact on recoverable quantity, the manufacturer prefers to work with the recycler. This is because when the impact of recycling advertising on recoverable quantity is lower, the collaboration between the manufacturer and the retailer can mitigate the positive supply chain's double marginal effect and result in more significant benefits. As demonstrated in Proposition 5.7, collaboration between the manufacturer and the recycler can help mitigate the reverse supply chain's double marginal effect. When recycling advertising has a significant impact on recoverable quantity, each unit of recycling advertising investment results in a significant increase in recoverable quantity, and when the manufacturer and the recycler work together, cost savings from remanufacturing can be realized, effectively lowering production costs. At this point, the benefits of mitigating the reverse supply chain's double marginal effect outweigh the benefits of mitigating the forward supply chain's double marginal effect, and the manufacturer tends to cooperate with the recycler.

Proposition 5.9. *Effect of cooperation strategies on supply chain profit.*

(1) When the coefficient of recycling advertising on recoverable quantity h is small, that is $\mathrm{h} < \mathrm{h}_o$*, the supply chain profit in four models satisfies:* $\pi_S^N < \pi_S^{MO} < \pi_S^{MR} < \pi_S^{MRO}$

(2) *When the coefficient of recycling advertising on recoverable quantity h is small, that is* $\mathrm{h} \geq \mathrm{h}_o$*, the supply chain profit in four models satisfies:* $\pi_S^N < \pi_S^{MR} < \pi_S^{MC} < \pi_S^{MCR}$.

Proposition 5.9 states that the total profit of the supply chain in model N is always less than in other models. In Model N, the manufacturer adopts a non-cooperative strategy, and the negative impact of the dual marginal effects in the forward supply chain and the reverse supply chain is noticeable. As shown in Propositions 5.2 and 5.3, the sales in Model N are smaller than those in other models, and the investment in retail advertising and recycling advertising is meager. Consistent with Zheng *et al.* [48], Li *et al.* [24] the total profit of the supply chain is maximized under the centralized model. This is because when the manufacturer cooperates with both the recycler and the retailer, the dual marginal problem of the forward supply chain and the reverse supply chain is solved, and the objectives of the manufacturer, the retailer, and the recycler are consistent, which effectively alleviates the supply chain conflict. As shown in Propositions 5.2 and 5.3, sales, recoverable quantity, retail advertising, and recycling advertising of the model MRC are the maximum. As a result, the manufacturer should collaborate as much as possible with other supply chain members. The more members of an alliance collaborate, the greater the supply chain's total profit.

Unlike the studies by Alamdar *et al.* [3] and Ma *et al.* [29], the total supply chain profit is not necessarily larger when the manufacturer collaborates only with the retailer (MR) than when it collaborates only with the recycler (MO). There are some interesting findings: The effect of the manufacturer's cooperation strategy on the relationship between the size of supply chain profits under different models depends on the coefficient of recycling advertising. Specifically, if the coefficient of recycling advertising on recoverable quantity (h) is small, supply chain profits are higher when the manufacturer cooperates only with the retailer (MR) than when the manufacturer cooperates only with the recycler (MO). This is because, as shown in Proposition 5.8, when the impact of recycling advertising on recoverable quantity is small, the cost savings from manufacturer-recycler cooperation is smaller, and manufacturer-retailer cooperation can increase sales quantity, so the manufacturer-retailer cooperation model can bring greater profits to the supply chain. When recycling advertising has a greater impact on recoverable quantity, although manufacturer-retailer cooperation can increase sales quantity, the recoverable quantity per unit of recycling advertising will bring a larger increase. At this time, manufacturer-recycler cooperation can increase the recoverable quantity and save more cost, so the profit of the manufacturer-recycler cooperation model (MO) is greater than the manufacturer-retailer cooperation model (MR).

6. Numerical study

In this section, numerical analyses are carried out to further study how the advertising coefficients (z, h) affect the equilibrium results, supply chain profit, and cooperation strategy. The parameter setting closely follows Ma *et al.* [29] and Jena *et al.* [16], and $\alpha = 10000$, $\beta = 40$, $c_M = 200$, $\Delta = 100$, $a = 100$, $f = 40$, $k = 1$.

Figure 2a focuses on how the coefficient of retail advertising on sales (z) affects the retail price. Numerical studies have verified that retail price is positively correlated with retail advertising coefficient. This is because, as the impact of retail advertising on sales grows, increasing retail price will not result in a significant decrease in sales, which encourages the alliance members to increase retail price to increase revenue. Another interesting finding is that when the manufacturer cooperates with the retailer, the rate of growth of retail price is higher than when the manufacturer does not cooperate with the retailer. The partial derivation of the retail advertising coefficient (z) under different models is obtained as $\frac{\delta p_{MRO}}{\delta z} = \frac{\delta p_{MC}}{\delta z} = \frac{2kz(x-My)}{(2ky-z^2)^2} > \frac{\delta p_N}{\delta z} = \frac{\delta p_{MO}}{\delta z} = \frac{kz(x-My)}{(2ky-z^2)^2} > 0$, which also confirms this conclusion. As expressed in Proposition 5.3, $q_{MR} = q_{MRO} > q_N = q_{MO}$, $g_{MR} = g_{MRO} > g_N = g_{MO}$. This means that collaboration between the manufacturer and the retailer results in increased investment in retail advertising and sales. Specifically, when the manufacturer collaborates with the retailer, the adverse effect of increased retail prices resulting in decreased sales is mitigated further; conversely, higher sales provide the alliance members with a greater incentive to increase retail prices. In addition, the growth inflection point is determined to be at 6.5. In other words, when z is between 6.5 and 8, it has a substantial impact on retail price. When z is between 0 and 6.5, the effect of z on retail price is slight.

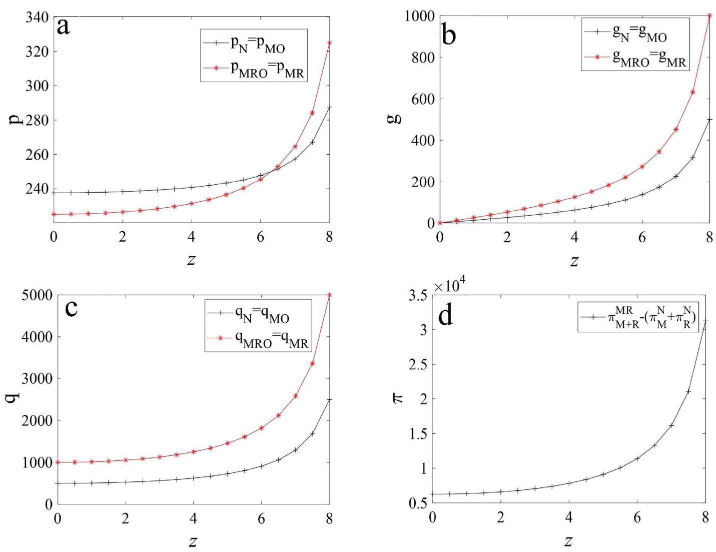

FIGURE 2. Effect of z on equilibrium results and cooperative tendency (a) Effect of z on p, (b) Effect of z on g, (c) Effect of z on q, (d) Effect of z on the cooperative tendency.

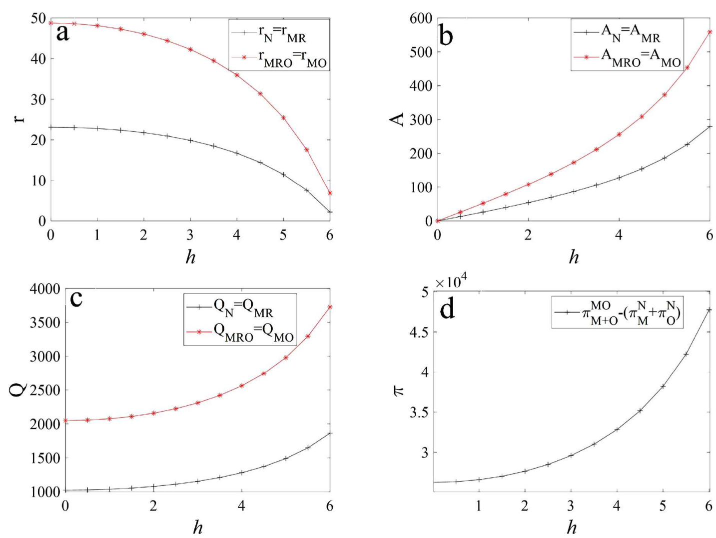

FIGURE 3. Effect of h on equilibrium results and cooperative tendency (a) Effect of h on r, (b) Effect of h on A, (c) Effect of h on Q, (d) Effect of h on the cooperative tendency.

Figures 2b and 2c show that retail advertising effort and retail sales are positively correlated with retail advertising coefficient regardless of the type of cooperation. This is because, as the retail advertising coefficient grows, the retailers' retail advertising efforts will increase, which results in increased retail sales. Additionally, as illustrated in Figure 2d, the higher the retail advertising coefficient, the more willing the manufacturer would be to collaborate with the retailer. This is because, as the retail advertising coefficient increases, the retailer will increase their level of retail advertising effort, leading to increased sales, thereby making the benefits of manufacturer-retailer cooperation more significant.

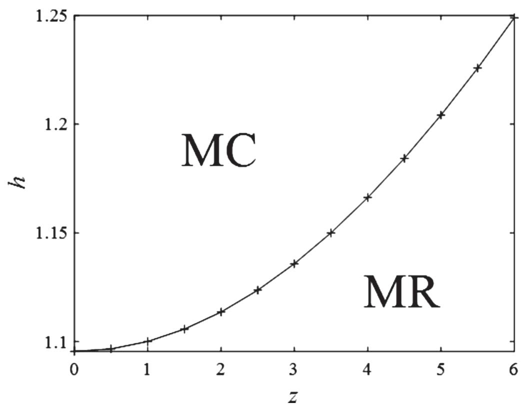

FIGURE 4. Effect of h and z on the cooperative strategy.

Figure 3a focuses on how the coefficient of recycling advertising on recoverable quantity (h) affects recycling price. This figure demonstrates that regardless of cooperation strategy, the recycling price is inversely related to the recycling advertising coefficient. As the impact of recycling advertising on recoverable quantity increases, the online recycling platform will rely heavily on recycling advertising to increase recoverable quantity, while gradually reducing recycling price. Another interesting finding is that when the manufacturer works with the recycler, the rate of decline in the recycling price is higher than when not work with. The partial derivation of the recycling advertising coefficient (h) under different models is obtained as $\frac{\delta r_{MRO}}{\delta h} = \frac{\delta r_{MO}}{\delta h} = -\frac{2hk(a+Nf)}{(2fk-h^2)^2} < \frac{\delta r_N}{\delta h} = \frac{\delta r_{MR}}{\delta h} = -\frac{hk(a+Nf)}{(2fk-h^2)^2} < 0$, which confirms this conclusion. As stated in Proposition 5.5, $A_{MO} = A_{MRO} > A_N = A_{MR}$, $Q_{MO} = Q_{MRO} > Q_N = Q_{MR}$. This means that the collaboration between the manufacturer and the recycler will result in increased recycling advertising and recoverable quantity. Specifically, when the manufacturer cooperates with the recycler, the negative effect of lowering the recycling price, which results in a reduction in recoverable quantity, is mitigated further; conversely, the vast recoverable quantity makes the alliance members more incentive to save costs by reducing the recycling price. As a result of this collaboration, the recycling advertising coefficient's effect on the recycling price is amplified.

Figures 3b and 3c demonstrate that recycling advertising effort and recoverable quantity is positively correlated with the recycling advertising coefficient regardless of the type of cooperation. This is because, as the impact of recycling advertising on recoverable quantity grows, recyclers' advertising efforts will increase, resulting in increased recoverable quantity. Additionally, as illustrated in Figure 3d, as the recycling advertising coefficient increases, manufacturer's willingness to cooperate with recyclers increases. This is because the higher the recycling advertising coefficient, the more recycling advertising recyclers place and the greater the recoverable quantity, which means that the manufacturer and the recycler can achieve greater cost savings and revenue through collaboration.

Figure 4 illustrates intuitively how retail advertising coefficient (z) and recycling advertising coefficient (h) affect manufacturer's cooperative tendency. The MR region is the range of the manufacturer's cooperation with retailers, while the MC region is the range of the manufacturer's cooperation with recyclers. As illustrated in Figure 2d, as the recycling advertising coefficient increases, the manufacturer's willingness to cooperate with recyclers also increases. As a result, the greater the value of h, the larger will be the MC region. As illustrated in Figure 3d, as the retail advertising coefficient increases, the manufacturer's willingness to cooperate with retailers also increases. As a result, the greater the value of z, the larger will be the MR region. This conclusion implies that the manufacturer will choose the supply chain members to cooperate with based on the values of h and z.

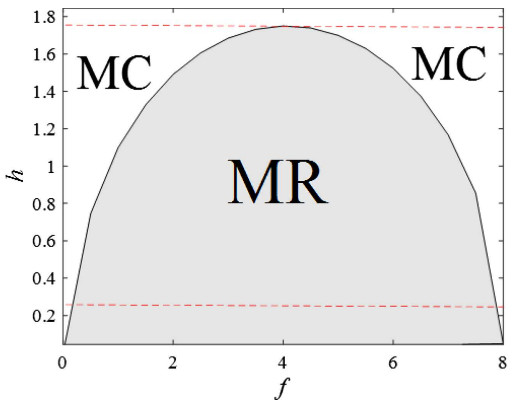

FIGURE 5. Effect of h and f on the cooperative strategy.

Figure 5 provides insights into how recycling price coefficient f and recycling advertising coefficient h affect manufacturer's cooperative tendency. In the graph, the grey area MR represents the range of cooperation between manufacturer and retailer, and the blank area MC represents the range of cooperation between manufacturer and recycler. As expressed in Proposition 5.8, when the recycling advertising coefficient is low, the cooperation between the manufacturer and the recycler cannot yield significant cost savings. So, the benefit of cooperation between the manufacturer and the retailer will be dominant; when h is low, the range will be almost entirely grey. Conversely, when the recycling coefficient is high, the cooperation between the manufacturer and the recycler avoids the double adverse effects of the reverse supply chain. Thus, the benefit of cooperation between the manufacturer and the recycler will be dominant; when h is high, the range will be almost entirely blank.

The figure is divided into three regions when the recycling advertising coefficient is in the mid-range. When the recycling price coefficient is low, the manufacturer will rely heavily on recycling advertising to increase the recoverable quantity. As described in Proposition 5.5, when the manufacturer collaborates with the recycler, the level of recycling advertising and recoverable quantity will increase. As a result, the manufacturer would be more willing to collaborate with the recycler. When the recycling price coefficient is also at an intermediate level, the manufacturer can increase recoverable quantity through both recycling advertising and recycling prices. As illustrated in Figure 3a, cooperation between the manufacturer and the recycler will further reduce the recycling price. For the moment, neither recycling price nor recycling advertising will result in a significant increase in recoverable quantity, which stays at a low level. Consequently, the benefits of the manufacturer collaborating with the retailer to avoid the double marginal effect of the forward supply chain outweigh the benefits of the manufacturer collaborating with the recycler to avoid the reverse supply chain's double marginal effect, and so, the manufacturer will choose to collaborate with the retailer at this time. When the recycling price coefficient is high, even though the cooperative alliance between the manufacturer and the recycler has a greater incentive to lower the recycling price, the lower recycling price will be sufficient to generate a significant recoverable quantity. The manufacturer and recycler cooperation will yield more benefits than the manufacturer and retailer cooperation, so the manufacturer will choose to cooperate with the recycler.

7. CONCLUSION

Concluding remarks

Recycling advertising plays an important role in increasing the recoverable quantity. Some online recycling platforms have begun to spend on recycling advertising to increase their recoverable quantity. In this study, based on the real-world observation that the online recycling platform engages in recycling advertising, while the retailer engages in retail advertising, we discuss how retail and recycling advertising affect the manufacturer's cooperation strategy from the perspective of a CLSC.

We construct a CLCS consisting of a manufacturer, an online recycling platform, and a retailer. In the retail channel, the retailer implements retail advertising to stimulate market demand. In the collecting channels, the online recycling platform implements recycling advertising to increase the recoverable quantity.

Our results show the following. (1) Cooperation between the manufacturer and the retailer increases retail advertising and sales, which incentivizes the manufacturer to collaborate with the retailer. Collaboration between the manufacturer and the online recycling platform will increase both recycling advertising and quantity, which incentivizes the manufacturer to collaborate with the online recycling platform. (2) The total profit of the supply chain will be the highest under model MRO and the lowest will be under model N. The more cooperative the members of a supply chain, the greater the supply chain's total profit. (3) The coefficient of retail advertising is positively correlated with the retail price, and collaboration between the manufacturer and the retailer will accelerate the rate of growth of retail prices. The recycling advertising coefficient is inversely proportional to the recycling price and collaboration between the manufacturer and the recycler will accelerate the decline in the recycling price. (4) The manufacturer collaborates with the retailer, or the recycler based on the retail or recycle advertising coefficients. When the retail advertising coefficient is high, the willingness of the manufacturer to cooperate with retailers will be high; when the recycling advertising coefficient is high, the willingness of the manufacturer to cooperate with recyclers will be high. The recycling price coefficient is also an important factor that affects the choice of cooperation strategy for the manufacturer. When the coefficients of both recycling price and recycling advertising are in the mid-range, the manufacturer will choose to work with the retailer.

Managerial insights and implications

The following are the key takeaways for managers from our findings. First, the recycler is encouraged to actively engage in recycling advertising because recycling advertising can increase both recoverable quantity and the recycler's competitiveness in the CLSC. Specifically, the higher the recycling advertising coefficient, the greater will be the benefits of collaboration between the manufacturer and the recycler, thereby greater will be the recycler's competitiveness. Additionally, we recommend that the recycler and retailer determine the level of advertising in accordance with their supply chain collaboration strategy. When the manufacturer collaborates with the recycler, the recycler should increase their level of recycling advertising; when the manufacturer collaborates with the retailer, the retailer should increase their level of retail advertising. In other words, the manufacturer's cooperation strategy will influence the retailer's or recycler's advertising investment strategy. Second, collaboration between the manufacturer and the recycler has the potential to significantly increase the recoverable quantity. Therefore, it pays for manufacturers and recyclers to collaborate to reduce their carbon emissions. Conversely, because recycling advertising contributes to increased recycling, recyclers should be encouraged to invest in recycling advertising from an environmental protection standpoint. Finally, consistent with Zheng *et al.* [48], Li *et al.* [24], a manufacturer's partnership strategy is a critical decision that has a direct impact on the supply chain's profitability. The more supply chain partners there are, the more profitable the entire supply chain will be, which means that manufacturers should cultivate the best possible relationships with other supply chain members. Additionally, when a manufacturer is limited to partnering with a single supply chain member, the manufacturer's partnership strategy should be considered carefully. When the retail advertising coefficient is high, manufacturers should prioritize their partnerships with retailers. Similarly, when the recycling advertising coefficient is high, manufacturers should prioritize cooperating with recyclers. Additionally, recycling advertising and recycling price coefficients have a significant impact on the manufacturer's collaboration strategy. When manufacturers make cooperative strategy decisions, they should consider the coefficients of recycling advertising, retail advertising, and recycling price.

Future research

Our investigation can be further carried out from the following aspects. First, there is only one recycler in the model constructed in this paper. There may be multiple recyclers, some of which will put advertisements, and some will not. Therefore, this situation should be considered in further research. Secondly, this paper studies the deterministic demand in CLCS. Therefore, considering uncertainty or random demand is an interesting but challenging future research direction. Third, the impact of government policy is not considered in our study. Therefore, another future research direction is to explore the impact of government incentives and subsidies. Furthermore, future research can consider the cooperation model, which aims to ensure a mutually beneficial and long-term relationship between retailers and online recycling platforms. This model includes the following aspects: Revenue sharing: The cooperation model incorporates a revenue-sharing mechanism that fairly distributes the profits generated from increased recycling volume and retail sales. This ensures that both parties have a financial incentive to maintain the partnership and contribute to its success. Information sharing: The model encourages information exchange between retailers and online recycling platforms, such as consumer behavior data, advertising effectiveness, and recycling rates. This information sharing enables both parties to make more informed decisions and adjust their strategies to maximize the benefits of the cooperation. Joint decision-making: The cooperation model involves joint decision-making on key aspects, such as advertising strategies, pricing, and recycling incentives. This collaborative approach ensures that both parties have a say in the decisions that affect their partnership and can work together to find mutually beneficial solutions.

Appendix A.

Proof of Model N. According to the Game order of CLSC with dominant manufacturer, the reverse recursive method is used to solve the problem. First, the first-order partial derivatives of the decision variables are found for the profit function of the retailer (π_R). Then the first-order partial derivative is equal to zero, and the optimal solutions are obtained.

$$\begin{cases} \frac{\delta\pi_R}{\delta p} = \alpha - 2\beta p + \varpi\beta + zg = 0 \\ \frac{\delta\pi_R}{\delta g} = zp - z\varpi - gk = 0 \end{cases} \tag{A.1}$$

$$\begin{cases} p = \frac{(-\varpi z^2 + k\alpha + k\varpi\beta)}{-z^2 + 2k\beta} \\ g = \frac{z(\alpha - \varpi\beta)}{-z^2 + 2k\beta} \end{cases} \tag{A.2}$$

We use the Hessian matrix to check the concavity conditions, which points out the determinants of all its principal minors should be alternatively negative and positive. The Hessian matrix is as follows:

$$H = \begin{bmatrix} -2\beta & z \\ z & -k \end{bmatrix} \tag{A.3}$$

Because $|H_1| = -2\beta < 0$, when $2\beta k - z^2 > 0$ $|H_2| = 2\beta k - z^2 > 0$, so (A.2) is the optimal solution.

Then the first-order partial derivatives of the decision variables are found for the profit function of the online recycling platform (π_O). Let the partial derivatives equal to zero, the optimal solution is obtained.

$$\begin{cases} \frac{\delta\pi_C}{\delta r} = -2fr - hA + fb - a = 0 \\ \frac{\delta\pi_C}{\delta A} = -rh - kA + bh = 0 \end{cases} \tag{A.4}$$

$$\begin{cases} A_N = \frac{h(a+bf)}{2fk-h^2} \\ r_N = \frac{fkb-bh^2-ak}{2fk-h^2} \end{cases} \tag{A.5}$$

We use the Hessian matrix to check the concavity conditions, the Hessian matrix is as follows:

$$H = \begin{bmatrix} -2f & -h \\ -h & -k \end{bmatrix} \tag{A.6}$$

Because $|H_1| = -2f < 0$, when $2fk - h^2 > 0$ $|H_2| = 2fk - h^2 > 0$, so (A.5) is the optimal solution. Substituting (A.2), (A.5) into the profit function of the manufacturer (π_M), the first-order partial derivatives of each decision variable are obtained. Let the partial derivatives equal to zero, the optimal solution is obtained.

$$\begin{cases} \frac{\delta\pi_M}{\delta\varpi} = \alpha + \frac{\beta z^2 - \beta(-\varpi z^2 + k\alpha + k\varpi\beta) + z^2(\alpha - \varpi\beta)}{-z^2 + 2k\beta} + \frac{\beta(-z^2 + k\beta)}{(-z^2 + 2k\beta)(c_M - \varpi)} = 0 \\ \frac{\delta\pi_M}{\delta b} = -a + \frac{(\Delta - b)(-fh^2 + kf^2)}{-h^2 + 2kf} + \frac{fh^2 - h^2(a + bf)}{-h^2 + 2kf} = 0 \end{cases} \tag{A.7}$$

$$\begin{cases} \varpi_N = \frac{\alpha}{2\beta} + \frac{1}{2}c_m \\ b_N = \frac{-a + \Delta f}{2f} \end{cases} \tag{A.8}$$

Then, the Hessian matrix is as follows:

$$H = \begin{bmatrix} -\frac{2ky^2}{2ky - z^2} & 0 \\ 0 & -\frac{2f^2k}{2fk - h^2} \end{bmatrix} \tag{A.9}$$

Because $|H_1| = -\frac{2ky^2}{2ky - z^2} < 0$, when $2\beta k - z^2 > 0$, $2fk - h^2 > 0$ $|H_2| = \frac{4k^2y^2f^2}{(2ky - z^2)(2fk - h^2)} > 0$, so (A.8) is the optimal solution. Substituting (A.8) into, (A.2), (A.5)

$$\begin{cases} P_N = \frac{3\alpha + c_m\beta}{4\beta} \\ g_N = \frac{z\left(\frac{\alpha}{2} - \frac{c_M\beta}{2}\right)}{2ky - z^2} \\ A_N = \frac{h\left(\frac{a}{2} + \frac{\Delta f}{2}\right)}{2fk - h^2} \\ r_N = \frac{ak + \left(k - \frac{h^2}{f}\right)\left(\frac{a}{2} - \frac{\Delta f}{2}\right)}{2fk - h^2} \\ \varpi_N = \frac{\alpha}{2\beta} + \frac{1}{2}c_m \\ b_N = -\frac{a - \Delta f}{2f} \end{cases} \tag{A.10}$$

From there, we calculate retail price, product demand, retail advertising effort recycling advertising effort, recycling price, wholesale price, and transfer price as (A.10), respectively.

Subsequently, Substituting (A.8) into demand function ($q = \alpha - \beta p + zg$), recoverable quantity function ($Q = a + fr + hA$), the profit function of the manufacturer (π_M), the profit function of the online recycling platform (π_O), and the profit function of the retailer (π_R).

$$\begin{cases} Q_N = \frac{fk(a + \Delta f)}{2(2fk - h^2)} \\ \pi_M^N = \frac{k(a + \Delta f)^2}{8fk - 4h^2} + \frac{k(\alpha - c_m\beta)^2}{8k\beta - 4z^2} \\ \pi_c^N = \frac{k(a + \Delta f)^2}{8(2fk - h^2)} \\ \pi_R^N = \frac{k(\alpha - C_m\beta)^2}{8(2k\beta - z^2)} \\ \pi_S^N = \pi_M + \pi_R + \pi_C = \frac{3k(\alpha - c_m\beta)^2}{8(2k\beta - z^2)} + \frac{3k(a + \Delta f)^2}{8(2fk - h^2)} \end{cases} \tag{A.11}$$

From there, we calculate product demand, recoverable quantity, the individual equilibrium profits, and channel equilibrium profits as (A.11), respectively.

Proof of Model MR, Model MO, and Model MRO. Similar to the solution method and process in Model N, it is omitted here.

Appendix B.

Proof of Proposition 5.1. $\varpi_N = \varpi_{MO} = \frac{\alpha}{2\beta} + \frac{1}{2}c_m$, $b_N = b_{MR} = -\frac{a-\Delta f}{2f}$

Proof of Proposition 5.2.

$$p_N = p_{MO} = \frac{k\alpha + \frac{k(\alpha+c_m\beta)}{2} - \frac{z^2(\alpha+c_m\beta)}{2\beta}}{2k\beta - z^2} \tag{B.12}$$

$$p_{MRO} = p_{MR} = \frac{-c_M z^2 + k\alpha + c_M k\beta}{2k\beta - z^2} \tag{B.13}$$

$$p_N - p_{MCR} = \frac{\left(k\beta - z^2\right)\left(\alpha - c_M\beta\right)}{2\beta\left(2k\beta - z^2\right)} \tag{B.14}$$

Because, $\alpha - \beta p > 0$, $p > c_M$ so $\alpha - c_M\beta > 0$. As shown in Appendix A, to ensure that the optimal solution exists, $2k\beta - z^2 > 0$ needs to be satisfied. So if $z < \sqrt{k\beta}$, $k\beta - z^2 > 0$, $p_N = p_{MO} > p_{MR} = p_{MRO}$; If $z > \sqrt{k\beta}$, $k\beta - z^2 < 0$ $p_{MR} = p_{MRO} > p_N = p_{MO}$.

Proof of Proposition 5.3.

(1)

$$g_N = g_{MO} = \frac{z\left(\frac{\alpha}{2} - \frac{c_M y}{2}\right)}{2ky - z^2} \tag{B.15}$$

$$g_{MC} = g_{MRO} = \frac{z\left(\alpha - c_M\beta\right)}{2k\beta - z^2} \tag{B.16}$$

$$g_N - g_{MRO} = -\frac{z\left(\alpha - c_M\beta\right)}{2\left(2ky - z^2\right)} < -\frac{z\left(\alpha - c_M\beta\right)}{2\left(2ky - z^2\right)} < 0 \tag{B.17}$$

(2)

$$q_N = q_{MO} = \frac{k\beta\left(\alpha - c_M\beta\right)}{2\left(2k\beta - z^2\right)} \tag{B.18}$$

$$q_{MRO} = p_{MR} = \frac{k\beta\left(\alpha - c_m\beta\right)}{2k\beta - z^2} \tag{B.19}$$

$$q_N - q_{MCR} = \frac{\alpha - c_m\beta}{4\beta} > \frac{\alpha - p\beta}{4\beta} > 0 \tag{B.20}$$

Proof of Proposition 5.4.

$$r_N = r_{MR} = \frac{ak + \left(k - \frac{h^2}{f}\right)\left(\frac{a}{2} - \frac{\Delta f}{2}\right)}{2fk - h^2} \tag{B.21}$$

$$r_{MRO} = r_{MO} = -\frac{\Delta h^2 + ak - \Delta fk}{2fk - h^2} \tag{B.22}$$

$$r_N - r_{MRO} = -\frac{\left(fk - h^2\right)\left(a + \Delta f\right)}{2f\left(2fk - h^2\right)'} \tag{B.23}$$

From Appendix A, it can be seen that the following conditions need to be satisfied in order to ensure the optimal solution $2kf - h^2 > 0$. So if $h < \sqrt{kf}$, $fk - h^2 > 0$, $r_{MO} = r_{MRO} > r_N = r_{MR}$; If $h > \sqrt{kf}$, $fk - h^2 < 0$, $r_{MO} = r_{MRO} < r_N = r_{MR}$.

Proof of Proposition 5.5. Similar to the solution method and process in Proposition 5.3, it is omitted here.

Proof of Proposition 5.6.

$$\pi_{M+\mathrm{O}}^{MO} - \pi_M^N - \pi_O^N = \frac{k(a+\Delta f)^2}{8\left(2fk-h^2\right)} > 0 \tag{B.24}$$

Proof of Proposition 5.7.

$$\pi_{M+\mathrm{R}}^{MR} - \pi_M^N - \pi_R^N = \frac{k(\alpha - c_M\beta)^2}{8\left(2k\beta-z^2\right)} > 0 \tag{B.25}$$

Proof of Proposition 5.8.

$$\begin{aligned} &\pi_{M+\mathrm{O}}^{MO} - \pi_M^N - \pi_O^N - \left(\pi_{M+\mathrm{R}}^{MR} - \pi_M^N - \pi_R^N\right) \\ =&\frac{k(a+\Delta f)^2\left(2k\beta-z^2\right) - k(\alpha-c_M\beta)^2\left(2fk-h^2\right)}{8\left(2fk-h^2\right)\left(2k\beta-z^2\right)}. \end{aligned} \tag{B.26}$$

The positive and negative of equation (B18) are determined by the function $f(h) = k(a+\Delta f)^2\left(2k\beta - z^2\right) - k(\alpha - c_M\beta)^2\left(2fk-h^2\right)$. Due to $k > 0$ and $(\alpha - c_M\beta)^2 > 0$ if $h = h_0$, $f(h) = 0$; if $h < h_0$, $f(\mu) < 0$, $\pi_{M+\mathrm{O}}^{MO} - \pi_M^N - \pi_O^N < \pi_{M+\mathrm{R}}^{MR} - \pi_M^N - \pi_R^N$; if $h > h_0$, $f(h) > 0$, $\pi_{M+\mathrm{O}}^{MO} - \pi_M^N - \pi_O^N > \pi_{M+\mathrm{R}}^{MR} - \pi_M^N - \pi_R^N$, where $h_0 = \frac{\sqrt{2kc_M{}^2f\beta^2 - 4kc_Mf\alpha\beta - 2k\Delta^2f^2\beta + \Delta^2f^2z^2 - 4k\Delta af\beta + 2\Delta afz^2 - 2ka^2\beta + a^2z^2 + 2kf\beta^2}}{\alpha - c_M\beta}$.

Proof of Proposition 5.9. Similar to the solution method and process in Proposition 5.8, it is omitted here.

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