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Collection and Coordination Strategies in a Dual-Channel Closed-Loop Supply Chain Under Manufacturer Diseconomies of Scale

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ABSTRACT Manufacturing enterprises often face the problem of an increasing production cost per unit of output—that is, diseconomies of scale—due to technology or management ability. This paper examines the collection channel selection and coordination strategies of a dual-channel closed-loop supply chain (CLSC) in the presence of manufacturer diseconomies of scale. Decision models for a dual-channel CLSC with single- and dual-channel waste product collection are constructed from the perspectives of centralized and decentralized decision-making, and the effects of diseconomies of scale and sales/collection competition on the pricing of new products and the waste product collection rate are analyzed. Moreover, criteria for selecting a collection channel are given for CLSC members and the system as a whole, and two-part tariff contracts are designed to coordinate the dual-channel CLSC under different collection channels. We find that the optimal pricing decision and members' profits are negatively correlated with diseconomies of scale and positively correlated with sales competition. Under the dual-channel sales structure, the direct sales volume is more than twice that of retail sales, the stronger the sales competition, the more pronounced this advantage is. Further, from the perspective of collection, when collection competition is weak, the dual-channel collection strategy is optimal, while as competition increases, the single-channel collection strategy may be better. The manufacturer's collection rate is more than twice that of the retailer under dual-channel collection, and the stronger collection competition is, the larger this gap is. Finally, the conclusions are verified by numerical simulation, and management insights are proposed.

INDEX TERMS Diseconomies of scale, dual-channel closed-loop supply chain, pricing decision, collection strategy, coordination.

I. INTRODUCTION

With the large consumption of resources and increasing concerns over environmental protection, countries of the world are advocating the development of a green, low-carbon and circular economy [1]–[3]. The concept and meaning of sustainable development have deep roots. In 2003, European governments enacted a directive on waste electrical and electronic equipment (WEEE), covering the collection and remanufacture of all types of such equipment [4]. Subsequently, many countries, including Canada, Japan, China and the United States, introduced legislation similar to the WEEE directive [5]. In this context, in recent years, enterprises have begun to pay more attention to the implementation of CLSC management. For instance, traditional manufacturing enterprises such as IBM and Haier, in addition to purchasing raw materials and producing and selling products through the forward supply chain, have established reverse supply chains to collect waste products for reuse and remanufacture, with great success [6]. Volkswagen collects used engines and components to save 70% on manufacturing costs [7]. Through the Apple Trade In exchange program, Apple collected 7 million used mobile phones in 2018 alone, converting more than 48,000 tons of electronic waste and reducing its carbon emission by 2.8 million tons since 2011. Thus, the implementation of CLSC management can not only save on enterprise production costs but also effectively improve operational efficiency and thus plays a key role in promoting

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the sustainable development of the economy and the environment [8].

However, in the context of the fast economic development of all countries in the world, in order to seize market share, many companies continue to scale up and often carry out business expansions and mergers. These activities not only can diversify management modes but also may lead to varying degrees of decentralization in corporate organizational structures. This can lead to the phenomenon of diseconomies of scale [9]. Griffin [10] showed that 74 listed companies on the New York stock exchange featured diseconomies of scale in 1973. From 1985 to 1994, six types of vehicles in the Japanese automobile industry were produced under diseconomies of scale [11]. Alvarez and Arias [12] found for dairy farms that with management ability held constant, diseconomies of scale become increasingly prominent as the number of farms increases. In addition, Changhong, Kangjia, Hisense and other enterprises in China have seen rising costs due to diseconomies of scale [13], [14]. Therefore, in the following study, this paper attempts to explore effective ways to alleviate diseconomies of scale through the implementation of CLSCs.

In the past few years, with the rapid development of e-commerce, many enterprises have adopted the dual-channel marketing model of direct sales and distribution in supply chains. In this way, enterprises can enter markets and enhance their competitiveness [15]. Firms such as Apple, Lenovo, Haier and other large enterprises now not only sell through traditional channels such as Suning, Gome and other retail stores but also have established direct stores or e-commerce platforms to sell directly to consumers. This not only helps reduce the dependence on traditional distributors but also can develop new markets and enhance sensitivity to changes in consumer demand to alleviate adverse impacts of manufacturer diseconomies of scale and improve enterprise performance. At the same time, for enterprises implementing CLSCs, the exploration of optimal collection channels can effectively improve their collection efficiency, reduce collection costs, increase income, and alleviate diseconomies of scale. Consequently, the research in this paper theorizes this supply chain setting and provides decision support for enterprise management in similar situations.

At present, most studies on CLSCs focus on product pricing decisions, collection channel selection, channel leadership, and government regulation and coordination mechanisms, assuming fixed marginal production costs for the manufacturer and ignoring the impact of manufacturer diseconomies of scale on the operation of CLSCs. However, diseconomies of scale often arise in the process of business operation. Overall, based on the literature on manufacturer diseconomies of scale, this paper distinguishes the existing studies and explores the following issues:

(1) How do manufacturer diseconomies of scale influence new product pricing and waste product collection in dual-channel CLSCs?

(2) How does sales/collection competition influence new product pricing, waste product collection and profits for dual-channel CLSC members?

(3) What is the optimal collection strategy under manufacturer diseconomies of scale? What are the criteria by which dual-channel CLSC members and the whole system determine the optimal collection channel?

(4) In the context of manufacturer diseconomies of scale, can traditional two-part tariff contracts still coordinate dual-channel CLSCs under different collection channel structures?

The rest of this paper proceeds as follows. The second part summarizes references related to the research in this paper. Section 3 describes the relevant problems, the notation, and the models. Section 4 presents a centralized decision-making model of a dual-channel CLSC with manufacturer production diseconomies under different collection modes and derives the results. Section 5 further explores a decentralized decision model on the basis of the previous section and offers the results. In Section 6, we propose to a two-part tariff contract to coordinate a dual-channel CLSC under manufacturer diseconomies of scale. In Section 7, the accuracy of the conclusions and the validity of the coordination contract are analyzed and verified through numerical simulation, and some management insights from the models are given. The last part of this paper summarizes the research and points out shortcomings and further research directions.

II. LITERATURE REVIEW

Current research on CLSCs has yielded many insights. This paper focuses on the impact of diseconomies of scale on pricing decisions and collection and coordination strategies in a dual-channel supply chain and explores the optimal collection channel to mitigate the impact of diseconomies of scale. Next, we analyze existing literature in regard to these aspects.

A. PRICING AND COORDINATION STRATEGY OF A DUAL-CHANNEL CLSC

A great deal of research has been done on dual-channel CLSC pricing decisions and coordination strategies. Saha *et al.* [16] studied the coordination of a dual-channel CLSC and remanufacturing policies with a government incentive mechanism. Taleizadeh *et al.* [17] analyzed the impact of marketing efforts on optimal pricing strategies and dual-channel CLSC member profits. He *et al.* [18] discussed the impact of consumer free-riding behavior and a government e-commerce tax policy on the carbon emission of a dual-channel CLSC. Zheng *et al.* [19] considered the two situations of information symmetry and asymmetry and analyzed the influence of power structures and competition among collection channels on the optimal pricing strategy in a CLSC. Zhang, He, and Shi discussed retailers' selection of the optimal sales channel from among online, offline and dual-channel sales and derived the selection criteria [20]. Xie *et al.* [21] thoroughly discussed the impact of cooperative advertising on the pricing and coordination strategy of a dual-channel CLSC. Based on this work, in 2018, he further explored the service strategy of a dual-channel CLSC under cost-benefit sharing contracts [22]. Zhang *et al.* [23] analyzed the influence of quality level on vertical dual-channel pricing options and integrated product quality and revenue to design a dual-channel CLSC coordination mechanism. He *et al.* [24] discussed optimal pricing and coordination of a dual-channel CLSC under government subsidies. Liu *et al.* [25] studied the influence of dual sales channels in a CLSC on manufacturer and retailer pricing and production decisions. Although the above studies on dual-channel CLSCs have yielded abundant results, few works have studied the optimal collection strategy and coordination of a dual-channel CLSC. For enterprises implementing CLSCs, adopting the marketing model of dual-channel sales offers a way to improve their earnings. At the same time, exploring an optimal collection channel can also boost the operating efficiency of enterprises, reduce collection costs and increase revenue.

B. COLLECTION CHANNEL SELECTION IN A CLSC

Many studies have discussed the pricing decision and coordination strategy of CLSCs under different collection channel structures. Savaskan *et al.* [26] established three decision models with manufacturer, retailer and third-party collection, respectively; the results show that the outcome is the best with retailer collection. Comparing channel structures with retailer and third-party collection, Hong and Yeh [27] indicated that the collection rate and channel profit when the retailer is responsible for collection are not always greater than those when collection is done by a third-party. Based on a third-party collection structure, Choi *et al.* [28] compared the pricing strategies and revenue of a CLSC under the leadership of three different channels. In a setting with information asymmetry, Wei *et al.* [29] discussed the impact of a change in channel power structure on the selection of a CLSC's reverse collection channels. Under three different collection channels, Hong *et al.* [30] analyzed the impact of the demonstration effect on a CLSC's selection of recycling mode. In a setting with competing mixed reverse collection channels, Liu *et al.* [31] indicated that a hybrid collection channel in which both manufacturers and retailers collect simultaneously is the best choice for the manufacturer. Modak *et al.* [32] studied the pricing decision of a CLSC under three collection modes—dominant manufacturer collection, dominant retailer collection and dominant third-party collection—and analyzed the impact of collecting channels and product quality on the pricing decision. In a setting with uncertain conditions of collected products and dual-channel collection, Giri and Dey [33] theoretically analyzed the pricing strategy of a dual-channel CLSC with backup suppliers. Wan and Hong [34] discussed the impact of government subsidy and transfer pricing policies on the pricing strategy and member profit in a CLSC with dual-channel collection. Xiao *et al.* [35] constructed two CLSC decision models for retail channel collection and dual-channel collection in order to determine the optimal collection channel for trade-ins. Wu *et al.* [36] studied the selection of optimal collection channels by environmentally responsible CLSCs under different decision-making modes. Yang *et al.* [37] discussed collection channel selection in the case of a CLSC under a cap-and-trade regulation. For a dual-channel CLSC in which traditional retailers and online recyclers are jointly responsible for collection, Yuan *et al.* [38] studied collection and pricing decision-making and analyzed the necessary conditions for coordination. Chen and Gao [39] discussed the effects of collection services and incentives on waste products collection and enterprise performance under four different collection modes. Scarkar and Bhala [40] studied decision-making over different collection channels in the presence of fairness concerns among supply chain partners and found that under the manufacturer collection mode, the efficiency of waste product collection is higher. The above studies on the design and optimization of CLSC collection channels have yielded many important results. However, they have not considered diseconomies of scale. Second, they have only rarely studied the selection of collection channels in a dual-channel CLSC.

C. DISECONOMIES OF SCALE

Another stream of literature related to this paper is on diseconomies of scale. In reality, almost all companies are likely to display diseconomies of scale, which can arise from obsolescing production technology and suboptimal management. In addition, if the operating scale of an enterprise is lower than the minimum scale required by the industry or exceeds a certain limit, diseconomies of scale also arise. In the supply chain, diseconomies of scale directly affect the decisions and benefits of supply chain members. Mollick [11] and Rawley and Simcoe [14] discussed in depth the impact of production diseconomies in an enterprise on its operational efficiency and performance. Considering the case of retailer information sharing, Ha *et al.* [41] discussed the impact of diseconomies of scale on the supply chain structure in the presence of supply chain competition. Wang and Zhuo [42] discussed strategic information sharing under supplier encroachment in a two-stage supply chain and found that the supplier is more likely to encroach on the retailer in the case of lower sales costs and greater production diseconomies. All the above studies focused on the forward supply chain structure, and few studies have discussed the impact of diseconomies of scale on pricing and members' profit in a CLSC. Second, as mentioned above, there is no literature discussing collection channel selection and coordination strategies in a dual-channel CLSC under diseconomies of scale.

To sum up, in the context of manufacturer diseconomies of scale, this paper discusses the optimal pricing decision and recycling channel selection of a dual-channel CLSC and derives a coordination strategy that can be implemented in different decision situations. First, the profit models of a dual-channel CLSC under three different collection channels are established for cases in which the decision is centralized and decentralized, respectively, and the equilibrium results of the different decision models are obtained by using a Stackelberg

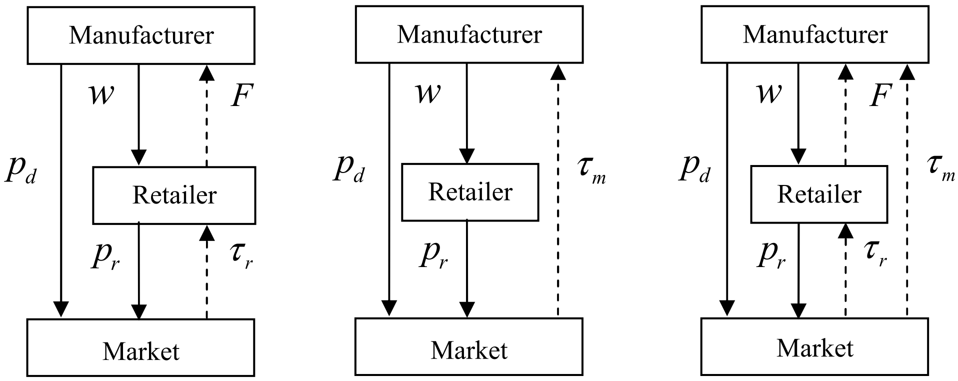

FIGURE 1. Dual-channel CLSC structure under three collection modes.

game and optimization theory. Then, through comparative analysis, this paper derives the criteria according to which CLSC members and the whole system can choose the optimal collection channel under diseconomies of scale. Finally, two-part tariff contracts are designed to coordinate the CLSC with different collection channels based on the optimal decision in the centralized model, and we identify the corresponding range of contract parameters. In short, this paper theorizes the selection of collection channels and coordination strategies in a dual-channel CLSC in the presence of diseconomies of scale.

III. PROBLEM DESCRIPTION AND ASSUMPTIONS

This paper considers a dual-channel CLSC consisting of a manufacturer and a retailer. In the forward supply chain, the manufacturer produces a single product, which is characterized by diseconomies of scale. The manufacturer sells the product, on the one hand, at the direct price through the direct channel and, on the other hand, at the retail price in the market through the retail channel. In the reverse supply chain, waste products are processed and remanufactured by the manufacturer. There are three main ways for the manufacturer to obtain waste products: the manufacturer can collect them itself, can delegate collection to the retailer, or collect waste products alongside the retailer at the same time. The specific structural framework is shown in figure 1.

According to the research of Zheng *et al.* [19], we assume that there exists price competition between the manufacturer and retailer in the forward supply chain; the corresponding demand functions of the direct and retail channels are as follows:

$$q_d = a - p_d + \beta p_r, \tag{1}$$

$$q_r = a - p_r + \beta p_d. \tag{2}$$

Referring to Savaskan and Van Wassenhove [43] and Huang *et al.* [44], we assume that the collection cost function of the manufacturer or retailer is $I_i^* = k\tau_i^2, i \in \{m, r\}$. We can construct the collection cost functions of the manufacturer and retailer when the two compete in the collection process, which are

$$I_m = \frac{k(\tau_m^2 + \alpha\tau_r^2)}{1-\alpha^2}, \quad I_r = \frac{k(\tau_r^2 + \alpha\tau_m^2)}{1-\alpha^2}. \tag{3}$$

In addition, consistent with the actual development of manufacturing enterprises, we assume that the manufacturer has diseconomies of scale, which could be a need to invest more production capacity or incur a greater cost for each additional unit of output at a certain level of production, reflected in the nonlinear structure of the manufacturer's production cost function. Referring to the study of Ha *et al.* [41], we assume that the total production cost of the manufacturer with diseconomies of scale is

$$c(q) = bq^2. \tag{4}$$

The relevant symbols and variables used in this paper are shown in table 1.

In this paper, we discuss some key problems of a dual-channel CLSC in the context of diseconomies of scale, including the pricing decision, collection strategy and coordination in the supply chain. Therefore, the model quantifying CLSC management problems is quite complicated. To ensure tractability, the following main assumptions are made without loss of generality.

(1) The manufacturer and retailer play a Stackelberg game under complete information, where the manufacturer is the leader and both are risk neutral [26], [28], [43].

(2) The waste products are strictly evaluated and monitored to ensure that the used products are worth collecting, processing and remanufacturing [45].

(3) The new and remanufactured products are the same in terms of quality, performance and appearance, and the customers' evaluation of the two products is similar [46].

(4) The two sales channels face potential consumers in the same market, and potential consumers can choose whether to buy the products through the direct or retail channel.

(5) To avoid interference of the initial and final time cycle effects, sales and collection in the dual-channel CLSC system occur in a single cycle [26], [28], [43]; forward sales and reverse collection of products are also completed in the same cycle.

TABLE 1. Symbol definitions and assumptions.

Symbol	Definitions and assumptions
a	a constant, represents potential demand of the channel, $a>0$
p_d	the direct price decided by the manufacturer
p_r	the retail price decided by the retailer
β	the cross-price elasticity coefficient between different sales channels, which represents the degree of sales competition between the direct sales channel and distribution channel, $0<\beta<1$
τ_i	the member enterprise's collection rate, where $i\in\{m,r\}$ represents the manufacturer and retailer, respectively
k	the difficulty of collecting waste products, $k>0$; the higher the value, the lower is the collection efficiency of the collector
α	the degree of collection competition between the manufacturer and retailer, $0\le\alpha\le1$
b	a constant, represents the coefficient of diseconomies of scale, $b>0$
q	the total production of the manufacturer, $q=q_d+q_r$
w	the wholesale price of each new product, $p\ge w$
c_m	the manufacturer's production cost per unit, $w>c_m$
c_r	the manufacturer's remanufacturing cost per unit; $\Delta=c_m-c_r>0$ represents the unit cost saved by the manufacturer through remanufacturing
$c(F)=F\tau_r$	the collection transfer price offered by the manufacturer to the retailer, where F is the total amount paid to the retailer by the manufacturer when the retailer's collection rate is 1
π_x	the profits of each member enterprise and the whole system in a CLSC; $x=\{m,r,s\}$ represents the manufacturer, retailer and the whole system, respectively

IV. CENTRALIZED DUAL-CHANNEL CLSC DECISION MODEL

A. SINGLE-CHANNEL COLLECTION BY THE MANUFACTURER OR RETAILER (MODEL S)

Based on the literature on manufacturer diseconomies of scale, this section first discusses the dual-channel CLSC decision problem for single-channel collection carried out by the manufacturer or retailer. Centralized decision-making is done based on the performance of the whole CLSC system to maximize the profits of the dual-channel CLSC. In this case, the direct price p_d, distribution price p_r and collection rate τ_s are determined by both manufacturer and retailer. At this point, the total profit function of the dual-channel CLSC can be expressed as

$$\pi_s^S(p_d, p_r, \tau_s)=(p_d-c_m)q_d+(p_r-c_m)q_r + \Delta\tau_s(q_d+q_r)-b(q_d+q_r)^2-k\tau_s^2. \quad (5)$$

Proposition 1: Model S has a unique optimal solution when $k>\frac{\Delta(a-(1-\beta)c_m+(1-\beta)\Delta)}{2(1+2b(1-\beta))}$. The specific results are shown in table 2.

B. DUAL-CHANNEL COLLECTION BY THE MANUFACTURER AND RETAILER (MODEL SS)

When the dual-channel CLSC adopts the dual-channel collection mode, the direct price p_d, distribution price p_r and collecting rate τ_m and τ_r are determined by the manufacturer and retailer jointly. At this point, the total profit function of the dual-channel CLSC can be expressed as

$$\pi_s^{SS}(p_d, p_r, \tau_m, \tau_r) =(p_d-c_m)q_d+(p_r-c_m)q_r + \Delta(\tau_m+\tau_r)(q_d+q_r)-b(q_d+q_r)^2-\frac{k(\tau_m^2+\tau_r^2)}{1-\alpha}. \quad (6)$$

Proposition 2: The model SS has a unique optimal solution when $k>\frac{\Delta(1-\alpha)(a-(1-\beta)c_m+(1-\beta)\Delta)}{1+2b(1-\beta)}$. The specific results are shown in table 2.

Conclusion 1: Under centralized decision-making, (a) $p_d^{S*}=p_r^{S*}\ge p_d^{SS*}=p_r^{SS*}$, $q_d^{S*}=q_r^{S*}\le q_d^{SS*}=q_r^{SS*}$, and $\tau_s^{S*}\le\tau_s^{SS*}$ when $0<\alpha\le0.5$, and $p_d^{S*}=p_r^{S*}<p_d^{SS*}=p_r^{SS*}$, $q_d^{S*}=q_r^{S*}>q_d^{SS*}=q_r^{SS*}$, and $\tau_s^{S*}>\tau_s^{SS*}$

TABLE 2. Equilibrium results and profits in different models under centralized decision-making.

	Model S	Model SS
$p_d^*=p_r^*$	$\frac{4kab(1-\beta)+a(k-(1-\beta)\Delta^2)+kc_m(1-\beta)}{(1-\beta)(4kb(1-\beta)+2k-(1-\beta)\Delta^2)}$	$\frac{4kab(1-\beta)+a(k-2(1-\beta)(1-\alpha)\Delta^2)+kc_m(1-\beta)}{2(1-\beta)(2kb(1-\beta)+k-(1-\beta)(1-\alpha)\Delta^2)}$
$q_d^*=q_r^*$	$\frac{k(a-(1-\beta)c_m)}{4kb(1-\beta)+2k-(1-\beta)\Delta^2}$	$\frac{k(a-(1-\beta)c_m)}{2(2kb(1-\beta)+k-(1-\beta)(1-\alpha)\Delta^2)}$
$\tau_m^*=\tau_r^*$	$\frac{\Delta(a-(1-\beta)c_m)}{4kb(1-\beta)+2k-(1-\beta)\Delta^2}$	$\frac{\Delta(1-\alpha)(a-(1-\beta)c_m)}{2(2kb(1-\beta)+k-(1-\beta)(1-\alpha)\Delta^2)}$
$\tau_s^*=\tau_m^*+\tau_r^*$	$\frac{\Delta(a-(1-\beta)c_m)}{4kb(1-\beta)+2k-(1-\beta)\Delta^2}$	$\frac{\Delta(1-\alpha)(a-(1-\beta)c_m)}{2kb(1-\beta)+k-(1-\beta)(1-\alpha)\Delta^2}$
π_s^*	$\frac{k(a-(1-\beta)c_m)^2}{(1-\beta)(4kb(1-\beta)+2k-(1-\beta)\Delta^2)}$	$\frac{k(a-(1-\beta)c_m)^2}{2(1-\beta)(2kb(1-\beta)+k-(1-\beta)(1-\alpha)\Delta^2)}$

when $0.5 < \alpha < 1$; (b) $\pi_s^{S*} \leq \pi_s^{SS*}$ when $0 < \alpha \leq 0.5$ and $\pi_s^{S*} > \pi_s^{SS*}$ when $0.5 < \alpha < 1$.

The analysis of conclusion 1 shows that in a dual-channel CLSC where the manufacturer has diseconomies of scale, when a centralized decision is made, no matter which collection model is chosen by the dominant manufacturer (be it manufacturer collection, retailer collection, or joint collection), the optimal direct sales price is always the same as the optimal distribution price. For the two sales channels, the market demands are also equal. In reality, to improve the competitiveness of enterprises and boost market demand for new products, many large enterprises (e.g., Haier, Gree) have established dual (online and offline) sales channels. Companies usually adopt a unified pricing strategy to avoid upsetting consumers with obvious price differences—a fact that underscores the practical explanatory significance of this research.

Further, according to conclusion 1, under centralized decision-making with dual-channel collection by the manufacturer and retailer, when the degree of collection competition between them is relatively low (that is, $0 < \alpha \leq 0.5$), products with dual-channel collection have a lower sales price, higher market demand, a higher collection rate of used products, and higher profits for the CLSC overall than in the case of single-channel collection by the manufacturer or retailer. As collection competition increases beyond a certain threshold (that is, $0.5 < \alpha < 1$), single-channel collection by the manufacturer or retailer represents a better channel structure for the CLSC overall. Moderate competition between member enterprises helps increase the overall profits of the dual-channel CLSC. However, excessively competitive behavior can have counterproductive effects; this conclusion aligns with general trends in economic markets.

V. DECENTRALIZED DUAL-CHANNEL CLSC DECISION MODEL

A. SINGLE-CHANNEL COLLECTION BY THE MANUFACTURER (MODEL M)

In model M, the manufacturer independently produces new products and collects old products, and it also opens direct marketing channels to sell those products. In reality, large electrical and electronic equipment manufacturers such as IBM, Panasonic and Dell not only cooperate with retailers such as JD.com to sell products together but have also set up corresponding subsidiaries or collection workshops to collect waste products.

The decision sequence of each member enterprise in model M is as follows: First, the dominant manufacturer announces its own decision variables, including the wholesale price w, direct sales price p_d and collection rate τ_m, and then the retailer determines the retail price p_r based on the manufacturer's decision. In summary, the profit functions of the manufacturer and retailer, respectively, can be expressed as

$$\pi_m^M(w,\ p_d,\ \tau_m) = (p_d - c_m)q_d + (w - c_m)q_r + \Delta\tau_m(q_d+q_r) - b(q_d+q_r)^2 - k\tau_m^2, \quad (7)$$

$$\pi_r^M(p_r) = (p_r - w)q_r. \quad (8)$$

Proposition 3: Model M has a unique optimal solution when $k > \frac{\Delta(3+\beta)(a-(1-\beta)c_m+(1-\beta)\Delta)}{4(2+b(1-\beta)(3+\beta))}$. The specific results are shown in table 3.

Proof: See the Appendix.

B. SINGLE-CHANNEL COLLECTION BY THE RETAILER (MODEL R)

In model R, the retailer undertakes the task of collecting waste products. Kodak is a practical example of this closed-loop structure: it delegates collection of discarded cameras to retailers that sell its products. Other examples include Gome, Suning and other large retail enterprises that provide a full range of trade-in services for the enormous number of products that they sell.

The decision sequence of each member enterprise in model R is as follows: First, the dominant manufacturer announces its own decision variables, including the wholesale price w, direct sales price p_d and transfer payment F, and then the retailer determines the retail price p_r and collection rate τ_r based on the manufacturer's decision. In summary, the profit functions of the manufacturer and retailer, respectively, can

TABLE 3. Equilibrium results and profits in different models under decentralized decision-making.

	Model M	Model R	Model MR
w^*	$\frac{4kabA_1A_3+a\Delta_1+4kc_mA_1}{A_1(4kbA_1A_3+\Delta_2)}$	$\frac{8kabA_1A_3+a\Delta_2+8kc_mA_1}{A_1(8kbA_1A_3+\Delta_4)}$	$\frac{4kabA_1A_3B_1+a\Delta_7+4kc_mA_1B_1}{A_1(4kbA_1A_3B_1+\Delta_6)}$
p_d^*	$\frac{4kabA_1A_3+a\Delta_1+4kc_mA_1}{A_1(4kbA_1A_3+\Delta_2)}$	$\frac{8kabA_1A_3+a\Delta_2+8kc_mA_1}{A_1(8kbA_1A_3+\Delta_4)}$	$\frac{4kabA_1A_3B_1+a\Delta_7+4kc_mA_1B_1}{A_1(4kbA_1A_3B_1+\Delta_6)}$
p_r^*	$\frac{4kabA_1A_3+a\Delta_3+2kc_mA_5}{A_1(4kbA_1A_3+\Delta_2)}$	$\frac{8kabA_1A_3+a\Delta_5+4kc_mA_5}{A_1(8kbA_1A_3+\Delta_4)}$	$\frac{4kabA_1A_3B_1+a\Delta_8+2kc_mA_5B_1}{A_1(4kbA_1A_3B_1+\Delta_6)}$
F^*	—	$\frac{2k\Delta A_3(a-A_1c_m)}{8kbA_1A_3+\Delta_4}$	$\frac{2k\Delta A_3(a-A_1c_m)}{4kbA_1A_3B_1+\Delta_6}$
τ_m^*	$\frac{\Delta A_3(a-A_1c_m)}{4kbA_1A_3+\Delta_2}$	—	$\frac{\Delta A_3B_1B_2(a-A_1c_m)}{4kbA_1A_3B_1+\Delta_6}$
τ_r^*	—	$\frac{\Delta A_3(a-A_1c_m)}{8kbA_1A_3+\Delta_4}$	$\frac{\Delta A_3B_2(a-A_1c_m)}{4kbA_1A_3B_1+\Delta_6}$
q_d^*	$\frac{2kA_2(a-A_1c_m)}{4kbA_1A_3+\Delta_2}$	$\frac{4kA_2(a-A_1c_m)}{8kbA_1A_3+\Delta_4}$	$\frac{2kA_2B_1(a-A_1c_m)}{4kbA_1A_3B_1+\Delta_6}$
q_r^*	$\frac{2k(a-A_1c_m)}{4kbA_1A_3+\Delta_2}$	$\frac{4k(a-A_1c_m)}{8kbA_1A_3+\Delta_4}$	$\frac{2kB_1(a-A_1c_m)}{4kbA_1A_3B_1+\Delta_6}$
π_m^*	$\frac{kA_3(a-A_1c_m)^2}{A_1(4kbA_1A_3+\Delta_2)}$	$\frac{2kA_3(a-A_1c_m)^2}{A_1(8kbA_1A_3+\Delta_4)}$	$\frac{kA_3B_1(a-A_1c_m)^2}{A_1(4kbA_1A_3B_1+\Delta_6)}$
π_r^*	$\frac{4k^2(a-A_1c_m)^2}{(4kbA_1A_3+\Delta_2)^2}$	$\frac{k(16k+A_3^2\Delta^2)(a-A_1c_m)^2}{(8kbA_1A_3+\Delta_4)^2}$	$\frac{k(4kB_1^2-A_3^2B_2B_4\Delta^2)(a-A_1c_m)^2}{(4kbA_1A_3B_1+\Delta_6)^2}$
π_s^*	$\frac{k(4kbA_1A_3^2+\Delta_9)(a-A_1c_m)^2}{A_1(4kbA_1A_3+\Delta_2)^2}$	$\frac{k(16kbA_1A_3^2+\Delta_{10})(a-A_1c_m)^2}{A_1(8kbA_1A_3+\Delta_4)^2}$	$\frac{k(4kbA_1A_3^2B_1^2+\Delta_{11})(a-A_1c_m)^2}{A_1(4kbA_1A_3B_1+\Delta_6)^2}$

be expressed as

$$\pi_m^R(w,\ p_d,\ F) = (p_d - c_m)q_d + (w - c_m)q_r + \Delta\tau_r(q_d+q_r) - b(q_d+q_r)^2 - F\tau_r, \quad (9)$$

$$\pi_r^R(p_r,\ \tau_r) = (p_r - w)q_r + F\tau_r - k\tau_r^2. \quad (10)$$

Proposition 4: Model R has a unique optimal solution when $k > \frac{\Delta(3+\beta)(a-(1-\beta)c_m+(1-\beta)\Delta)}{8(2+b(1-\beta)(3+\beta))}$. The specific results are shown in table 3.

C. DUAL-CHANNEL COLLECTION BY THE MANUFACTURER AND RETAILER (MODEL MR)

In model MR, in a forward or reverse supply chain, the manufacturer and retailer set up a dual-channel model to sell new products and collect waste products. Such cases are common in reality. For example, Xerox and Eastman Kodak cooperate with downstream retailers for both product sales and waste product collection, thereby improving decision-making efficiency and reducing costs [47].

The decision sequence of each member enterprise in model M is as follows: First, the dominant manufacturer announces its own decision variables, including the wholesale price w, direct sales price p_d, transfer payment F and collection rate τ_m, and then the retailer determines the retail price p_r and collection rate τ_r based on the manufacturer's decision. In summary, the profit functions of the manufacturer and retailer, respectively, can be expressed as

$$\pi_m^{MR}(w, p_d, F, \tau_m) = (p_d-c_m)q_d+(w-c_m)q_r - F\tau_r + \Delta(\tau_m+\tau_r)(q_d+q_r) - b(q_d+q_r)^2 - \frac{k(\tau_m^2+\alpha\tau_r^2)}{1-\alpha^2}, \quad (11)$$

$$\pi_r^{MR}(p_r,\ \tau_r) = (p_r - w)q_r + F\tau_r - \frac{k(\tau_r^2+\alpha\tau_m^2)}{1-\alpha^2}. \quad (12)$$

Proposition 5: Model *MR* has a unique optimal solution when $k > \frac{\Delta(3+\beta)(1-\alpha^2)(a-(1-\beta)c_m+(1-\beta)(3+\alpha)\Delta)}{4(4+b(1-\beta)(3+\beta)(2+\alpha))}$. The results are shown in table 3.

where $1-\beta = A_1$, $2+\beta = A_2$, $3+\beta = A_3$, $3-\beta = A_4$, $1-\beta^2 = A_5$, and $7+\beta = A_6$, $2+\alpha = B_1$, $1-\alpha^2 = B_2$, $3+\alpha = B_3$, $-1+4\alpha+4\alpha^2+\alpha^3 = B_4$, and $5+9\alpha+5\alpha^2+\alpha^3 = B_5$; and $4k - A_1A_3\Delta^2 = \Delta_1$, $8k-A_1A_3\Delta^2 = \Delta_2$, $2kA_4-A_1A_3\Delta^2 = \Delta_3$, $16k-A_1A_3\Delta^2 = \Delta_4$, $4kA_2 - A_1A_3\Delta^2 = \Delta_5$, $16k - A_1A_3B_2B_3\Delta^2 = \Delta_6$, $4kB_1 - A_1A_3B_2B_3\Delta^2 = \Delta_7$, $2kA_4B_1 - A_1A_3B_2B_3\Delta^2 = \Delta_8$, $4kA_6 - A_1A_3^2\Delta^2 = \Delta_9$, $16kA_6 - A_1A_3^2\Delta^2 = \Delta_{10}$, and $4kA_6B_1^2 - A_1A_3^2B_2B_5\Delta^2 = \Delta_{11}$ when parameter k satisfies the assumptions $\Delta_1, \Delta_2, \ldots, \Delta_{11} > 0$.

Conclusion 2: Under decentralized decision-making, (a) $w^{M*} = p_d^{M*} < p_r^{M*}$, $w^{R*} = p_d^{R*} < p_r^{R*}$, and $w^{MR*} = p_d^{MR*} < p_r^{MR*}$.

(b) $q_d^{M*}/q_r^{M*} = 2+\beta$, $q_d^{R*}/q_r^{R*} = 2+\beta$, $q_d^{MR*}/q_r^{MR*} = 2+\beta$, and $\tau_m^{MR*}/\tau_r^{MR*} = 2+\alpha$.

The analysis in conclusion 2 indicates the following: (a) shows that under decentralized decision-making, no matter which collection mode the manufacturer chooses, the wholesale price set by the manufacturer is the same as its direct selling price. For the downstream retailer in the supply chain to make more profits, it must set the retail price higher than the wholesale price, which is in turn higher than the direct selling price. Due to this price disadvantage, consumers are more inclined to purchase from the manufacturer's direct channels. Further, it can be seen from (b) that no matter the collection channel, the sales volume of the manufacturer's direct channel is at least twice that of the retail channel, and as competition between the two channels increases, the advantages of the manufacturer's direct channel become more pronounced. In addition, when dual-channel collection is adopted, the manufacturer's collection rate is always more than twice the retailer's, and as collection competition between them increases, the manufacturer's collection advantage becomes more significant.

This result is because as the core enterprise of the CLSC, the manufacturer's priority decision-making power has a great impact on the retailer's decision. For example, in forward sales, the retailer's retail price and sales volume depend on the manufacturer's wholesale and direct prices. In the reverse collection process, the retailer's collection rate depends on the manufacturer's transfer payment and collection cost. Therefore, whether in the sales or collection market, the retailer's decision is always influenced by the dominant manufacturer.

Conclusion 3: Under decentralized decision-making, (a) $w^{MR*} \leq w^{M*} < w^{R*}$, $p_d^{MR*} \leq p_d^{M*} < p_d^{R*}$, and $p_r^{MR*} \leq p_r^{M*} < p_r^{R*}$ when $0 < \alpha \leq 0.53$; $w^{M*} < w^{MR*} \leq w^{R*}$, $p_d^{M*} < p_d^{MR*} \leq p_d^{R*}$, and $p_r^{M*} < p_r^{MR*} \leq p_r^{R*}$ when $0.53 < \alpha \leq 0.79$; and $w^{M*} < w^{R*} < w^{MR*}$, $p_d^{M*} < p_d^{R*} < p_d^{MR*}$, and $p_r^{M*} < p_r^{R*} < p_r^{MR*}$ when $0.79 < \alpha < 1$.

(b) $q_d^{MR*} \geq q_d^{M*} > q_d^{R*}$, $q_r^{MR*} \geq q_r^{M*} > q_r^{R*}$, and $\tau^{MR*} \geq \tau^{M*} > \tau^{R*}$ when $0 < \alpha \leq 0.53$; $q_d^{M*} > q_d^{MR*} \geq q_d^{R*}$, $q_r^{M*} > q_r^{MR*} \geq q_r^{R*}$, and $\tau^{M*} > \tau^{MR*} \geq \tau^{R*}$ when $0.53 < \alpha \leq 0.79$; and $q_d^{M*} > q_d^{R*} > q_d^{MR*}$, $q_r^{M*} > q_r^{R*} > q_r^{MR*}$, and $\tau^{M*} > \tau^{R*} > \tau^{MR*}$ when $0.79 < \alpha < 1$.

The analysis of conclusion 3 shows that under manufacturer diseconomies of scale, compared with retailer collection, manufacturer collection has a lower product price, higher sales volume and higher collection rate. Furthermore, in a comparison with dual-channel collection, it is found that when collection competition is relatively weak ($0 < \alpha \leq 0.53$), the pricing decision under the dual-channel collection model is the best, followed by manufacturer collection, while that under retailer collection is the worst. As collection competition increases to $0.53 < \alpha \leq 0.79$, the manufacturer collection pricing decision is the best, followed by dual-channel collection, while the retailer collection effect is still the worst. In the case of relatively strong collection competition ($0.79 < \alpha < 1$), the effect of manufacturer collection is the best and dual-channel collection the worst.

This conclusion further indicates that relative to the outcomes under the manufacturer or retailer single-collection channel, moderate competition between them is beneficial to both parties and the system as a whole. Excessive competition, however, is counterproductive. Therefore, the manufacturer, as the channel leader, should control the degree of competition among members to the extent feasible and then encourage the CLSC members to make the optimal pricing decision.

Conclusion 4: Under the decentralized decision, when the profits of dual-channel CLSC members and the whole system under different collection channel structures are compared, we have the following:

(a) The manufacturer's profit satisfies $\pi_m^{MR*} \geq \pi_m^{M*} > \pi_m^{R*}$ when $0 < \alpha \leq 0.53$, $\pi_m^{M*} > \pi_m^{MR*} \geq \pi_m^{R*}$ when $0.53 < \alpha \leq 0.79$ and $\pi_m^{M*} > \pi_m^{R*} > \pi_m^{MR*}$ when $0.79 < \alpha < 1$.

(b) The retailer's profit satisfies $\pi_r^{MR*} \geq \pi_r^{R*} > \pi_r^{M*}$ when $0 < \alpha \leq \alpha_2$, $\pi_r^{R*} > \pi_r^{MR*} \geq \pi_r^{M*}$ when $\alpha_2 < \alpha \leq \alpha_3$ and $\pi_r^{R*} > \pi_r^{M*} > \pi_r^{MR*}$ when $\alpha_3 < \alpha < 1$, where α_2, $\alpha_3 \in (0, 1)$ are the only positive real roots of equation $\pi_r^{R*} = \pi_r^{MR*}$ and $\pi_r^{M*} = \pi_r^{MR*}$ that satisfy the conditions.

(c) The total profits of the whole system satisfy $\pi_s^{MR*} \geq \pi_s^{M*} > \pi_s^{R*}$ when $0 < \alpha_2 < \alpha \leq \alpha_4 < 0.53$, $\pi_s^{M*} > \pi_s^{MR*} \geq \pi_s^{R*}$ when $\alpha_3 < \alpha_4 < \alpha \leq \alpha_5 < 0.79$ and $\pi_s^{M*} > \pi_s^{MR*} \geq \pi_s^{R*}$ when $\alpha_5 < \alpha < 1$, where α_4, $\alpha_5 \in (0, 1)$ are the only positive real roots of equation $\pi_s^{M*} = \pi_s^{MR*}$ and $\pi_s^{R*} = \pi_s^{MR*}$ that satisfy the conditions.

(d) The profits of the manufacturer and retailer under the same collection channel structure satisfy $\pi_m^{M*} > \pi_r^{M*}$, $\pi_m^{R*} > \pi_r^{R*}$ and $\pi_m^{MR*} > \pi_r^{MR*}$.

By the analysis of conclusion 4, (a) indicates that for the dominant manufacturer, compared with retailer collection, doing its own collection can yield greater profit. Further, if we compare the manufacturer and retailer profits under the dual-channel collecting mode, we find that when collection competition is relatively weak ($0 < \alpha \leq 0.53$), the manufacturer's profit is the best under dual-channel collection, second-best under manufacturer collection, and worst under retailer collection. As collection competition increases to $0.53 < \alpha \leq 0.79$, the manufacturer obtains more profits by collecting itself; dual-channel collection yields the second-highest profits, and profits are smallest under retailer collection. When collection competition is relatively strong ($0.79 < \alpha < 1$), the manufacturer still obtain more profit when collecting itself, followed by retailer collection, while the profit under dual-channel collection is the lowest.

(b) indicates that relative to the profit under manufacturer collection, the retailer can always make more profit by collecting under its own channel structure. Further, compared with the profit under dual-channel collecting, when $0 < \alpha \leq \alpha_2$, the retailer's profit is the largest under dual-channel collection and the smallest under the manufacturer collection channel structure. Further, when $\alpha_2 < \alpha \leq \alpha_3$, the retailer obtains the greatest profit when collecting itself and the smallest under manufacturer collection. Finally, when $\alpha_3 < \alpha < 1$, the retailer still obtains the most profit when collecting by itself and the least profit through dual-channel collection.

(c) indicates that for the whole CLSC system, the trend in total profits is consistent with the trend of the dominant manufacturer. That is, when collection competition is weak ($0 < \alpha_2 < \alpha \leq \alpha_4 < 0.53$), the total profits of the CLSC system under the dual-channel collection mode are larger; when collecting competition is relatively strong ($\alpha_3 < \alpha_4 < \alpha \leq \alpha_5 < 1$), total profits under the manufacturer collection mode are larger. When this point is combined with (d), it can be seen that compared with the retailer, the dominant manufacturer always obtains greater benefits. Yue *et al.* [48] came to the same conclusion for the forward supply chain: the manufacturer has a greater impact on the system trend, while changes in the retailer's profit affect only the change range of the α value.

To sum up, conclusion 4 shows that under manufacturer diseconomies of scale, relative to the outcomes under single-channel collection by the manufacturer or retailer, moderate competition between members can enable the dual-channel CLSC system to have a lower product price, higher waste product collection rate and larger product sales volume, while the dual-channel CLSC members can also obtain greater benefits. This further suggests that the members of the CLSC can compete as well as cooperate; this requires the leader of the supply chain to have certain coordination ability to better control the level of competition between members, thereby greatly improving the operational efficiency of the whole dual-channel CLSC as well as the overall benefits of each member and the whole system.

Conclusion 5: By comparing the equilibrium results of each decision model under the centralized and decentralized models, we find that (a) $p_d^{R*} > p_d^{M*} > p_d^{S*}$, $p_r^{R*} > p_r^{M*} > p_r^{S*}$, $q_d^{R*} < q_d^{M*} < q_d^{S*}$, $q_r^{R*} < q_r^{M*} < q_r^{S*}$, $\tau_r^{R*} < \tau_m^{M*} < \tau_s^{S*}$, and $\pi_s^{R*} < \pi_s^{M*} < \pi_s^{S*}$.

(b) $p_d^{MR*} > p_d^{SS*}$, $p_r^{MR*} > p_r^{SS*}$, $q_d^{MR*} < q_d^{SS*}$, $q_r^{MR*} < q_r^{SS*}$, $\tau_m^{MR*} + \tau_r^{MR*} = \tau_s^{MR*} < \tau_s^{SS*}$, and $\pi_s^{MR*} < \pi_s^{SS*}$.

Conclusion 5 shows that no matter the collection channel structure, the direct and retail prices of products are significantly lower in the centralized than in the decentralized CLSC. At the same time, product sales and the waste product collection effect are better, and the total profits of the CLSC system are higher. In fact, the decentralized decision causes the CLSC system to produce a "double marginal" effect, ultimately harming the overall profits of the whole system. However, the centralized decision-making mode treats all members as a community of interests to maximize the overall profits of the system as a decision-making goal. Therefore, compared with those in the decentralized setting, members of CLSC in the centralized scheme have less "internal friction" and higher operational efficiency, which helps improve product sales and the collection effect.

VI. COORDINATION OF A DUAL-CHANNEL CLSC UNDER DIFFERENT COLLECTION CHANNEL STRUCTURES

As mentioned above, under decentralized decision-making, the CLSC produces a double margin effect and fails to achieve the optimal decision for each member. In an environment of diseconomies of scale, the manufacturer, as the channel leader, has the responsibility of improving the overall performance of the CLSC system by increasing product sales and the collection rate. Based on this objective, this paper develops a two-part tariff contract to achieve perfect coordination of a dual-channel CLSC under different collection channels and discusses the value ranges of the contract parameters under different decision models.

A. SINGLE-CHANNEL COLLECTION BY THE MANUFACTURER (MODEL CM)

In model CM, the coordination process for the two-part tariff contract is as follows: First, the manufacturer offers a lower wholesale price w^{CM*}, which enables the retailer to set the retail price to p_r^{S*}. Then, the retailer pays the manufacturer a fixed fee f^{CM*} to make up for the profits lost to achieve coordination. The contract can be expressed as (w^{CM*}, f^{CM*}). Under the coordination strategy of (w^{CM*}, f^{CM*}), the profit functions of the manufacturer and retailer are, respectively,

$$\begin{aligned}\pi_m^{CM}(w, p_d, \tau_m) &= (p_d - c_m)q_d + (w - c_m)q_r \\ &\quad + \Delta\tau_m(q_d + q_r) - b(q_d + q_r)^2 - k\tau_m^2 + f, \end{aligned} \tag{13}$$

$$\begin{aligned}\pi_r^{CM}(p_r, f) &= (p_r - w)q_r - f, \\ s.t.\ &\begin{cases} (p_d - c_m)q_d + (w - c_m)q_r + \Delta\tau_m(q_d + q_r) \\ -b(q_d + q_r)^2 - k\tau_m^2 + f \geq \pi_m^{M*} \\ (p_r - w)q_r - f \geq \pi_r^{M*} \\ p_r^{CM*} = p_r^{S*} = p_d^{CM*} = p_d^{S*},\ \tau_m^{CM*} = \tau_s^{S*} \end{cases}\end{aligned} \tag{14}$$

Proposition 6: When the contract parameters satisfy $w^{CM*} = \frac{abk+a(1-\beta)(4kb-\Delta^2)+kc_m(1-\beta)(2-\beta)}{(1-\beta)(2k+(1-\beta)(4kb-\Delta^2))}$, $f^{CM*} \in [\underline{f}^{CM*}, \bar{f}^{CM*}]$, the contract can coordinate the dual-channel CLSC under manufacturer collection.

Proof: See Appendix.

B. SINGLE-CHANNEL COLLECTION BY THE RETAILER (MODEL CR)

In model *CR*, the manufacturer proposes a new contract (w^{CR*}, F^{CR*}, f^{CR*}), where w^{CR*} is the wholesale price reset by the manufacturer, F^{CR*} is the transfer payment reset by the manufacturer, and f^{CR*} is the fixed compensation paid by the retailer to the manufacturer. Under the coordination strategy of (w^{CR*}, F^{CR*}, f^{CR*}), the profit functions of the manufacturer and retailer are, respectively,

$$\begin{aligned}\pi_m^{CR}(w, p_d, F) &= (p_d - c_m)q_d + (w - c_m)q_r \\ &\quad + \Delta\tau_r(q_d + q_r) - b(q_d + q_r)^2 - F\tau_r + f \end{aligned} \tag{15}$$

$$\begin{aligned}\pi_r^{CR}(p_r, \tau_r, f) &= (p_r - w)q_r + F\tau_r - k\tau_r^2 - f,\\ s.t. &\begin{cases} (p_d - c_m)q_d + (w - c_m)q_r + \Delta\tau_r(q_d + q_r) \\ -b(q_d + q_r)^2 - F\tau_r + f \geq \pi_m^{R*} \\ (p_r - w)q_r + F\tau_r - k\tau_r^2 - f \geq \pi_r^{R*} \\ p_r^{CR*} = p_r^{S*} = p_d^{CR*} = p_d^{S*},\ \tau_r^{CR*} = \tau_s^{S*} \end{cases}\end{aligned} \tag{16}$$

Proposition 7: When the contract parameters satisfy $w^{CR*} = \frac{abk+a(1-\beta)(4kb-\Delta^2)+kc_m(1-\beta)(2-\beta)}{(1-\beta)(2k+(1-\beta)(4kb-\Delta^2))}$, $F^{CR*} = \frac{2k\Delta(a-(1-\beta)c_m)}{2k+(1-\beta)(4kb-\Delta^2)}$, $f^{CR*} \in [\underline{f}^{CR*}, \bar{f}^{CR*}]$, the contract can realize coordinate the dual-channel CLSC under retailer collection.

Proof: See Appendix.

C. DUAL-CHANNEL COLLECTION BY THE MANUFACTURER AND RETAILER (MODEL CMR)

In model *CMR*, the manufacturer offers a contract (w^{CMR*}, F^{CMR*}, f^{CMR*}) to the retailer. The specific coordination process is similar to that in 6.2 and is not described here. Under the coordination strategy of (w^{CMR*}, F^{CMR*}, f^{CMR*}), the profit functions of the manufacturer and retailer are, respectively,

$$\begin{aligned}\pi_m^{CMR}(w,\ p_d,\ F,\ \tau_m) &= (p_d - c_m)q_d + (w - c_m)q_r - F\tau_r \\ &\quad + \Delta(\tau_m + \tau_r)(q_d + q_r) + f - b(q_d + q_r)^2 \\ &\quad - \frac{k(\tau_m^2 + \alpha\tau_r^2)}{1 - \alpha^2}\end{aligned} \tag{17}$$

$$\begin{aligned}\pi_r^{CMR}(p_r,\ \tau_r,\ f) &= (p_r - w)q_r + F\tau_r - \frac{k(\tau_r^2 + \alpha\tau_m^2)}{1 - \alpha^2} - f,\\ s.t. &\begin{cases} (p_d - c_m)q_d + (w - c_m) \\ q_r + \Delta(\tau_m + \tau_r)(q_d + q_r) - b(q_d + q_r)^2 \\ -\frac{k(\tau_m^2 + \alpha\tau_r^2)}{1 - \alpha^2} - F\tau_r + f \geq \pi_m^{MR*} \\ (p_r - w)q_r + F\tau_r - \frac{k(\tau_r^2 + \alpha\tau_m^2)}{1 - \alpha^2} \\ -f \geq \pi_r^{MR*} \\ p_r^{CMR*} = p_r^{SS*} = p_d^{CMR*} = p_d^{SS*}, \\ \tau_m^{CMR*} = \tau_m^{SS*} = \tau_r^{CMR*} = \tau_r^{SS*} \end{cases}\end{aligned} \tag{18}$$

Proposition 8: When the contract parameters satisfy $w^{CMR*} = \frac{2a(1-\beta)(2kb-\Delta^2)+2a\alpha(1-\beta)\Delta^2+kc_m(1-\beta)(2-\beta)}{2(1-\beta)(k+(1-\beta)(2kb-(1-\alpha)\Delta^2))}$, $F^{CMR*} = \frac{k\Delta(a-(1-\beta)c_m)}{(1+\alpha)(k+(1-\beta)(2kb-(1-\alpha)\Delta^2))}$, $f^{CMR*} \in [\underline{f}^{CMR*}, \bar{f}^{CMR*}]$, the contract can coordinate the dual-channel CLSC under dual-channel collection.

Proof: See Appendix.

Conclusion 6: Under the two-part tariff contract, the optimal wholesale prices under different decision models satisfy $w^{CM*} = w^{CR*} > w^{CMR*}$ when $0 < \alpha \leq 0.5$ and $w^{CM*} = w^{CR*} < w^{CMR*}$ when $0.5 < \alpha < 1$.

It can be seen from the analysis result of conclusion 6 that whether the single-channel collection is carried out by the manufacturer or retailer, the equilibrium wholesale price after contract coordination is the same. This conclusion further reveals that the manufacturer needs to pay more to coordinate the dual-channel CLSC under the channel structure with retailer collection than under that with manufacturer collection. This result is easy to understand in combination with conclusion 3 under decentralized decision-making: the wholesale price under manufacturer collection is lower than the wholesale price under retailer collection. If the pricing of the two collection channels reaches the price under the centralized decision, the manufacturer needs to pay more under the channel structure with retailer collection (i.e., $w^{R*} - w^{CR*} > w^{M*} - w^{CM*}$).

Further, by comparing the equilibrium wholesale price in the contract under single- and dual-channel collection, we find that when collection competition between the manufacturer and retailer is weak ($0 < \alpha \leq 0.5$), the equilibrium price is lower in the dual- than in the single-channel collection contract. As collection competition increases to $0.5 < \alpha < 1$, the equilibrium price is higher in the dual- than in the single-channel collection contract. This result indicates that selection of the optimal collection channel in the dual-channel CLSC under the two-price contract is still affected by the degree of collection competition. Therefore, a manufacturer that adopts dual-channel collection should understand that the level of competition between the collectors, while improving the operating efficiency of the CLSC, also reflects the decision-making ability of the CLSC leader.

VII. NUMERICAL SIMULATION AND MANAGEMENT INSIGHTS

In this section, the main conclusions are analyzed and verified by numerical simulation. The setting of relevant parameters

TABLE 4. The influence of parameter b on the optimal decision under different decision models.

	b	$w=p_d$	p_r	F	τ	q_d	q_r	π_m	π_r	π_s
Model M	1	443.39	482.54	—	0.46	97.88	39.15	40082.12	1532.90	41615.02
	3	519.15	539.36	—	0.24	50.53	20.21	20693.13	408.57	21101.70
	5	545.51	559.13	—	0.16	34.06	13.62	13946.68	185.59	14132.27
Model R	1	443.70	482.77	341.91	0.23	97.69	39.08	40004.04	1565.90	41569.94
	3	519.23	539.42	176.69	0.12	50.48	20.19	20672.30	418.15	21090.45
	5	545.54	559.16	119.12	0.08	34.03	13.61	13937.22	190.07	14127.28
Model MR	1	443.27	482.46	285.70	0.54	97.95	39.18	40111.88	1505.37	41617.25
	3	519.12	539.34	147.44	0.28	50.55	20.22	20701.06	400.94	21102.00
	5	545.49	559.12	99.36	0.19	34.07	13.63	13950.28	182.08	14132.36

TABLE 5. The influence of parameter β on the optimal decision under different decision models.

	β	$w=p_d$	p_r	F	τ	q_d	q_r	π_m	π_r	π_s
Model M	0.1	302.57	316.41	—	0.14	29.07	13.84	6831.32	191.68	7023.00
	0.4	440.15	458.10	—	0.20	43.10	17.96	14804.98	322.43	15127.41
	0.8	1152.52	1187.27	—	0.44	97.29	34.75	98040.58	1207.40	99247.98
Model R	0.1	302.60	316.43	107.18	0.07	29.04	13.83	6823.65	195.08	7018.73
	0.4	440.21	458.15	152.47	0.10	43.05	17.94	14789.47	329.50	15118.97
	0.8	1152.78	1187.50	329.86	0.22	97.22	34.72	97967.99	1241.88	99209.87
Model MR	0.1	302.55	316.40	89.45	0.17	29.09	13.85	6834.24	188.92	7023.16
	0.4	440.12	458.09	127.24	0.24	43.11	17.96	14810.88	316.77	15127.66
	0.8	1152.43	1187.18	275.16	0.52	97.32	34.76	98068.19	1180.44	99248.63

should meet the assumptions in the basic model, so it is assumed that $a = 300$, $c_m = 15$, $c_r = 10$, and $k = 750$. When analyzing coefficient b, which captures diseconomies of production scale, we set $\beta = 0.5$ and $\alpha = 0.4$. When analyzing β, which captures the competition among sales channels, we set $b = 3$ and $\alpha = 0.4$. When analyzing α, which captures the degree of collection competition, we set $b = 3$ and $\beta = 0.5$. The specific simulation results can be seen in tables 4-6 and figures 2-3.

A. INFLUENCE OF PARAMETERS b AND β ON THE OPTIMAL DECISION OF THE DUAL-CHANNEL CLSC UNDER DIFFERENT COLLECTION CHANNELS

First, from the columns in table 4, under the three different decision models, as manufacturer diseconomies of scale increase, the wholesale, retail and direct prices are all increasing, while the product sales and waste collection rate under the two sales channels are all decreasing. Further observation shows that the profits of CLSC members and the whole system decrease as manufacturer diseconomies of scale increase. This shows that the manufacturer and retailer cannot make up for the loss caused by the diseconomies of scale through the strategy of increasing product prices.

Second, as seen from the columns in table 5, as competition between manufacturer and retail sales increases, the wholesale, retail and direct prices of products are also increasing. At the same time, the product sales volume, waste collection rate and profits of CLSC members and the whole system are all increasing. The numerical analysis shows that the more intense is the sales competition between the dual-channel CLSC members, the higher is the product sales volume, which also increases the profits of both parties and the whole system.

Finally, from the rows in tables 4 and 5, regardless of the diseconomies of scale and the degree of sales competition, the manufacturer's direct price is always lower than the retailer's retail price. In addition, the direct product sales volume is always higher than the retail sales volume, with direct sales always more than double the retail sales. In addition, the stronger the sales competition, the larger this gap is.

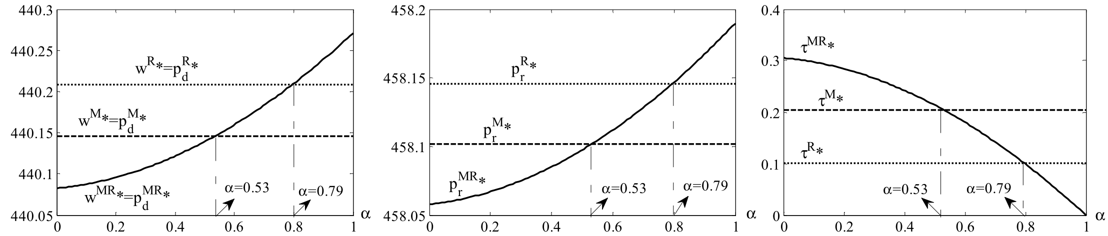

FIGURE 2. The influence of parameter α on w, p_m, p_r and τ in different decision models.

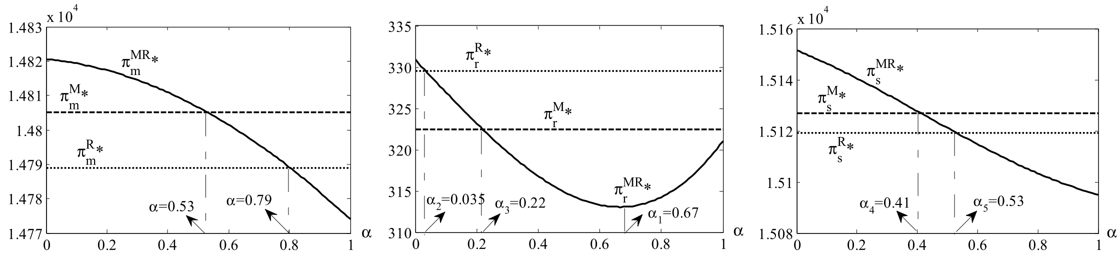

FIGURE 3. The influence of parameter α on the profits of dual-channel CLSC members and the whole system under different decision models.

Furthermore, the profits of the dominant manufacturer are much higher than those of the retailer, and with an increase in sales competition, the growth rate is greater. From this we can see that although sales competition is helpful for the CLSC members and the whole system, these benefits are more pronounced for the dominant manufacturer.

B. INFLUENCE OF PARAMETER α ON THE OPTIMAL DECISION OF THE DUAL-CHANNEL CLSC UNDER DIFFERENT COLLECTION CHANNELS

As shown in figure 2, we first observe in the equilibrium results in model *MR* that with an increase in collection competition between the manufacturer and retailer, the wholesale, direct and retail prices of products are increasing, while the waste collection rate is gradually decreasing. The conclusion reveals that an increase in collection competition is unfavorable for the pricing strategy of each member enterprise.

Second, it can be seen from figure 2 that compared with the product price under the retailer collection mode, the price of the product is lower and the collection rate of waste products is higher under manufacturer collection. Further, we find that when the degree of collection competition between the manufacturer and retailer is weak ($0 < \alpha \leq 0.53$), the pricing decision of dual-channel collection is the best. However, with growing collection competition, the advantage of the pricing decision under the dual-channel collection model gradually decreases. When competition reaches $0.53 < \alpha \leq 0.79$, the pricing decision under the manufacturer collection mode is optimal. Then, with further growth of collection competition to $0.79 < \alpha < 1$, the pricing decision under retailer collection is better than that under dual-channel collection. The simulation results reveal that the moderate competition between the CLSC members under dual-channel collection yields the benefits of a lower product price and higher collection rate than those under single-channel collection.

As shown in figure 3, looking first at each member enterprise's profit under the dual-channel collection mode, we find that with an increase in collection competition, the profit obtained by the dominant manufacturer always declines. For the retailer, when collection competition reaches a certain level, profit increases. However, because the increase in the retailer's profit is not enough to offset the decline in the dominant manufacturer's profit, the overall profits of the dual-channel CLSC are always on a downward trend. Thus, higher collection competition is unfavorable to the dual-channel CLSC overall.

Second, by comparing the profit of each member enterprise under the three different decision models, we find that when collection competition between the manufacturer and retailer is relatively weak ($0 < \alpha \leq 0.53$ or $0 < \alpha = \alpha_2 \leq 0.035$), whether for the manufacturer, the retailer or the whole system, profit is largest under the dual-channel collection mode. However, as collection competition reaches $0.53 < \alpha < 1$ or $0.035 < \alpha < 1$, the manufacturer and the retailer, respectively, obtain greater profit under their own collection channel structures, while the overall system has the largest total profit with manufacturer collection. This further show that compared with retailer, the manufacturer, as the dominant partner, has more impact on the dual-channel CLSC system and controls the development trend of the whole system.

C. ANALYSIS OF EFFECTIVENESS OF CONTRACT COORDINATION

First, by comparing the equilibrium results of models *S*, *M*, and *CM*, models *S*, *R*, and *CR*, and models *SS*, *MR*, and *CMR* in table 6, we find that under the two-part tariff

TABLE 6. Analysis of Effectiveness of contract coordination under different collection channels.

Model	f	w	p_d	p_r	F	τ_m	τ_r	τ_s	π_m	π_r	π_s
S	--	--	526.72	526.72	--	--	--	0.25	--	--	21434
SS	--	--	526.69	526.69	--	0.15	0.15	0.30	--	--	21443
M	--	519.15	519.15	539.36	--	0.23	--	0.23	20693	409	21102
R	--	519.23	519.23	539.42	176.69	--	0.12	0.12	20672	418	21090
MR	--	519.12	519.12	539.34	147.44	0.19	0.08	0.27	20701	401	21102
CM	601.82	490.08	526.72	526.72	--	0.25	--	0.25	20693	741	21434
CM	933.84	490.08	526.72	526.72	--	0.25	--	0.25	21025	409	21434
CR	625.73	490.08	526.72	526.72	366.38	--	0.25	0.25	20672	762	21434
CR	968.99	490.08	526.72	526.72	366.38	--	0.25	0.25	21016	418	21434
CMR	613.43	490.04	526.69	526.69	261.82	0.15	0.15	0.30	20701	742	21443
CMR	954.09	490.04	526.69	526.69	261.82	0.15	0.15	0.30	21042	401	21443

contract, the dominant manufacturer provides the retailer with a lower wholesale price and higher collection transfer payment. At this time, the retailer can raise the market price to the level under the centralized decision, and the collection rate and total profits of the CLSC are equal to those under centralized decision-making.

Further, according to table 6, under the two-part tariff contract, with an increase in parameter f, the manufacturer's profit is increasing while the retailer's profit is decreasing, but both of them are higher than the level under the decentralized decision. This is because the dominant manufacturer significantly reduces wholesale prices and increases the transfer payment to bring the retail price of the retailer to the level under centralized decision-making, thus improving product sales and the waste product collection rate, so that the retailer's sales revenue and collection profit are greatly increased. At the same time, the compensation f paid by the retailer to the manufacturer not only makes up for the loss caused by the low sale price but also delivers part of the surplus. Thus, within the identified range of contract parameters, the two-part tariff contract can not only achieve perfect coordination of the whole CLSC but also improve the profit of each member enterprise.

VIII. CONCLUSION

In this paper, the pricing, collection and coordination strategies of a dual-channel CLSC with manufacturer diseconomies of scale are studied, and the level of competition in sales/collection and effect of the coefficient for diseconomies of scale on the profits of CLSC members and the whole system are analyzed. The following main conclusions are drawn.

(1) No matter the collection channel structure, manufacturer diseconomies of scale are detrimental to the dual-channel CLSC pricing strategy and the profit acquisition of member firms. (2) No matter the collection channel structure, an increase in competition between the positive sales channels benefits the pricing strategy of the dual-channel CLSC and the profit of each member enterprise and the system overall. (3) In dual-channel forward sales, the wholesale product price is always equal to the direct sales price and lower than the retail price. At the same time, product sales in the direct channel are always more than twice those in the retail channel, and as the level of competition increases, the sales gap between the two channels widens. (4) It is disadvantageous to the pricing strategy and profits of dual-channel CLSC members when the manufacturer and retailer compete in collection. (5) In dual-channel reverse collection, the manufacturer's collection rate is more than twice the retailer's, and the greater the competition between collection channels, the larger is the gap in collection rates between them. (6) When collection competition is relatively weak, the optimal collection structure for the manufacturer, the retailer and the system is the dual-channel structure. When collection competition is relatively strong, the manufacturer and the retailer do better by setting up their own collection channels, while the dual-channel CLSC achieves the largest total profits with manufacturer collection. (7) A two-part tariff contract could perfectly coordinate the dual-channel CLSC under the three different collection channels within a certain range of contract parameters.

Unlike previous articles, this paper explores the selection of collection channels, pricing and coordination strategies when the dominant manufacturer displays diseconomies of scale. This work is of both theoretical and practical significance and can serve as a reference for the selection of a collection strategy in a dual-channel CLSC with diseconomies of scale. However, there are still many issues that need to be further explored in research in this area: (1) The model proposed in this paper is based on a simple one-to-one supply chain structure. In reality, supply chains often feature complex one-to-many or many-to-one structures. Therefore, further research can consider the decision-making and coordination of a CLSC with multiple competing manufacturers or retailers. (2) This paper assumes that the information among members of the supply chain is symmetrical. However, in actual business activities, there are often information asymmetries among members. Therefore, it would be of practical significance to study the decision-making and coordination of an CLSC with manufacturer diseconomies of scale under information asymmetries. (3) The research in this paper is carried out with market demand taken as given. However, with the growth in consumer purchasing power and development of new consumption preferences, it is increasingly difficult for companies to predict consumer market demand. Therefore, to address the practical problems faced by enterprises, it would be helpful to study the decision-making and coordination of a CLSC with manufacturer diseconomies of scale under demand uncertainty. These problems represent the content and direction of our future research.

APPENDIX

PROOF OF PROPOSITION 3

Under the decentralized decision, because the solution process to obtain equilibrium results for the three different collection channel structures is similar, only the process of manufacturer collection is detailed here. First, since $\partial^2\pi_r^M(p_r)/\partial p_r^2 = -2 < 0$, that is, $\pi_r^M(p_r)$ is a strictly concave function around p_r^M, equation (8) has an optimal solution. By the first-order condition, the optimal response function of retailer is $p_r^M = (a + w + \beta p_d)/2$. By substituting p_r^M into equation (7), it is straightforward to verify that the $\pi_m^M(w,\ p_d,\ \tau_m)$ around the wholesale price w^M, direct price p_d^M and collection rate τ_m^M is a joint concave function. By the first-order condition, the manufacturer's optimal wholesale price w^{M*}, optimal direct price p_d^{M*} and collection rate τ_m^{M*} of waste products can be obtained. Furthermore, by substituting w^{M*} and p_d^{M*} into p_r^M, we obtain the optimal retail price p_r^{M*}. Then, by substituting p_d^{M*} and p_r^M into equations (1) and (2), the maximum direct sales volume q_d^{M*} and the maximum retail volume q_r^{M*} of the new products can be obtained. Finally, the above equilibrium results are substituted into equation (7) and equation (8) to obtain the maximum profit of the manufacturer and retailer.

PROOF OF PROPOSITION 6

Solving the above model shows that the wholesale price after contract coordination is

$$w^{CM*} = \frac{abk + a(1-\beta)(4kb-\Delta^2) + kc_m(1-\beta)(2-\beta)}{(1-\beta)(2k + (1-\beta)(4kb-\Delta^2))}.$$

The manufacturer's maximum profit is

$$\pi_m^{CM*} = \frac{k\left((1+\beta)k+(1-\beta)\left(4\,kb-\Delta^2\right)\right)(a-(1-\beta)c_m)^2}{(1-\beta)\left(2\,k+(1\,|-\beta)\left(4\,kb-\Delta^2\right)\right)^2} + f^{CM*}.$$

The retailer's maximum profit is

$$\pi_r^{CM*} = \frac{k^2\,(a-(1-\beta)c_m)^2}{\left(2\,k+(1-\beta)\left(4\,kb-\Delta^2\right)\right)^2} - f^{CM*}.$$

After contract coordination, the total profits of the dual-channel CLSC satisfy $\pi_s^{CM*} = \pi_s^{S*}$.

When the profits satisfy the conditions $\pi_m^{CM*} \geq \pi_m^{M*}$ and $\pi_r^{CM*} \geq \pi_r^{M*}$, the dual-channel CLSC members accept the contract, and the upper and lower bounds of the contract parameters f^{CM*} are

$$f^{CM*} \geq f^{CM*} = \frac{k^2(a-(1-\beta)c_m)^2}{(8k+(1-\beta)(3+\beta)(4kb-\Delta^2))} \times \frac{(4k+(1-\beta^2)(4kb-\Delta^2))}{(2k+(1-\beta)(4kb-\Delta^2))^2},$$

$$f^{CM*} \leq \bar{f}^{CM*} = \frac{k^2((4k+(1-\beta^2)(4kb-\Delta^2))}{(8k+(1-\beta)(3+\beta)(4kb-\Delta^2))^2} \times \frac{(12k+(1-\beta)(5+\beta)(4kb-\Delta^2)))(a-(1-\beta)c_m)^2}{(2k+(1-\beta)(4kb-\Delta^2))^2}$$

PROOF OF PROPOSITION 7

Solving the above model shows that the wholesale price and transfer payment after contract coordination are

$$w^{CR*} = \frac{abk + a(1-\beta)\left(4\,kb-\Delta^2\right) + kc_m(1-\beta)(2-\beta)}{(1-\beta)\left(2\,k+(1-\beta)\left(4\,kb-\Delta^2\right)\right)},$$

$$F^{CR*} = \frac{2k\Delta(a-(1-\beta)c_m)}{2k+(1-\beta)(4kb-\Delta^2)}.$$

The manufacturer's maximum profit is

$$\pi_m^{CR*} = \frac{k\left((1+\beta)k+2(1-\beta)\left(2\,kb-\Delta^2\right)\right)(a-(1-\beta)c_m)^2}{(1-\beta)\left(2\,k+(1-\beta)\left(4\,kb-\Delta^2\right)\right)^2} + f^{CR*},$$

The retailer's maximum profit is

$$\pi_r^{CR*} = \frac{k(k+\Delta^2)(a-(1-\beta)c_m)^2}{(2k+(1-\beta)(4kb-\Delta^2))^2} - f^{CR*}.$$

After contract coordination, the total profits of the dual-channel CLSC satisfy $\pi_s^{CR*} = \pi_s^{S*}$.

When the profits satisfy the conditions $\pi_m^{CR*} \geq \pi_m^{R*}$ and $\pi_r^{CR*} \geq \pi_r^{R*}$, the dual-channel CLSC members accept the contract, and the upper and lower bounds of the contract parameters f^{CR*} are shown at the top of the next page, where $11-4\beta+\beta^2 = C_1$, $2-\beta-\beta^2 = C_2$, $47-6\beta+7\beta^2 = C_3$, $5-4\beta-6\beta^2+4\beta^3+\beta^4 = C_4$, $9-12\beta-2\beta^2+4\beta^3+\beta^4 = C_5$, $67-72\beta+6\beta^2-\beta^4 = C_6$, $38-33\beta-\beta^2-3\beta^3-\beta^4 = C_7$.

PROOF OF PROPOSITION 8

Solving the above model shows that the wholesale price and transfer payment after contract coordination w^{CMR*}, F^{CMR*}, are shown at the top of the next page.

The manufacturer's maximum profit is π_m^{CMR*}, as shown at the top of the next page.

$$
\begin{aligned}
f^{CR*} \geq \underline{f}^{CR*} &= \frac{k^2(a-(1-\beta)c_m)^2}{(16k+(1-\beta)(3+\beta)(8kb-\Delta^2))} \\
&\times \times \frac{(8k+8kb(1-\beta^2)+4b(1-\beta)(3+\beta)\Delta^2+C_1\Delta^2)}{(2k+(1-\beta)(4kb-\Delta^2))^2}, \\
f^{CR*} \leq \bar{f}^{CR*} &= \begin{bmatrix} 64k^2(3-4C_2b+C_4b^2)-(C_6+8C_5b)\Delta^4 \\ +4k(C_3+4bC_7+12C_5b^2)\Delta^2 \end{bmatrix} \\
&\times \frac{k^2(a-(1-\beta)c_m)^2}{(2k+(1-\beta)(4kb-\Delta^2))^2(16k+(1-\beta)(3+\beta)(8kb-\Delta^2))^2},
\end{aligned}
$$

$$
\begin{aligned}
w^{CMR*} &= \frac{2a(1-\beta)(2kb-\Delta^2)+2a\alpha(1-\beta)\Delta^2+kc_m(1-\beta)(2-\beta)}{2(1-\beta)(k+(1-\beta)(2kb-(1-\alpha)\Delta^2))}, \\
F^{CMR*} &= \frac{k\Delta(a-(1-\beta)c_m)}{(1+\alpha)(k+(1-\beta)(2kb-(1-\alpha)\Delta^2))}.
\end{aligned}
$$

$$
\begin{aligned}
\pi_m^{CMR*} &= \left[k(1+\beta)(1+\alpha)+4kb(1-\beta)(1+\alpha)-(1-\beta)(1-\alpha)(3+\alpha)\Delta^2\right] \\
&\times \frac{k(a-(1-\beta)c_m)^2}{4(1-\beta)(1+\alpha)(k+(1-\beta)(2kb-(1-\alpha)\Delta^2))^2}+f^{CMR*}.
\end{aligned}
$$

The retailer's maximum profit is

$$
\pi_r^{CMR^*} = \frac{k\left(k(1+\alpha)+(1-\alpha)^2\Delta^2\right)(a-(1-\beta)c_m)^2}{4(1+\alpha)\left(k+(1-\beta)\left(2kb-(1-\alpha)\Delta^2\right)\right)^2} - f^{CMR^*}.
$$

After contract coordination, the total profits of the dual-channel CLSC satisfy $\pi_s^{CMR*} = \pi_s^{SS*}$.

When this profit satisfies the conditions $\pi_m^{CMR*} \geq \pi_m^{MR*}$ and $\pi_r^{CMR*} \geq \pi_r^{MR*}$, the dual-channel CLSC members accept the contract; the upper and lower bounds of the contract parameters f^{CMR*} are abridged here, because the formula is slightly too long.

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REFERENCES

[1] I. E. Nielsen, S. Majumder, S. S. Sana, and S. Saha, "Comparative analysis of government incentives and game structures on single and two-period green supply chain," *J. Cleaner Prod.*, vol. 235, pp. 1371–1398, Oct. 2019.

[2] K. Rana, S. R. Singh, N. Saxena, and S. S. Sana, "Growing items inventory model for carbon emission under the permissible delay in payment with partially backlogging," *Green Finance*, vol. 3, no. 2, pp. 153–174, 2021.

[3] S. S. Sana, "Price competition between green and non green products under corporate social responsible firm," *J. Retailing Consum. Services*, vol. 55, Jul. 2020, Art. no. 102118.

[4] P. Georgiadis and M. Besiou, "Environmental and economical sustainability of WEEE closed-loop supply chains with recycling: A system dynamics analysis," *Int. J. Adv. Manuf. Technol.*, vol. 47, nos. 5–8, pp. 475–493, Mar. 2010.

[5] J. Q. F. Neto, G. Walther, J. Bloemhof, J. A. E. E. van Nunen, and T. Spengler, "From closed-loop to sustainable supply chains: The WEEE case," *Int. J. Prod. Res.*, vol. 48, no. 15, pp. 4463–4481, Aug. 2010.

[6] V. D. R. Guide, Jr., and L. N. Wassenhove, "Managing product returns for remanufacturing," *Prod. Oper. Manage.*, vol. 10, no. 2, pp. 142–155, Jan. 2009.

[7] T. S. Genc and P. D. Giovanni, "Trade-in and save: A two-period closed-loop supply chain game with price and technology dependent returns," *Int. J. Prod. Econ.*, vol. 183, pp. 514–527, Jan. 2017.

[8] T. Maiti and B. C. Giri, "Two-way product recovery in a closed-loop supply chain with variable markup under price and quality dependent demand," *Int. J. Prod. Econ.*, vol. 183, pp. 259–272, Jan. 2017.

[9] W. Shang, A. Ha, and S. Tong, "Information sharing in a supply chain with a common retailer," *Mark. Sci.*, vol. 62, no. 1, pp. 245–263, 2016.

[10] J. M. Griffin, "The process analysis alternative to statistical cost functions: An application to petroleum refining," *Amer. Econ. Rev.*, vol. 62, pp. 46–56, Mar. 1972.

[11] A. V. Mollick, "Production smoothing in the Japanese vehicle industry," *Int. J. Prod. Econ.*, vol. 91, no. 1, pp. 63–74, Sep. 2004.

[12] A. Alvarez and C. Arias, "Diseconomies of size with fixed managerial ability," *Amer. J. Agricult. Econ.*, vol. 85, no. 1, pp. 134–142, Feb. 2003.

[13] H. D. Dixon, "Inefficient diversification in multi-market oligopoly with diseconomies of scope," *Economica*, vol. 61, pp. 213–219, May 1994.

[14] E. Rawley and T. S. Simcoe, "Diversification, diseconomies of scope, and vertical contracting: Evidence from the taxicab industry," *Manage. Sci.*, vol. 56, no. 9, pp. 1534–1550, Sep. 2010.

[15] P. Zhang, Y. He, and X. Zhao, "'Preorder-online, pickup-in-store' strategy for a dual-channel retailer," *Transp. Res. E, Logistics Transp. Rev.*, vol. 122, pp. 27–47, Feb. 2019.

[16] S. Saha, S. P. Sarmah, and I. Moon, "Dual channel closed-loop supply chain coordination with a reward-driven remanufacturing policy," *Int. J. Prod. Res.*, vol. 54, no. 5, pp. 1503–1517, Mar. 2016.

[17] A. A. Taleizadeh, E. Sane-Zerang, and T. M. Choi, "The effect of marketing effort on dual-channel closed-loop supply chain systems," *IEEE Trans. Syst., Man, Cybern. Syst.*, vol. 48, no. 2, pp. 265–276, Feb. 2018.

[18] R. He, Y. Xiong, and Z. Lin, "Carbon emissions in a dual channel closed loop supply chain: The impact of consumer free riding behavior," *J. Cleaner Prod.*, vol. 134, pp. 384–394, Oct. 2016.

[19] B. Zheng, C. Yang, J. Yang, and M. Zhang, "Dual-channel closed loop supply chains: Forward channel competition, power structures and coordination," *Int. J. Prod. Res.*, vol. 55, no. 12, pp. 3510–3527, Jun. 2017.

[20] P. Zhang, Y. He, and C. Shi, "Retailer's channel structure choice: Online channel, offline channel, or dual channels?" *Int. J. Prod. Econ.*, vol. 191, pp. 37–50, Sep. 2017.

[21] J. Xie, L. Liang, L. Liu, and P. Ieromonachou, "Coordination contracts of dual-channel with cooperation advertising in closed-loop supply chains," *Int. J. Prod. Econ.*, vol. 183, pp. 528–538, Jan. 2017.

[22] J. Xie, W. Zhang, L. Liang, Y. Xia, J. Yin, and G. Yang, "The revenue and cost sharing contract of pricing and servicing policies in a dual-channel closed-loop supply chain," *J. Cleaner Prod.*, vol. 191, pp. 361–383, Aug. 2018.

[23] Z. Zhang, S. Liu, and B. Niu, "Coordination mechanism of dual-channel closed-loop supply chains considering product quality and return," *J. Clean Prod.*, vol. 248, pp. 1–51, Mar. 2020.
[24] P. He, Y. He, and H. Xu, "Channel structure and pricing in a dual-channel closed-loop supply chain with government subsidy," *Int. J. Prod. Econ.*, vol. 213, pp. 108–123, Jul. 2019.
[25] Z. Liu, J. Chen, C. Diallo, and U. Venkatadri, "Pricing and production decisions in a dual-channel closed-loop supply chain with (re) manufacturing," *Int. J. Prod. Econ.*, vol. 232, pp. 1–62, Feb. 2021.
[26] R. C. Savaskan, S. Bhattacharya, and L. N. Van Wassenhove, "Closed-loop supply chain models with product remanufacturing," *Manage. Sci.*, vol. 50, no. 2, pp. 239–252, 2004.
[27] I.-H. Hong and J.-S. Yeh, "Modeling closed-loop supply chains in the electronics industry: A retailer collection application," *Transp. Res. E, Logistics Transp. Rev.*, vol. 48, no. 4, pp. 817–829, Jul. 2012.
[28] T.-M. Choi, Y. Li, and L. Xu, "Channel leadership, performance and coordination in closed loop supply chains," *Int. J. Prod. Econ.*, vol. 146, no. 1, pp. 371–380, Nov. 2013.
[29] J. Wei, K. Govindan, Y. Li, and J. Zhao, "Pricing and collecting decisions in a closed-loop supply chain with symmetric and asymmetric information," *Comput. Oper. Res.*, vol. 54, pp. 257–265, Feb. 2015.
[30] X. Hong, L. Xu, P. Du, and W. Wang, "Joint advertising, pricing and collection decisions in a closed-loop supply chain," *Int. J. Prod. Econ.*, vol. 167, pp. 12–22, Sep. 2015.
[31] L. Liu, Z. Wang, L. Xu, X. Hong, and K. Govindan, "Collection effort and reverse channel choices in a closed-loop supply chain," *J. Cleaner Prod.*, vol. 144, pp. 492–500, Feb. 2017.
[32] N. Modak, N. Modak, S. Panda, and S. S. Sana, "Analyzing structure of two-echelon closed-loop supply chain for pricing, quality and recycling management," *J. Cleaner Prod.*, vol. 171, pp. 512–528, Jan. 2018.
[33] B. C. Giri and S. K. Dey, "Game theoretic analysis of a closed-loop supply chain with backup supplier under dual channel recycling," *Comput. Ind. Eng.*, vol. 129, pp. 179–191, Mar. 2019.
[34] N. Wan and D. Hong, "The impacts of subsidy policies and transfer pricing policies on the closed-loop supply chain with dual collection channels," *J. Cleaner Prod.*, vol. 224, pp. 881–891, Jul. 2019.
[35] L. Xiao, X.-J. Wang, and K.-S. Chin, "Trade-in strategies in retail channel and dual-channel closed-loop supply chain with remanufacturing," *Transp. Res. E, Logistics Transp. Rev.*, vol. 136, pp. 1–19, Apr. 2020.
[36] W. W. Wu, Q. Zhang, and Z. Liang, "Environmentally responsible closed-loop supply chain models for joint environmental responsibility investment, recycling and pricing decisions," *J. Clean Prod.*, vol. 259, pp. 1–23, Jun. 2020.
[37] L. Yang, Y. Hu, and L. Huang, "Collecting mode selection in a remanufacturing supply chain under cap-and-trade regulation," *Eur. J. Oper. Res.*, vol. 287, no. 2, pp. 480–496, Dec. 2020.
[38] Y. Yuan, J. Yang, Y. Li, and W. Li, "Necessary conditions for coordination of dual-channel closed-loop supply chain," *Technol. Forecast Social Change*, vol. 151, pp. 1–11, Feb. 2020.
[39] L. Chen and M. Gao, "Optimizing strategies for e-waste supply chains under four operation scenarios," *Waste Manage.*, vol. 124, pp. 325–338, Apr. 2021.
[40] S. Sarkar and S. Bhala, "Coordinating a closed loop supply chain with fairness concern by a constant wholesale price contract," *Eur. J. Oper. Res.*, vol. 295, no. 1, pp. 140–156, Nov. 2021, doi: 10.1016/j.ejor.2021.02.052.
[41] A. Y. Ha, S. Tong, and H. Zhang, "Sharing demand information in competing supply chains with production diseconomies," *Manage. Sci.*, vol. 57, pp. 566–581, Mar. 2011.
[42] J. R. Wang and W. Y. Zhuo, "Strategic information sharing in a supply chain under potential supplier encroachment," *Comput. Ind. Eng.*, vol. 150, pp. 1–18, Dec. 2020.
[43] R. C. Savaskan and L. N. Van Wassenhove, "Reverse channel design: The case of competing retailers," *Manage. Sci.*, vol. 52, no. 1, pp. 1–14, Jan. 2006.
[44] M. Huang, M. Song, L. H. Lee, and W. K. Ching, "Analysis for strategy of closed-loop supply chain with dual recycling channel," *Int. J. Prod. Econ.*, vol. 144, no. 2, pp. 510–520, Aug. 2013.
[45] R. Subramanian, M. E. Ferguson, and L. B. Toktay, "Remanufacturing and the component commonality decision," *Prod. Oper. Manage.*, vol. 22, no. 1, pp. 36–53, Jan. 2013.
[46] Y. Xiong, Q. Zhao, and Y. Zhou, "Manufacturer-remanufacturing vs supplier-remanufacturing in a closed-loop supply chain," *Int. J. Prod. Econ.*, vol. 176, pp. 21–28, Jun. 2016.
[47] J.-M. Chen and C.-I. Chang, "The co-opetitive strategy of a closed-loop supply chain with remanufacturing," *Transp. Res. E, Logistics Transp. Rev.*, vol. 48, no. 2, pp. 387–400, Mar. 2012.
[48] J. Yue, J. Austin, Z. Huang, and B. Chen, "Pricing and advertisement in a manufacturer–retailer supply chain," *Eur. J. Oper. Res.*, vol. 231, pp. 492–502, Dec. 2013.

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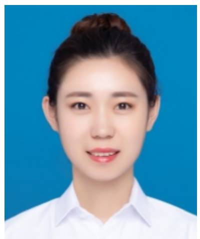

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