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Research article

Decision-making of third-party remanufacturing supply chain with risk aversion and retail service

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Abstract: This paper studies risk aversion and retail service in third-party remanufacturing. We consider a closed-loop supply chain (CLSC) comprising an original equipment manufacturer (OEM), a risk-averse retailer, and a third-party remanufacturer (TPR). The retailer sells new products and provides retail services. The TPR is responsible for the remanufacturing. Two Stackelberg game models are developed: authorized remanufacturing (Model A) and outsourcing remanufacturing (Model O). Based on the analysis results, we can conclude that in response to risk aversion, the OEM raises the outsourcing fee to incentivize remanufacturing and increase the TPR's expected profit. The retailer reduces service level due to risk aversion, but appropriate risk aversion could help the retailer optimize expected profit. Under certain parameter conditions, an increase in recycling difficulty may elevate the TPR's expected profit due to a higher outsourcing fee. The retailer provides a higher service level and achieves greater expected profit under Model A, while the OEM prefers Model O. The TPR prefers Model O only when both the market recognition of remanufactured products and the recycling difficulty coefficient are sufficiently high. Model O is more environmentally friendly when the unit remanufactured product environmental impact is sufficiently low. Supply-chain expected environmental impact negatively correlates with retailer risk aversion level, while recycling difficulty's environmental impact depends on the environmental performance of the unit remanufactured product. We recommend that the retailer, while optimizing service costs, should promptly understand the respective bargaining power of the OEM and TPR in negotiations over remanufacturing model selection to avoid the risk of high service efficiency leading the TPR to accept model O, which is disadvantageous to the retailer. The government should support TPR in enhancing recycling efficiency while encouraging the retailer to improve the effectiveness of retail services. This study provides a scientific reference for operational decision-making and remanufacturing cooperation model selection in third-party remanufacturing CLSCs with retail service and risk aversion issues. Furthermore, our findings contribute theoretical foundations for policymakers to formulate policies that balance economic development and environmental benefits.

Keywords: closed-loop supply chain; third-party remanufacturing; retail service; risk aversion
Mathematics Subject Classification: 90B06

1. Introduction

Current economic development and technological advancements have driven consumers to demand greater personalization and functionality in products. This has accelerated product iteration and the consumption of natural resources, while increasing the environmental burden as more used products are discarded. Remanufacturing has gained widespread recognition as an effective and sustainable operation method [1,2]. Remanufacturing involves disassembling, inspecting the recycled products, replacing or repairing components, and reassembling them to meet the same quality standards as new products [3]. Compared to manufacturing new products, the remanufacturing process typically reduces costs by half while saving 60% of energy and 70% of raw materials [4]. According to Global E-waste Flows Monitor 2024, global e-waste generation reached 62 million metric tons in 2022, with projections exceeding 82 million metric tons by 2030. Only a relatively small fraction of this waste receives regulated treatment and recycling, resulting in significant losses of valuable natural resources [5].

In practice, due to technical limitations, cannibalization effect on new product sales, high remanufacturing costs, and capital constraints, many original equipment manufacturers (OEMs) focus on manufacturing new products and entrusting their remanufacturing operations to third-party remanufacturers (TPRs) [6,7]. An OEM usually has two third-part remanufacturing strategy options: authorized and outsourcing remanufacturing. Under the authorized remanufacturing model, a TPR is responsible for remanufacturing end-of-life products and selling them through its own channel, with the OEM charging a licensing fee. In the outsourcing remanufacturing model, OEM pays an outsourcing fee to purchase remanufactured products from the TPR for resale to consumers. For instance, Land Rover outsourced its remanufacturing operations to Caterpillar, while Apple authorized Foxconn to produce and sell remanufactured products in China [8,9].

On the other hand, today's consumers increasingly prioritize service quality when purchasing products. Focusing on the shopping experience has become an integral part of people's purchasing habits. Delivering high-quality service is an effective way for retailers to enhance competitiveness and capture market share. Many retailers have implemented and innovated service strategies within their stores. For instance, Suning [10] has introduced digital shopping guides and AI store assistants in its retail outlets to achieve multidimensional breakthroughs in operational efficiency, service experience, and sales growth. With heightened environmental awareness, as an embodiment of the circular economy, closed-loop supply chain (CLSC) management has been recognized by numerous scholars and the business communities [11]. Sales of new product retailers in third-party remanufacturing closed-loop supply chains (CLSCs) face encroachment from remanufactured goods channels. Beyond relying solely on price reductions, there is merit in addressing remanufactured product competition through service decisions. While some studies have examined retail service decisions within the CLSC models [12−14], our study specifically considers retailer service within third-party remanufacturing.

With socioeconomic development and shifts in the business environment, consumer markets exhibit high uncertainty and frequent fluctuations. Against this backdrop, supply chain enterprises pursue profits while also focusing on risk aversion [15]. Risk awareness helps businesses navigate dynamically changing operational environments. Managers may sacrifice some expected returns to balance risks through risk aversion [16]. Competition between new products and remanufactured products within CLSCs further intensifies market uncertainty, creating more complex decision-making environments that encourage members to exhibit risk-averse tendencies. Several studies have examined the impact of risk aversion on supply chain system decisions within third-party remanufacturing environments [6,17,18]. However, no existing literature simultaneously considers a retailer's service and risk aversion in CLSC decision-making under different third-party remanufacturing models. Incorporating risk aversion issues alongside retail services into third-party remanufacturing supply chain decision-making aligns with the current context of intensifying retail competition and growing corporate risk awareness. This approach plays a significant role in enriching third-party remanufacturing management theory and sustainability research. To address this gap, this paper constructs a CLSC comprising one OEM, one TPR, and one retailer. The retailer sells new products and provides retail services. We analyze the Stackelberg game models under authorized remanufacturing (Model A) and outsourcing remanufacturing (Model O). The following research questions are addressed:

(1) What are the optimal decisions and expected profits of two remanufacturing models?
(2) What are the impacts of the retailer's risk aversion on the decision-making of CLSC with retail service?
(3) Which model is more favorable for CLSC members? Which model is more environmentally friendly?

Our paper has three main contributions. First, we consider the retailer's service decision and risk aversion in the authorized and outsourcing remanufacturing decision models for the first time. Second, we analyze the equilibrium decisions under the impacts of retail service and risk aversion in two models, which will provide a decision reference for members of the third-party remanufacturing CLSCs. Third, by analyzing the selection of remanufacturing models and the impacts of key parameters, this paper provides a scientific basis for environmental policy-making.

The remainder of this study is organized as follows: Section 2 provides a literature review. Section 3 provides problem description and assumptions. Model formulation and solutions are provided in Section 4. We perform equilibrium result analysis in Section 5. Section 6 is the numerical analysis. Section 7 presents management implications and conclusions.

2. Literature review

The related literature for this study comprises three streams: (1) Authorized and outsourcing remanufacturing in CLSC, (2) Service decision in supply chains, and (3) CLSC with risk aversion.

2.1. Authorized and outsourcing remanufacturing in CLSC

In recent years, authorized and outsourcing remanufacturing in CLSC models have attracted the attention of numerous scholars. Zhou et al. [19] examined the scenario where the OEM utilizes the authorized remanufacturer to counter the unauthorized remanufacturer. They found that Pareto improvement regions exist regardless of whether authorization fees are set by the authorized remanufacturer or the OEM. Wang et al. [20] studied the impact of emission reduction on outsourcing remanufacturing operations in two-period game models between an OEM and a TPR. The results show that emissions reduction promotes the sales of new products but reduces the amount of remanufacturing and TPR's profits. They proposed that supply chain coordination can be achieved by having the TPR bear part of the emission reduction costs while increasing outsourcing fees. Xia et al. [21] studied emission reduction strategies in the outsourcing remanufacturing decision-making model under carbon trading. They found that the unit outsourcing cost decreases with the increase in emission reduction investment. Liu et al. [22] studied financing strategies for capital-constrained authorized TPR in CLSC decision-making and analyzed the critical impacts of initial capital size and unit remanufacturing cost. They found that the TPR tends to obtain loans from OEM when the unit remanufacturing cost is low, and the capital gap is not substantial. Esenduran et al. [23] analyzed scenarios where an OEM adopts either a laissez-faire policy or an enforced authorization policy toward an independent remanufacturer. They noted that when the unit remanufacturing cost is low, enforced authorization can generate higher profits for supply chain members. Furthermore, enforced authorization can also enhance environmental performance and consumer surplus.

Some scholars simultaneously consider both remanufacturing operation modes in the CLSC. Zhang et al. [7] examined CLSC games dominated by a TPR with a capital-constrained OEM as the follower. They investigated trade credit and bank loans in the authorized and outsourcing remanufacturing models. Their findings revealed that under this financing combination, the OEM prefers the authorized remanufacturing model while the TPR does the opposite. Ma and Li [24] examined financing strategies in decision models for outsourcing and authorizing remanufacturing CLSC. Their findings show that under the outsourcing remanufacturing model, the TPR achieves higher profit, while the OEM prefers to borrow money from the TPR rather than the bank. Ding et al. [9] developed a three-tier CLSC consisting of one supplier, one manufacturer, and one TPR, and studied the supplier's differential and uniform pricing toward the OEM and TPR. They found that differential pricing may create a win-win situation for the supplier, TPR, and consumers, but simultaneously harms the OEM and reduces social welfare. Li et al. [25] considered recycling quality uncertainty and differences in willingness to pay for new products across various remanufacturing models. When the OEM has a low unit production cost for new products, outsourcing and authorized remanufacturing models prove most beneficial for the environment and consumers, respectively. Otherwise, the OEM remanufacturing model leads to superior environmental and economic benefits. Xia et al. [26] incorporated government differential carbon taxes on new and remanufactured products into a third-party remanufacturing CLSC. Their finding indicates that outsourcing remanufacturing is the optimal choice for the OEM when the carbon tax differential between two products does not exceed a certain threshold. Qiao and Xu [27] examined trade-in for cash, trade-in for new, and trade-in for remanufacturing in a supply chain game involving an OEM and a TPR. Their findings indicate that trade-in for new is most suitable under the outsourcing remanufacturing model. Used products with higher residual values are suitable for adopting both the trade-in for new and trade-in for remanufacturing.

The above literature offers us a solid research foundation, but none of them consider risk aversion and retail service in remanufacturing decision-making.

2.2. Service decision in the supply chain

Some studies have considered retail service in supply chain decision-making models. Xia et al. [28] analyzed the impact of service competition between two supply chains on distribution channel selection. They found that if manufacturers provide services, both supply chains choose the resale model as an equilibrium decision when price elasticity, service costs, and the degree of competition are low. Delaying service decisions can narrow the scope of this symmetric equilibrium. Zhang et al. [29] examined after-sales service and retailer demand information sharing strategies within a supply chain model. They found that when the manufacturer undertakes after-sales service, the retailer is willing to share information if the manufacturer's after-sales service is cost-efficient. Guan et al. [30]developed two supply chains that compete on service and price, where the manufacturer provides after-sales service, and the retailer holds market forecasting information. They found that the retailer is more willing to share information when the manufacturer's service is cost-efficient, and consumer acceptance of the service is high. Qu et al. [13] studied the manufacturer's cost misreporting and fairness concerns of the retailer. They found that the misleading report by the manufacturer can lead to a lower retail price and improve service level. The retailer can maintain fairness concerns to counteract misreporting behavior and secure greater profit. Zhang et al. [31] simultaneously considered service decisions for both new and remanufactured products in a supply chain. They designed four service scenarios: the manufacturer provides services for both products, the retailer provides services, and the services of both products are provided separately by the manufacturer and retailer. They found that asymmetric service provision models can achieve the highest and lowest service levels.

There is also a growing interest in the services offered in CLSCs. Zhao et al. [4] considered retailer service effort and authorized remanufacturing in the third-party recycling supply chain. They noted that when consumer willingness to purchase remanufactured products is sufficiently high, the fixed-fee retailer remanufacturing model enables the manufacturer, retailer, and third party to achieve higher profits simultaneously, compared to the unit authorization fee model. Hong et al. [32] studied the CLSC game model, where value-added service is provided by a manufacturer and a retailer. They found that the manufacturer-service model yields higher supply chain profit and adopted a two-part tariff contract that elevates overall profits to the level achieved under centralized decision-making. Shan et al. [33] studied the optimal decisions of a CLSC comprising one manufacturer, one retailer, and one recycler under the government subsidy. They considered cost-sharing of recycling costs of the third-party recycler and service investment costs of the retailer, and identified the impact of parameters such as the government subsidy and consumer service sensitivity on the conditions for coordinating cost-sharing strategies. Shi et al. [34] examined different CLSC alliance models containing a retailer providing service, a manufacturer conducting green investment, and a recycler: manufacturer-retailer alliance and manufacturer-recycler alliance. They found that the manufacturer-retailer alliance yields higher economic and environmental benefits than the manufacturer-recycler alliance. Gong et al [35] incorporated the effects of product value-added service and corporate social responsibility into the CLSC decision-making. They noted that the impacts of consumer acceptance level for value-added service on optimal decisions and profits depend on the firm's level of commitment to social responsibility and the scenarios where different members bear these two inputs. Gong et al. [14] studied the impact of customer free-riding behavior on pricing and retail service decisions in a dual-channel CLSC. They found that consumers' free riding has a positive effect on the online price and a negative effect on the offline price. In the centralized decision-making model, the retailer's service level may increase due to the high free-riding rate. Zhang [36] developed a dual-channel closed-loop supply chain consisting of a retailer and a manufacturer and examined decisions regarding after-sales and recycling services. They indicated that enhancing the service level can motivate consumers to participate in recycling, thereby promoting circular economy benefits and social value. However, these studies do not consider risk aversion and different third-party remanufacturing patterns.

2.3. CLSC with risk aversion

Risk aversions have important impacts on practical supply chain operations. Scholars have studied risk aversion in CLSC management models. Deng [37] examined consumers' risk aversion toward remanufactured products and investigated models where different supply chain enterprises take responsibility for remanufacturing. They analyzed the specific impacts of consumers' aversion levels and the relative profits of remanufacturing on equilibrium decisions and supply chain members' model selection. Niu et al. [38] examined the effect of blockchain technology adoption on improving consumer distrust toward remanufactured products within a supply chain comprising a manufacturer and a supplier. They found that blockchain adoption consistently benefits the manufacturer, but the supply chain will not adopt blockchain technology when consumer risk aversion exceeds a certain threshold. Xu et al. [39]simultaneously considered the risk aversion of the retailer and manufacturer as well as carbon tax policies in CLSC decision-making. They noted that the government can lower the carbon tax to incentivize the manufacturer to invest more in energy-saving efforts and encourage the retailer to recycle more products. Song and Li [40] examined the CLSC decision-making where the manufacturer, retailer, and third-party recycler exhibit risk aversion, and investigated government recycling price subsidies provided to different recipients. They analyzed how the risk aversion levels of supply chain enterprises affect subsidy effectiveness and found that high remanufacturing costs make the recycler subsidy model more environmentally and economically beneficial. Xu et al. [2] constructed an omnichannel CLSC game that consists of a manufacturer and a risk-averse physical retail store. They found that the risk aversion exhibited by manufacturer-owned retail store enhances overall supply chain benefits. Gong et al. [41] examined recycler risk aversion toward uncertainty in waste product quality and the manufacturer's disregard for risk attitude. Through the decision-making model analysis, they found that if the manufacturer ignores recycler risk aversion, it will lead to lower product prices, thereby increasing demand and recycling rates and favoring the recycler's utility. Zhou et al. [42] examined remanufacturing under fluctuating recycling quality and introduced cap-and-trade mechanism into a CLSC Stackelberg game model containing a retailer and a risk-averse manufacturer. They found that the increase in risk aversion level of the manufacturer negatively impacts recycling volumes and drives up product prices.

With the development of the remanufacturing industry, scholars have begun to study risk aversion in CLSCs where manufacturers do not directly engage in remanufacturing. Xia and Nan [43] considered the risk aversion of a distributor authorized to produce remanufactured products and the manufacturer's capital constraints to examine the manufacturer's debt financing and equity financing decisions. They noted that when the manufacturer's dividend ratio falls below a certain threshold, equity financing is preferred, and the debt financing tends to yield higher environmental benefits. Xia et al. [17] investigated different financing decision models for a remanufacturer with risk aversion and a capital-constrained OEM. They found that the capital-constrained OEM derives greater benefits from the debt financing strategy due to a high dividend payout ratio, while the debt financing model yields superior environmental benefits. Ding et al. [18] proposed a two-part tariff contract that improves recycling rates and social welfare within a supply chain decision model comprising an outsourced remanufacturer and a risk-averse OEM. Furthermore, results from their extended model indicate that the degree of risk aversion does not influence firms' choice between authorized or outsourcing remanufacturing.

Based on this literature review, it can be concluded that, to the best of our knowledge, there is no existing study that considers retail service decision and risk aversion in the third-party remanufacturing model. To fill this research gap, we develop a CLSC with an OEM, a TPR, and a retailer with risk aversion. Two Stackelberg game models are developed to analyze the optimal decisions of CLSC decision-making with retailer's risk aversion and service in authorized and outsourcing remanufacturing models. This study offers a new reference for third-party remanufacturing CLSC practical operation with retail service and risk aversion.

3. Problem description and formulation

We develop a supply chain consisting of an OEM, a TPR, and a retailer. The retailer sells new products manufactured by the OEM and provides retail services. Remanufacturing activity is conducted by TPR. We analyze two remanufacturing Stackelberg game models: authorized remanufacturing (Model A) and outsourcing remanufacturing (Model O). The OEM is the leader, while the retailer and TPR are followers. The decision-making sequences are as follows: the OEM first decides the wholesale price of new product w and the authorization fee f charged to the TPR in Model A or the outsourcing fee p_o paid to TPR in Model O. Subsequently, in both models, based on the OEM's decision, the TPR sets the quantity of remanufactured products q_r, and the retailer decides the quantity of the new products q_n and the service level e.

In Table 1, we provide the notations used throughout this study.

Table 1. Notations.

Symbols	Description
q_n	Quantity of new products
q_r	Quantity of remanufactured products
w	Wholesale price of new product
f	Unit authorization fee
p_o	Unit outsourcing fee
e	Retail service level
p_n	Price of new product
p_r	Price of remanufactured product
ϕ	Market capacity
c_n	Unit cost of new product
c_r	Unit cost of remanufactured product
β	Scaling parameter of retail service costs
θ	Service level elastic coefficient
k	Scaling parameter of collection cost
v	Consumer WTP for the new product
δ	Consumer acceptance for the remanufactured product
η	The retailer's risk aversion coefficient
π_t	The profit of TPR
π_r	The profit of retailer
π_m	The profit of OEM
U_r	The utility of retailer
$E(I)$	Expected environmental impact
*	Superscript indicating the optimal decision

The key assumptions are provided as follows:

Assumption 1. We denote the market capacity as ϕ. The consumer willingness-to-pay (WTP) for a unit of new product is denoted as v, and v obeys a uniform distribution on the interval $[0, \phi]$. Consumer WTP of a remanufactured product is $v\delta$, where $\delta \in (0, 1)$ represents the consumer recognition for the remanufactured product. Consumers who purchase new and remanufactured products can receive utility $u_n = v - p_n + \theta e$ and $u_r = v\delta - p_r$, respectively, where θ is the service level elastic coefficient. When $u_n > u_r$ and $u_n > 0$, consumers buy new products; when $u_r > u_n$ and $u_r > 0$, consumers buy remanufactured products. Each consumer will not purchase more than one product. According to Cao and Shao [44], we express inverse demand functions of new and remanufactured products as:

$$p_n = \phi - q_n - \delta q_r + \theta e \tag{1}$$

$$p_r = \delta(\phi - q_n - q_r) \tag{2}$$

Assumption 2. To characterize demand uncertainty, we write the new product's expected demand function as $p_n = \phi - q_n - \delta q_r + \theta e + \varepsilon$, and ε is a random variable with variance σ^2 and mean 0 [45].

Assumption 3. To ensure that remanufacturing is cost-effective, the unit remanufacturing cost is lower than the unit production cost of a new product, i.e., $c_r < c_n$ [46].

Assumption 4. The service level of the new product retailer is e. The cost of this service investment is denoted by $-\frac{\beta x^2}{2}$, where β is the cost scaling parameter [4,14].

Assumption 5. The collection cost of TPR is $\frac{k(q_r)^2}{2}$, where k denotes the scaling parameter 8. The TPR can remanufacture all recycled products, and $q_r \leq q_n$.

Assumption 6. According to Niu and Zou [45], the risk aversion utility function of the retailer is $U_r = E(\pi_r) - \eta\sqrt{Var(\pi_r)}$, where $\eta > 0$ is the coefficient representing the degree of risk aversion. The expected profit of the retailer and the profit variance are $E(\pi_r)$ and $Var(\pi_r)$, respectively.

Assumption 7. Three supply chain enterprises' decisions are all made in a single period. Assuming products has previously existed in the market, the TPR can recycle sold products in previous periods [8].

Assumption 8. According to Xia et al. [47] and Ding et al. [18], we express CLSC's environmental impact as the sum of carbon emissions from new and remanufactured products, as well as pollution from unrecycled end-of-life products. Hence, we have the function of expected environmental impact $E(I) = q_n + \lambda q_r + d(q_n - q_r)$, where $\lambda < 1$ reflects that remanufacturing is less environmentally harmful than manufacturing new products. For simplicity, the emission for a unit new product is assumed to be 1. d represents the pollution from a unrecycled used product.

In our models, the decision-making goal of the retailer is utility maximization, while the objectives of the OEM and TPR are to maximize expected profits.

4. Model development

In this section, we develop authorized remanufacturing and outsourcing remanufacturing Stackelberg game models with risk aversion and obtain the equilibrium decisions.

4.1. Model A

In this model, the OEM sells new products through the retailer, and TPR is authorized to manufacture and sell remanufactured products. The expected profits of CLSC members and the utility of retailer are represented as follows:

$$E\left(\pi_m^A\right)=\left(w-c_n\right)q_n+fq_r \tag{3}$$

$$E\left(\pi_r^A\right)=\left(p_n-w\right)q_n-\frac{\beta e^2}{2}=\left(\phi-q_n-\delta q_r+\theta e-w\right)q_n-\frac{\beta e^2}{2} \tag{4}$$

$$E\left(\pi_t^A\right)=\left(p_r-f-c_r\right)q_r-\frac{k}{2}{q_r}^2=\left(\delta\phi-c_r-\delta q_n-f\right)q_r-\left(\delta+\frac{k}{2}\right){q_r}^2 \tag{5}$$

$$U_r^A=\left(\phi-\eta\sigma-q_n-\delta q_r+\theta e-w\right)q_n-\frac{\beta e^2}{2} \tag{6}$$

Using backward induction, the optimal response of the retailer and TPR is obtained first.

Proposition 1. *U_r^A is jointly concave with respect to q_n* and e under the condition $2\beta-\theta^2>0$ *, and $E\left(\pi_t^A\right)$ is concave with respect to q_r under the condition $-\left(2\delta+k\right)<0$. The best response functions of the retailer and TPR can be obtained as follows:*

$$q_n^A=\frac{\left(2\delta+k\right)\beta\left(\phi-\eta\sigma-w\right)-\beta\delta\left(\delta\phi-c_r-f\right)}{\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2} \tag{7}$$

$$e^A=\frac{\theta\left(2\delta+k\right)\left(\phi-\eta\sigma-w\right)-\theta\delta\left(\delta\phi-c_r-f\right)}{\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2} \tag{8}$$

$$q_r^A=\frac{\left(2\beta-\theta^2\right)\left(\delta\phi-c_r-f\right)-\beta\delta\left(\phi-\eta\sigma-w\right)}{\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2} \tag{9}$$

All proofs of this paper are provided in the Appendix.

Based on followers' best responses, the OEM sets the optimal wholesale price and authorization fee. Substituting Eqs. (7), (8), and (9) into Eq. (3), the expected profit function of OEM can be written as:

$$E\left(\pi_m^A\right)=\frac{\left(w-c_n\right)\left(\left(2\delta+k\right)\beta\left(\phi-\eta\sigma-w\right)-\beta\delta\left(\delta\phi-c_r-f\right)\right)}{\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2}$$
$$+\frac{f\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)\left(\delta\phi-c_r-f\right)-\left(2\delta+k\right)\beta\delta\left(\phi-\eta\sigma-w\right)\right)}{\left(2\delta+k\right)\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)} \tag{10}$$

Proposition 2. *$E\left(\pi_m^A\right)$ is jointly concave with respect to w and f under the condition $\left(2\delta+k\right)\left(2\beta-\theta^2\right)-\beta\delta^2>0$. The optimal wholesale price and authorization fee can be obtained as follows:*

$$w^{A*}=\frac{\phi-\eta\sigma+c_n}{2} \tag{11}$$

$$f^{A*}=\frac{\delta\phi-c_r}{2} \tag{12}$$

Then, through substitution, we can obtain all optimal solutions in Model A as shown in Table 2.

4.2. Model O

In Model O, the OEM outsources remanufacturing operation to the TPR with a payment p_o. The expected profit functions of the OEM and the TPR are:

$$E\left(\pi_m^O\right)=\left(w-c_n\right)q_n+\left(\delta\left(\phi-q_n-q_r\right)-p_o\right)q_r \tag{13}$$

$$E\left(\pi_t^O\right)=\left(p_o-c_r\right)q_r-\frac{kq_r^{\ 2}}{2} \tag{14}$$

The retailer's optimal response function is the same as the first model. The TPR's optimal response is considered first.

Proposition 3. *$E\left(\pi_t^O\right)$ is concave with respect to q_r. The optimal response functions of TPR and retailer under model O can be obtained as follows:*

$$q_r^O=\frac{p_o-c_r}{k} \tag{15}$$

$$e^O=\frac{\theta k\left(\phi-\eta\sigma-w\right)-\theta\delta\left(p_o-c_r\right)}{k\left(2\beta-\theta^2\right)} \tag{16}$$

$$q_n^O = \frac{k\beta(\phi - \eta\sigma - w) - \beta\delta(p_o - c_r)}{k(2\beta - \theta^2)} \tag{17}$$

The expected profit function of OEM by substituting optimal responses of the retailer and TPR into Eq. (13) is as follows:

$$E(\pi_m^O) = \frac{(w - c_n)\beta(k(\phi - \eta\sigma - w) - \delta(p_o - c_r))}{k(2\beta - \theta^2)} + \left(\delta\left(\phi - \frac{k\beta(\phi - \eta\sigma - w) - \beta\delta(p_o - c_r)}{k(2\beta - \theta^2)} - \frac{p_o - c_r}{k}\right) - p_o\right)\frac{p_o - c_r}{k} \tag{18}$$

Proposition 4. $E(\pi_m^O)$ *is jointly concave with respect to* w *and* f *under the condition* $(\delta + k)(2\beta - \theta^2) - \beta\delta^2 > 0$. *The OEM's optimal decisions in model O are:*

$$w^{O*} = \frac{\phi - \eta\sigma + c_n}{2} \tag{19}$$

$$p_o^{O*} = \frac{k\delta((2\beta - \theta^2)\phi - \beta(\phi - \eta\sigma - c_n)) + ((2\delta + k)(2\beta - \theta^2) - 2\delta^2\beta)c_r}{2((\delta + k)(2\beta - \theta^2) - \delta^2\beta)} \tag{20}$$

By simple substitution calculation, optimal solutions in Model O can be obtained as shown in Table 2.

Table 2. Optimal solutions of Model A and Model O.

	Model A	Model O
q_n^{j*}	$\frac{\beta\Delta_1}{2\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)}$	$\frac{\beta\Delta_6}{2\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)}$
q_r^{j*}	$\frac{\Delta_2}{2\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)}$	$\frac{\Delta_2}{2\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)}$
w^{j*}	$\frac{\phi-\eta\sigma+c_n}{2}$	$\frac{\phi-\eta\sigma+c_n}{2}$
f^{j*}	$\frac{\delta\phi-c_r}{2}$	
p_o^{j*}		$\frac{\Delta_5}{2\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)}$
e^{j*}	$\frac{\theta\Delta_1}{2\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)}$	$\frac{\theta\Delta_6}{2\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)}$
p_n^{j*}	$\phi-\frac{\Delta_3}{2\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)}$	$\phi-\frac{\Delta_7}{2\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)}$
p_r^{j*}	$\delta\phi-\frac{\delta\Delta_4}{2\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)}$	$\delta\phi-\frac{\delta\Delta_8}{2\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)}$
$E\left(\pi_m^{j*}\right)$	$\frac{\left(\phi-\eta\sigma-c_n\right)\beta\Delta_1+\left(\delta\phi-c_r\right)\Delta_2}{4\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)}$	$\frac{\beta\left(\phi-\eta\sigma-c_n\right)\Delta_6+\left(\delta\phi-c_r\right)\Delta_2}{4\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)}$
$E\left(\pi_r^{j*}\right)$	$\frac{\left(\phi+\eta\sigma-c_n\right)\beta\Delta_1}{4\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)}-\frac{\beta\theta^2{\Delta_1}^2+2\beta\Delta_1\Delta_3}{8\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)^2}$	$\frac{\beta\Delta_6\left(\phi+\eta\sigma-c_n\right)}{4\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)}-\frac{2\beta\Delta_6\Delta_7+\beta\theta^2{\Delta_6}^2}{8\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)^2}$
$E\left(\pi_t^{j*}\right)$	$\frac{\left(2\delta+k\right){\Delta_2}^2}{8\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)^2}$	$\frac{k{\Delta_2}^2}{8\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)^2}$
U_r^{j*}	$\frac{\beta\left(2\beta-\theta^2\right){\Delta_1}^2}{8\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)^2}$	$\frac{\beta\left(2\beta-\theta^2\right){\Delta_6}^2}{8\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)^2}$
$E\left(I^{j*}\right)$	$\frac{\left(1+\lambda_u\right)\beta\Delta_1+\left(\lambda_r-\lambda_u\right)\Delta_2}{2\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)}$	$\frac{\left(1+\lambda_u\right)\beta\Delta_6+\left(\lambda_r-\lambda_u\right)\Delta_2}{2\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)}$

$\Delta_1=\left(2\delta+k\right)\left(\phi-\eta\sigma-c_n\right)-\delta\left(\delta\phi-c_r\right)$, $\Delta_2=\left(2\beta-\theta^2\right)\left(\delta\phi-c_r\right)-\beta\delta\left(\phi-\eta\sigma-c_n\right)$,

$\Delta_3=\left(\left(\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)\left(\phi-\eta\sigma-c_n\right)+\beta\delta\left(\delta\phi-c_r\right)$,

$\Delta_4=\left(\delta+k\right)\beta\left(\phi-\eta\sigma-c_n\right)+\left(2\beta-\theta^2-\beta\delta\right)\left(\delta\phi-c_r\right)$,

$\Delta_5 = k\delta\left(\left(2\beta-\theta^2\right)\phi-\beta\left(\phi-\eta\sigma-c_n\right)\right)+\left(\left(2\delta+k\right)\left(2\beta-\theta^2\right)-2\delta^2\beta\right)c_r$,
$\Delta_6 = \left(\phi-\eta\sigma-c_n\right)\left(\delta+k\right)-\delta\left(\delta\phi-c_r\right)$,
$\Delta_7 = \left(\phi-\eta\sigma-c_n\right)\left(\left(\beta-\theta^2\right)\left(\delta+k\right)-\delta^2\beta\right)+\delta\left(\delta\phi-c_r\right)\beta$,
$\Delta_8 = \beta\left(\phi-\eta\sigma-c_n\right)k+\left(2\beta-\theta^2-\beta\delta\right)\left(\delta\phi-c_r\right)$.

The superscript $j \in \{A, O\}$ represents Models A and O, respectively.

5. Equilibrium result analysis

In this section, we analyze optimal decisions and compare the results of the two models.

Corollary 1.

(i) $\frac{\partial f^{A*}}{\partial \eta}=0$; $\frac{\partial w^{N*}}{\partial \eta}<0$; $\frac{\partial q_n^{N*}}{\partial \eta}<0$; $\frac{\partial e^{N*}}{\partial \eta}<0$; $\frac{\partial q_r^{N*}}{\partial \eta}>0$; $\frac{\partial p_n^{A*}}{\partial \eta}>0$ *when,* $\beta>\frac{\theta^2\left(2\delta+k\right)}{\left(2\delta+k-\delta^2\right)}$, *otherwise* $\frac{\partial p_n^{A*}}{\partial \eta}<0$; $\frac{\partial p_r^{N*}}{\partial \eta}>0$; $\frac{\partial p_o^{O*}}{\partial \eta}>0$; $\frac{\partial p_n^{O*}}{\partial \eta}>0$ *when* $\beta>\frac{\left(\delta+k\right)\theta^2}{\left(\delta+k-\delta^2\right)}$, *otherwise* $\frac{\partial p_n^{O*}}{\partial \eta}<0$;

(ii) $\frac{\partial E\left(\pi_m^{N*}\right)}{\partial \eta}<0$. $\frac{\partial E\left(\pi_r^{A}\right)}{\partial \eta}>0$ *when* $\eta<\frac{\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-2\beta\delta^2\right)\Delta_1}{2\sigma\left(2\delta+k\right)\left(\left(2\beta-\theta^2\right)\left(2\delta+k\right)-\beta\delta^2\right)}$, *otherwise,* $\frac{\partial E\left(\pi_r^{A}\right)}{\partial \eta}<0$. $\frac{\partial E\left(\pi_t^{N*}\right)}{\partial \eta}>0$. $\frac{\partial E\left(\pi_r^{O*}\right)}{\partial \eta}>0$ *when* $\eta<\frac{\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-2\delta^2\beta\right)\Delta_6}{2\sigma\left(\delta+k\right)\left(\left(\delta+k\right)\left(2\beta-\theta^2\right)-\delta^2\beta\right)}$, *otherwise,* $\frac{\partial E\left(\pi_r^{O*}\right)}{\partial \eta}<0$. $\frac{\partial U_r^{O*}}{\partial \eta}<0$. $\frac{\partial E\left(I\right)^{N*}}{\partial \eta}<0$. *Where N=A, O.*

Corollary 1(i) indicates that as η increases, wholesale prices, the quantity of new products, and retailer's service level decrease. The authorization fee is unaffected by risk aversion. In Model A, the TPR handles sales of remanufactured products, and the OEM does not change the authorization fee to regulate the remanufacturing market. The TPR adjusts the production volume to respond to changes in η. In Model O, the OEM controls the market price and sales volume of remanufactured products and further optimizes its expected remanufacturing channel profit by adjusting outsourcing fee based on η. Correspondingly, a high value of η incentivizes the TPR to produce more remanufactured products. Thus, we can see that η promotes the development of remanufacturing while dampening the retailer's enthusiasm for selling new products. When β exceeds a certain threshold, the price of new products increases as η increases; conversely, the price decreases. This can be interpreted as follows: when retail service efficiency is low, the decline in service level resulting from an increase in η is smaller, while the increase in remanufactured products is greater. Conversely, when retail service efficiency is high, the opposite occurs. Regardless of whether the model is authorized or outsourcing, the price of the remanufactured product is positively correlated with η. Therefore, the retailers' risk aversion leads consumers to experience better new product service but requires them to pay higher prices to obtain remanufactured products.

(ii) shows that η is negatively correlated with OEM's expected profit. That is, the negative impact on the new product channel profit from market contraction caused by growth of η can not be offset by η's incentive effect on the remanufacturing market. For the TPR's interests, the retailer's risk aversion is consistently favorable. Similarly, this is because reduced output of new products allows outsourcing and authorized remanufacturing operations to capture greater expected profits. Interestingly, for the retailer, when η does not exceed a certain value, the retailer can increase the expected profit by raising η; however, when η surpasses a specific threshold, η and the expected profit become negatively correlated. This is because an increase in η makes the OEM reduce the wholesale price and can lower the service effort costs by decreasing the service level, thereby facilitating higher profit of the retailer. However, when the increase in η exceeds a certain threshold, the negative impact of the increase in η on the expected profit of the retailer due to reduced new product quantities becomes more significant. This suggests that the retailer may use risk aversion behavior to generate greater economic returns for itself. Of course, risk aversion may benefit the retailer, but it is detrimental to utility. Furthermore, by suppressing new product production and incentivizing remanufacturing, the increase in η contributes to environmental improvement.

Corollary 2.

(i) $\frac{\partial f^{A*}}{\partial \beta}=0$; $\frac{\partial w^{A*}}{\partial \beta}=0$; $\frac{\partial q_n^{N*}}{\partial \beta}<0$; $\frac{\partial e^{N*}}{\partial \beta}<0$; $\frac{\partial q_r^{N*}}{\partial \beta}>0$; $\frac{\partial p_n^{N*}}{\partial \beta}<0$; $\frac{\partial p_r^{N*}}{\partial \beta}>0$. $\frac{\partial p_o^{O*}}{\partial \beta}>0$;

(ii) $\frac{\partial E\left(\pi_m^{N*}\right)}{\partial \beta}<0$; $\frac{\partial E\left(\pi_r^{N*}\right)}{\partial \beta}<0$; $\frac{\partial E\left(\pi_t^{O*}\right)}{\partial \beta}>0$; $\frac{\partial U_r^{N*}}{\partial \beta}<0$; $\frac{\partial E\left(I\right)^{N*}}{\partial \beta}<0$.

According to Corollary 2, it can be seen that β is unrelated to the authorization fee and wholesale price. q_n, e, and p_n are negatively correlated with β. q_r, p_r, and p_o are positively correlated with β. This indicates that the increase in β is detrimental to new product sales and channel expected profit, while promoting remanufacturing volume, recovery rates, and expected remanufacturing channel profit. The OEM will not adjust decisions in the authorized remanufacturing model according to the difficulty of the retail service. In contrast, under the outsourcing remanufacturing model, the outsourcing fee will increase with rising service difficulty to secure greater expected remanufacturing channel profit, and this indicates that the OEM will become more focused on remanufacturing in Model O.

Corollary 2 also indicates that an increase in β reduces the expected profits of the OEM and retailer, as well as the utility of retailer. Similarly, it is also due to the adverse impact of decreased new product sales. Conversely, the suppression of new product sales by the increase in β yields higher expected profit for the remanufacturing business, thereby benefiting the expected profit of TPR. Correspondingly, the increase in β yields higher recovery rate and reduced environmental impact from new products, thereby improving CLSC's overall expected environmental performance. Policymakers should pay close attention to changes in retail service difficulty to formulate policies that balance economic development and environmental impact.

Corollary 3.

(i) $\frac{\partial f^{A*}}{\partial k}=0$; $\frac{\partial w^{A*}}{\partial k}=0$; $\frac{\partial q_n^{N*}}{\partial k}>0$; $\frac{\partial e^{N*}}{\partial k}>0$; $\frac{\partial q_r^{N*}}{\partial k}<0$; $\frac{\partial p_n^{N*}}{\partial k}>0$; $\frac{\partial p_r^{N*}}{\partial k}>0$ *when* $\frac{2\beta-\theta^2}{\beta}>\delta$, *otherwise,* $\frac{\partial p_r^{N*}}{\partial k}<0$; $\frac{\partial p_o^{O*}}{\partial k}>0$ *when* $\frac{2\beta-\theta^2}{\beta}>\delta$, *otherwise,* $\frac{\partial p_o^{O*}}{\partial k}<0$.

(ii) $\frac{\partial E\left(\pi_m^{N*}\right)}{\partial k}<0$; $\frac{\partial E\left(\pi_r^{N*}\right)}{\partial k}>0$. $\frac{\partial E\left(\pi_t^{A*}\right)}{\partial k}<0$. $\frac{\partial U_r^{N*}}{\partial k}>0$. *When* $\delta-\frac{\delta^2\beta}{2\beta-\theta^2}>k$, $\frac{\partial\left(\pi_t^{O*}\right)}{\partial k}>0$, *otherwise,* $\frac{\partial\left(\pi_t^{O*}\right)}{\partial k}<0$. $\frac{\partial E(I)^{N*}}{\partial k}>0$, *when* $\frac{(1+\lambda_u)\beta\delta}{2\beta-\theta^2}+\lambda_u>\lambda_r$, *otherwise* $\frac{\partial E(I)^{N*}}{\partial k}<0$.

As shown by Corollary 3(i), changes in k do not affect the wholesale price and the authorization fee. The new product price is positively related to k, while the remanufactured product price is positively related to k only when recognition of remanufactured product is low, and similarly for p_o. This occurs because when δ is low, the negative impact of the increase in k on q_r is smaller than its positive impact on q_n, thereby raising remanufactured product price. Conversely, when δ exceeds a certain threshold, the remanufactured product price decreases as k increases. Similarly, this threshold also applies to p_o. This can be understood as follows: when the acceptance of remanufactured products is high, OEM sets lower p_o as k increases to encourage remanufacturing and expand the market of the remanufactured products. When the acceptance degree of remanufactured products is low, the OEM attaches more importance to sales volume of the new products and pursues higher unit profit on the remanufacturing channel.

According to Corollary 3(ii), the increases of quantity and price of new products resulting from an increase in k elevate both the retailer's expected profit and utility. For the OEM, the negative impact of a higher recycling difficulty on remanufacturing profit outweighs its contribution to expected new product channel revenue, thereby diminishing the OEM's total expected profit. Interestingly, k is inversely proportional to the TPR's expected profit in Model A, but the impact of k on the TPR's expected profit in Model O depends on multiple parameters. When the recycling difficulty is relatively small, that is, $\delta-\frac{\delta^2\beta}{2\beta-\theta^2}>k$, although increase in k reduces q_r, the higher value of k enables the OEM to raise the unit outsourcing price for remanufacturing when market recognition of remanufactured products is low and the retailer's service cost parameter is relatively high, which can benefit the TPR. Thus, for the TPR, more efficient recycling is not necessarily better. Selecting a relatively appropriate recycling efficiency based on the characteristics of the remanufacturing market and retail service difficulty of the new product can optimize profits through higher unit margin and lower production volumes.

Additionally, we find a threshold. When λ_r exceeds this threshold, an increase in k reduces expected environmental impact, while the opposite increases expected environmental impact. This indicates that raising recycling difficulty can decrease the quantity of remanufactured products with low environmental performance, thereby lowering the expected environmental impact of CLSC. When λ_r is relatively low or λ_u is relatively high, the increase in k leads to reduced enthusiasm for recycling, which can result in severe pollution caused by unrecycled products, thereby increasing the overall expected environmental impact. Furthermore, the reduction in quantity of new products and more remanufactured products resulting from the increase in retail service difficulty may lead to a decrease in remanufactured product pollution caused by higher k, thereby yielding positive impacts on the environment. Like η and β, k and environmental performance of the products are all key factors that the government should consider when formulating environmental policies. We recommend that the government encourage retailers to improve customer service satisfaction while supporting the TPR in enhancing recycling efficiency.

Corollary 4.

(i) $q_n^{A*} > q_n^{O*}$; $q_r^{A*} < q_r^{O*}$; $e^{A*} > e^{O*}$; $w^{A*} = w^{O*}$; $p_n^{A*} > p_n^{O*}$; *when* $\frac{2\beta-\theta^2}{\beta} > \delta$, $p_r^{A*} > p_r^{O*}$; *otherwise,* $p_r^{A*} < p_r^{O*}$.

(ii) $E\left(\pi_m^{A*}\right) < E\left(\pi_m^{O*}\right)$. $E\left(\pi_r^{A*}\right) > E\left(\pi_r^{O*}\right)$. $U_r^{A*} > U_r^{O*}$. *When* $\frac{2\beta-\theta^2}{2\beta} > \delta$, $E\left(\pi_t^{A*}\right) > E\left(\pi_t^{O*}\right)$. *When* $\frac{2\beta-\theta^2}{2\beta} < \delta$, *if* $k < \frac{2\delta^3\beta^2}{\left(2\delta\beta-2\beta+\theta^2\right)\left(2\beta-\theta^2\right)} - 2\delta$, *then* $E\left(\pi_t^{A*}\right) > E\left(\pi_t^{O*}\right)$; *otherwise* $E\left(\pi_t^{A*}\right) < E\left(\pi_t^{O*}\right)$.

$E(I)^{A*} > E(I)^{O*}$ *when* $\frac{\left(1+\lambda_u\right)\beta\delta}{2\beta-\theta^2} + \lambda_u > \lambda_r$; *otherwise,* $E(I)^{A*} < E(I)^{O*}$.

Corollary 4(i) shows that Model A yields a higher quantity of new products, greater retail service level, a higher new product price, and fewer remanufactured products. In other words, compared to the outsourcing remanufacturing model, Model A is more conducive to a new product business. In Model A, the OEM captures profit from the remanufacturing business through an authorization fee while exerting pressure on the TPR's production volume. In Model O, the OEM pays the outsourcing fee to maintain the remanufacturing channel, which leads the TPR to produce more units than in Model A. Correspondingly, the retailer captures the market share through ordering more and paying more marketing service efforts in Model A, while adopting low-price competition in Model O. When δ is small, remanufactured products under Model A have a higher price; otherwise, there is a higher remanufactured product price under Model O. This is mainly because when δ is large, the quantity of remanufactured products by which Model O exceeds Model A is smaller than when δ is low, but in Model A, the impact of the gap in q_n on pricing is more pronounced. In Model O, the OEM controls the pricing of remanufactured products and deals directly with consumers, enabling greater flexibility to adjust prices based on market acceptance of remanufactured products and maintain production volume by paying the outsourcing fee. Moreover, the wholesale prices are the same in both models. Consequently, as shown in Corollary 4(ii), Model A yields greater expected profit for the retailer. Although Model O has a lower risk for the retailer, Model A provides higher utility due to its notable advantages in expected retailer profit.

For the OEM, since Model O is more conducive to achieving substantial remanufacturing benefits, the optimal choice is outsourcing even if the new product channel yields slightly lower expected profit than Model A. For the TPR, the comparison of expected profits under the two models depends on multiple parameters. Only when both k and δ exceed certain thresholds, Model O is more profitable for the TPR. This can be interpreted as follows: when recognition of remanufactured products is high and recycling efficiency is strong, although the TPR generates less remanufacturing revenue in Model A than in Model O, it achieves significant savings in recycling costs. Under other conditions, the cost savings from Model A become less pronounced. It can also be found that a decline in retailer service efficiency can increase this recognition threshold. The poorer the retailer's service performance, the more TPR tends to favor Model A. This is because when the retailer's marketing capability is weak, the TPR prefers to directly engage in sales competition. We recommend that the OEM can design products to be less recyclable, such as by enhancing durability, and actively promote remanufactured products to boost the market recognition, thereby encouraging the TPR to favor Model O. Furthermore, when improving recycling efficiency, the TPR should negotiate a suitable remanufacturing model with the OEM based on market acceptance of remanufactured products, as well as the costs and market performance of the new product service of the retailer. When retailer service efficiency is high, the TPR should ensure sufficiently high recycling effectiveness before pursuing the authorized remanufacturing model. For the retailer, while optimizing service costs, it is crucial to recognize that an excessively low service scale cost coefficient may make the TPR more inclined to accept model O, which is unfavorable to the retailer. Therefore, fully and timely understanding the bargaining power of the OEM and the TPR in negotiation over model selection is vital for the retailer.

Additionally, in the comparison of environmental performance between the two models, there exists a threshold for λ_r that is identical to the threshold for the effect of k on environmental impact. An increase in λ_u will raise this threshold, which means that the greater the pollution from unrecycled waste products, the more likely Model A is to cause a greater environmental impact compared to Model O. As long as the environmental burden of the unit remanufacturing product is less than a certain value, Model O will not result in a worse overall expected environmental performance due to the higher environmental impact of remanufactured products. β has a negative impact on this threshold. This indicates that the positive effect of β on q_r is less in Model A, which may enable Model A to achieve better environmental performance than Model O due to less environmental impact from remanufactured products. We recommend that the policymaker not only develops the environmental infrastructure and promotes the consumption of remanufactured products but also considers the impact of retailer service on the environmental performance of different remanufacturing models. The government can utilize conditional subsidies for specific remanufacturing models. For instance, when the environmental burden per unit of remanufactured products is relatively high, and the retailer service cost coefficient is low, implementing policies that subsidize the TPR, which produces and sells remanufactured products, can encourage the CLSC to adopt the relatively environmentally friendly authorized remanufacturing model rather than outsourcing.

6. Numerical analysis

In this section, we use numerical experiments to validate our model results. First, we analyze the impact of k on equilibrium outcomes. The relevant base parameters are set as follows: $\phi = 40$, $c_n = 4$, $c_r = 2$, $\sigma = 4$, $\delta = 0.75$, $\eta = 0.8$, and $\beta = 1.2$; we can obtain the variations of the CLSC members' optimal solutions with k in Figures 1–10.

The effect of k on p_o under different parameter conditions ($\frac{2\beta-\theta^2}{\beta} < \delta$ and $\frac{2\beta-\theta^2}{\beta} > \delta$) is shown in Figure 1. We know that the OEM decides whether to increase or decrease the outsourcing fee based on different situations. When the market acceptance of remanufactured products is low, k is positively correlated with p_o; otherwise, k and p_o exhibit a negative correlation. That is, in the outsourcing remanufacturing model, the OEM determines the outsourcing fee based on the difficulty of recycling and consumer acceptance of remanufactured products. When remanufactured products face low market acceptance, the OEM is willing to offer a higher outsourcing fee for the TPR with low recycling efficiency to encourage remanufacturing. When remanufactured products gain higher market acceptance, the OEM will offer a higher outsourcing fee to the TPR with high recycling efficiency to further utilize the advantages of remanufacturing; however, the OEM will reduce the outsourcing fee offered to the TPR with low efficiency, thereby increasing its own unit remanufacturing profit. In other words, high consumer acceptance of remanufactured products can sometimes be detrimental to the TPR, which is in a disadvantageous position in the supply chain.

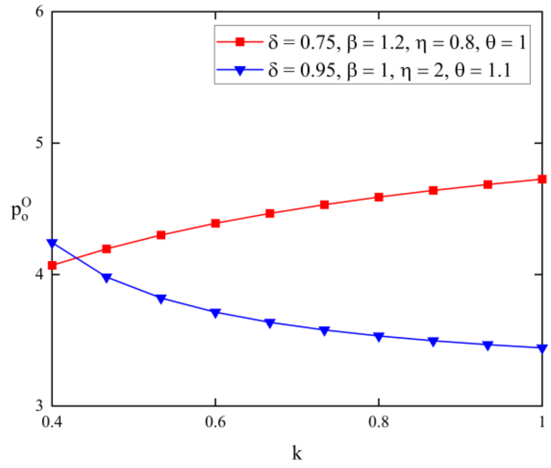


Figure 1. Effects of k on unit outsourcing fee.

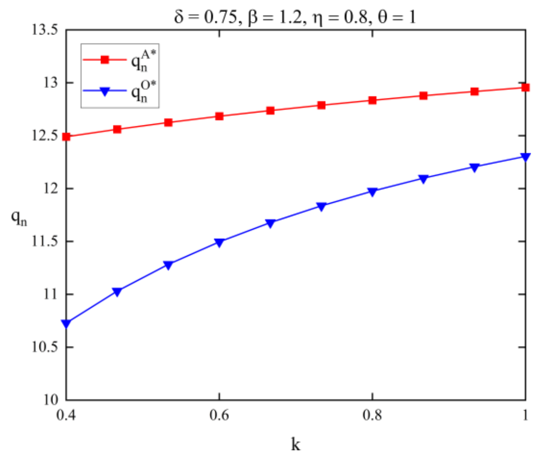


Figure 2. Effects of k on the quantity of new products.

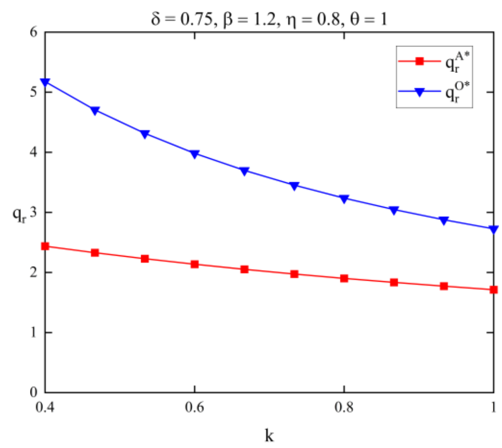


Figure 3. Effects of k on the quantity of remanufactured products.

Figures 2, 3, and 4 illustrate the impact of k on the optimal decision of followers when the parameters are set as $\phi = 40$, $c_n = 4$, $c_r = 2$, $\sigma = 4$, $\delta = 0.75$, $\eta = 0.8$, $\beta = 1.2$, $\theta = 1$. The quantity of new products increases with the increase of k, while the quantity of remanufactured products decreases. Compared to Model

O, Model A produces more new products and fewer remanufactured products. Undoubtedly, the increase in recycling difficulty consistently boosts the marketing effectiveness of new products. It can be observed that compared to Model O, Model A exhibits less variations in product quantities and retail service levels under the influence of k. Consequently, as k increases, the gap in product quantities and service levels between the two models narrows. The recovery rate under Model O consistently remains high, while the retailer has greater enthusiasm for retail service under Model A. Overall, higher recovery difficulty suppresses remanufacturing while boosting sales of new products and service enthusiasm. Under the authorized remanufacturing model, CLSC places more emphasis on new product business, while in Model O, the focus is on remanufactured products. Specifically, we can consider that when OEM and TPR reach an authorized remanufacturing cooperation, the retailer should improve the service level and provide more products to meet consumer needs, while TPR should reduce production to avoid excessive operating costs. In Model O, the leader OEM controls the sales of remanufactured products and demonstrates a stronger willingness to develop remanufacturing. This positions the retailer in a more passive role and puts the retailer under greater competitive pressure, resulting in lower service level and sales of new products.

Correspondingly, the variations in the products' prices determined by optimal decisions under different k values are illustrated in Figures 5 and 6. It can be observed that the price of the new product consistently increases with the increase in k. The increase in recycling difficulty reduces remanufacturing efficiency, giving the new product relatively stronger market competitiveness and higher price. Moreover, the price of new products in Model A is higher. Additionally, when consumer acceptance of remanufactured products is low, the price of remanufactured products is proportional to k, resulting in a higher price for remanufactured products under Model A. Conversely, when consumer acceptance is high, the opposite holds true. The above results are consistent with the statement in Corollary 3(i). It can also be seen that in the outsourcing remanufacturing model, where the OEM handles the sales of remanufactured products, the impact of k on pricing is more pronounced. This is mainly because the OEM flexibly adjusts the outsourcing fee based on the TPR's recycling efficiency, thereby impacting the remanufacturing market.

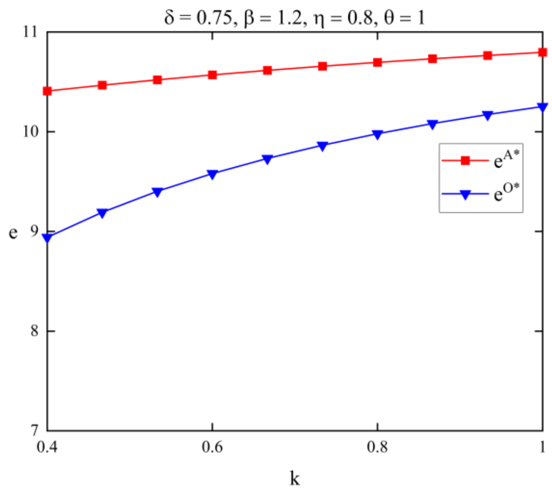


Figure 4. Effects of k on service level.

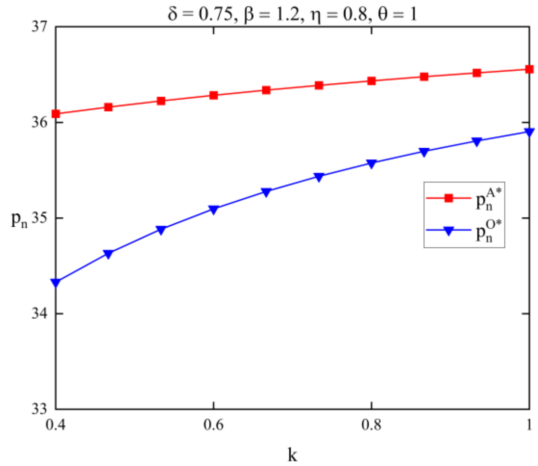
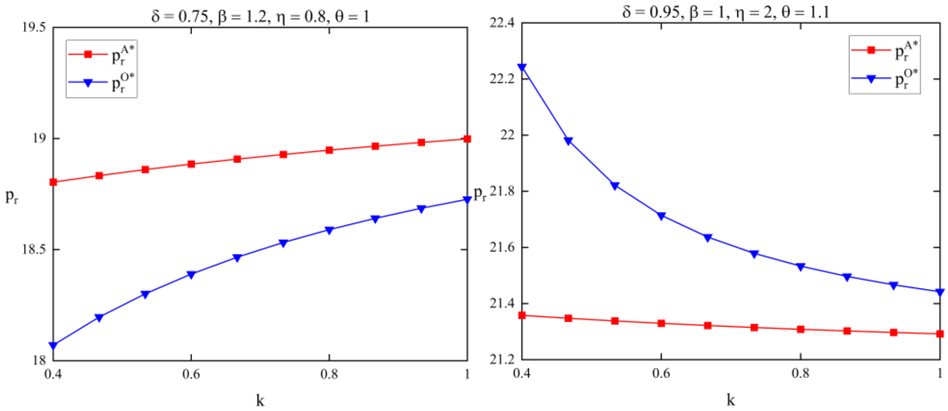


Figure 5. Effects of k on new product price.



(a) $\dfrac{2\beta-\theta^2}{\beta}>\delta$ (b) $\dfrac{2\beta-\theta^2}{\beta}<\delta$

Figure 6. Effects of k on remanufactured product price.

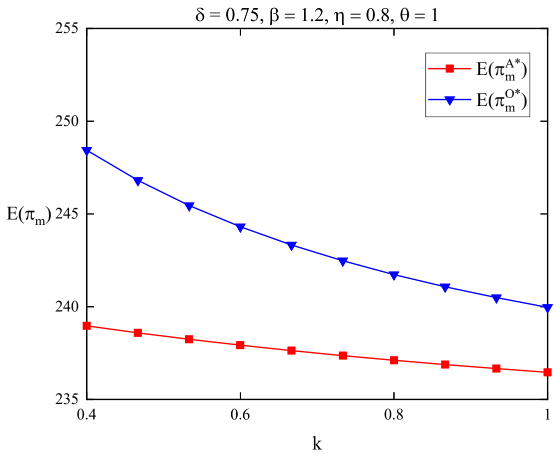


Figure 7. Effects of k on the OEM's expected profit.

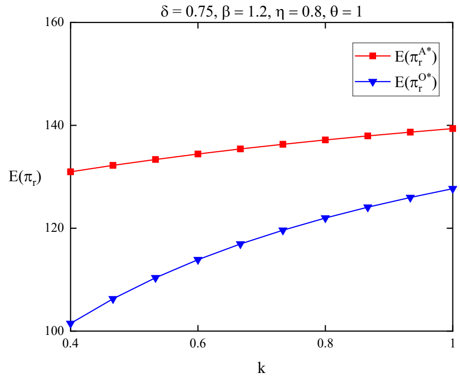


Figure 8. Effects of k on the retailer's expected profit.

Figure 7 illustrates the impact of k on the OEM's expected profit, which shows that an increase in k reduces the expected profit of the OEM. Furthermore, Model O proves more advantageous for the OEM than Model A. The negative effect of high recycling difficulty on the remanufacturing business outweighs the expected new product channel revenue, thus being detrimental to the OEM. Under the outsourcing remanufacturing model, the OEM controls the market sales of remanufactured products, which is more conducive to operating both channels from a profit-maximization perspective. The expected profit and utility of the retailer under the variation of k are illustrated in Figures 8 and 9, respectively. It is observed that Model A is more advantageous for the retailer to achieve higher expected profit and utility. The higher recycling difficulty coefficient enhances the competitiveness of new products, thereby effectively boosting both the retailer's expected profit and utility. Overall, the TPR should choose Model A, while OEM should pursue the opposite approach. In Figure 10, we analyze two sets of parameter values to validate the variations in TPR's expected profit under different levels of market acceptance for remanufactured products and varying k values across the two models. It can be observed that when market acceptance exceeds a certain threshold, Model A yields higher expected profit for the TPR when k is small. Conversely, when k is large, TPR tends to favor the outsourcing remanufacturing model. When the recognition level of remanufactured products is low, Model A yields a higher expected profit for the TPR. The expected profit of the TPR under Model A exhibits an inverse relationship with k. The impact of k on the expected profit of the TPR in Model O depends on multiple parameter values. As shown in Figure 10(b), the expected profit increases as k rises when k is below a certain threshold but decreases otherwise. These results validate Corollary 3(ii).

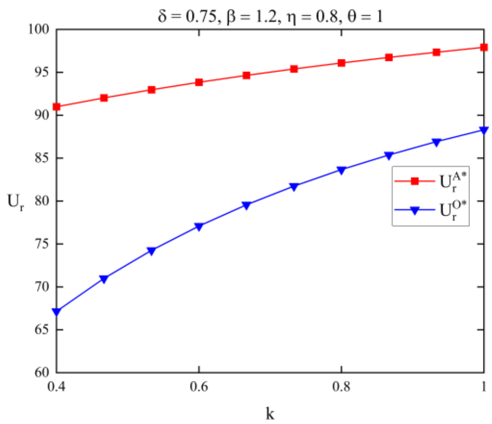
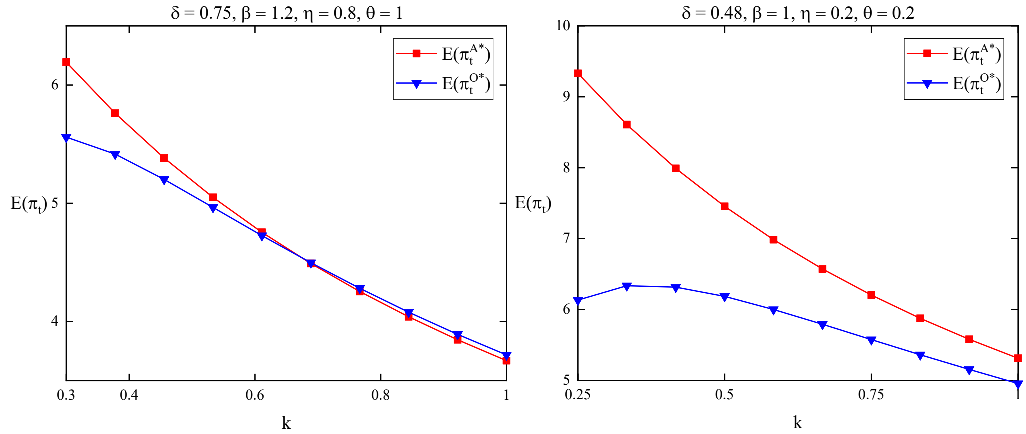


Figure 9. Effects of k on the retailer's utility.



(a) $\dfrac{2\beta-\theta^2}{2\beta}<\delta$ (b) $\dfrac{2\beta-\theta^2}{2\beta}>\delta$

Figure 10. Effects of k on the TPR's expected profit.

Next, we analyze the impact of β and η on the optimal solutions. Assuming $\phi = 40$, $c_n = 4$, $c_r = 2$, $\sigma = 4$, $\delta = 0.75$, $k = 1$, and $\theta = 1$, Figures 11 and 12 illustrate the influence of β and η on the OEM decision. It can be observed that the increases in β and η raise the p_o in Model O, while η reduces the wholesale price charged to the retailer. These results validate the incentive effect of retail service difficulty's increase and risk aversion on remanufacturing, as well as the concession made by the OEM to the retailer in terms of unit profit on new products driven by η. The OEM reduces the wholesale price to cope with the negative impact of the increase in risk aversion of the retailer on the quantity of new products, and raises the outsourcing fee in the Model O to encourage the TPR to recycle products, thereby establishing greater market competitiveness for remanufactured products.

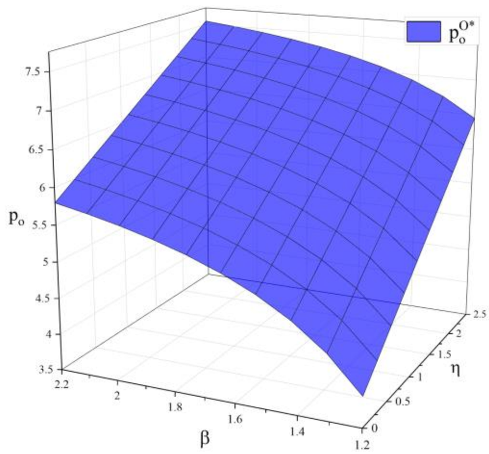


Figure 11. Effects of β and η on outsourcing fee.

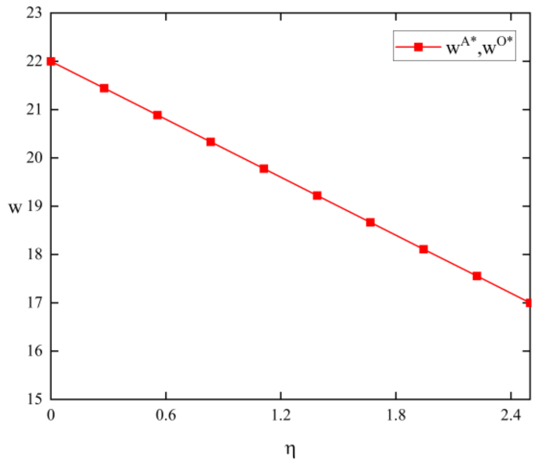


Figure 12. Effects of η on wholesale price of new product.

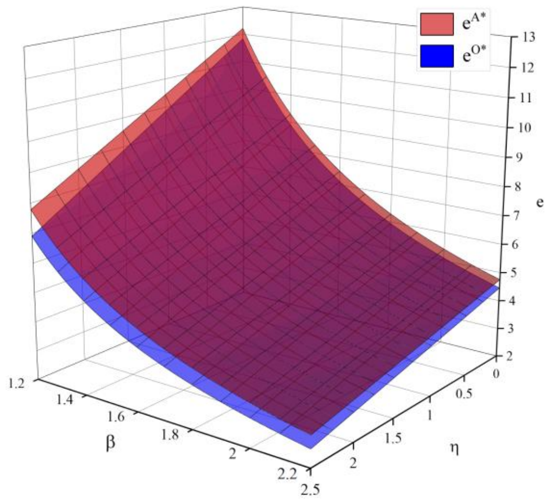


Figure 13. Effects of β and η on service level.

Figures 13–15 illustrate the impact of β and η on the decision-making of two CLSC followers. It can be observed that under both remanufacturing models, increases in β and η reduce e and q_n while increasing q_r. Retail service difficulty and risk aversion both hinder sales of new products while driving greater sales for remanufactured products. Market risk aversion and high service difficulty may lead the retailer to reduce enthusiasm for its retail service and decrease order volumes from the upstream OEM. In response to the retailer's risk aversion and low service efficiency, the TPR should adopt more proactive production planning to seize the opportunity for expanding the remanufactured products market.

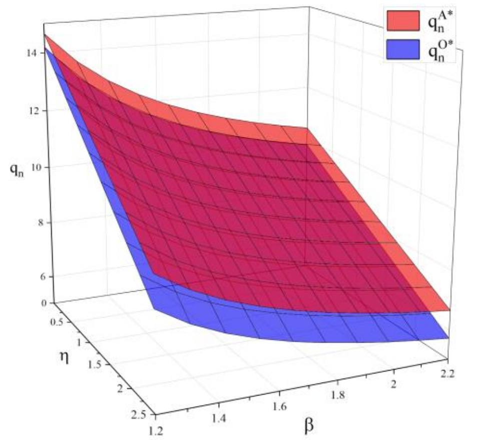


Figure 14. Effects of β and η on quantity of new products.

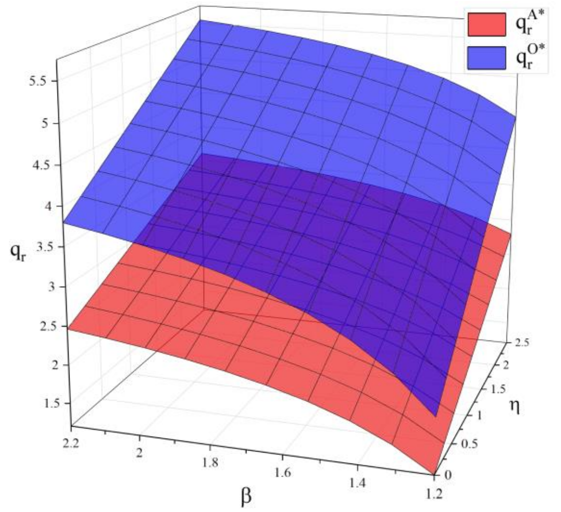


Figure 15. Effects of β and η on quantity of remanufactured products.

Figures 16 and 17 illustrate the impact of β and η on the optimal product pricing. It can be observed that an increase η reduces p_n when β is low, while the opposite occurs when β is high. This is because when retail service efficiency is low, η's increase leads to a smaller reduction in the service level and results in a greater increase in quantity of remanufactured products. Conversely, when retail service efficiency is high, the opposite holds true. β and p_n exhibit an inverse relationship. Additionally, growth in both β and η can increase p_r. The increase in difficulty of the retail service raises operational costs, necessitating higher prices for new products. This also gives the remanufacturer an opportunity to increase prices and boost profit. The increase in risk aversion reduces orders for new products and the service level, while also enabling remanufactured products to capture a larger market share at higher prices. Consequently, consumers experience improved new product retail services due to the risk aversion but must pay higher price to purchase remanufactured products.

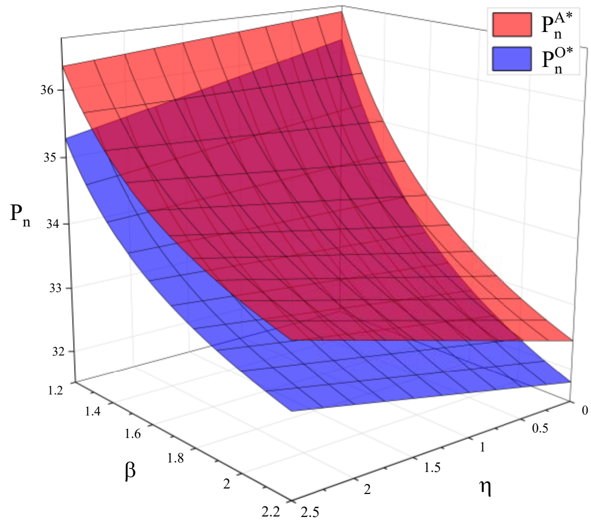


Figure 16. Effects of β and η on price of new products.

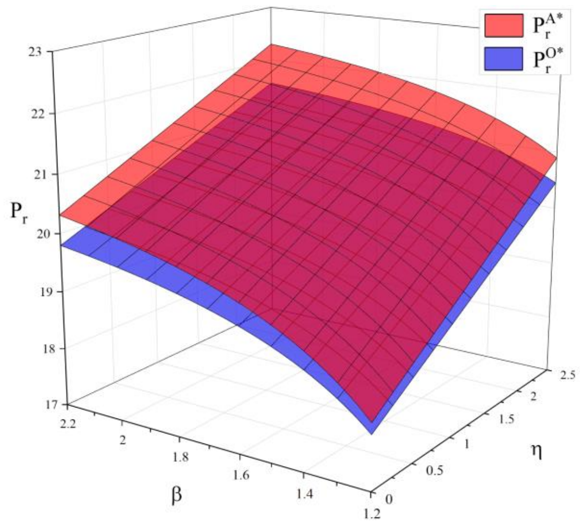


Figure 17. Effects of β and η on price of remanufactured products.

Figures 18–21 illustrate the effects of β and η on members' expected profits and retailer utility. Increases in both β and η are inversely proportional to the OEM's expected profit. Conversely, increases in β and η promote the expected profit of TPR. For the retailer, higher risk aversion reduces utility, while its expected profit first increases and then decreases with the increase in η. These findings align with the statements in Corollary 1 and Corollary 2. Low retail service efficiency not only reduces the retailer's expected profit but also disadvantages the OEM, even if it enhances new product market returns. Furthermore, the retailer can achieve optimized expected profit by maintaining appropriate risk aversion, though this will sacrifice the interests of the OEM. The more risk-averse the retailer becomes, the less likely it is to enhance the service level, which harms consumer experience. However, the retailer can strive to enhance retail service efficiency, thereby potentially making the TPR more willing to pursue the authorized remanufacturing model that benefits the retailer's expected profit and utility in the remanufacturing collaboration with the OEM.

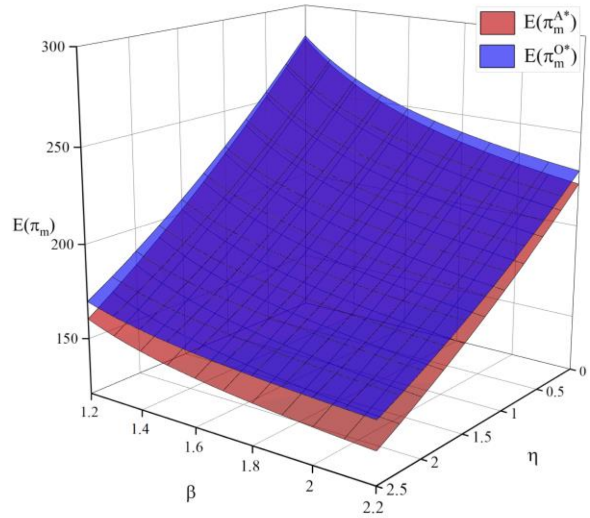


Figure 18. Effects of β and η on the OEM's expected profit.

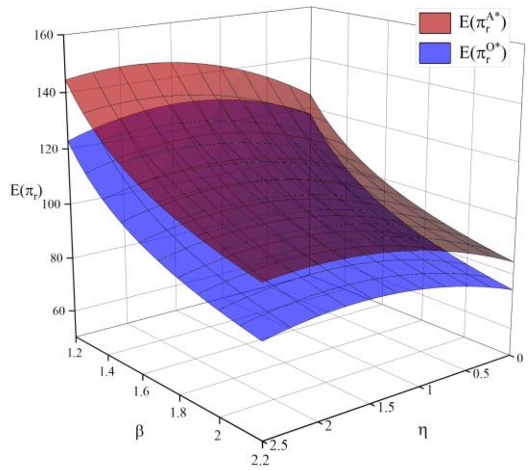


Figure 19. Effects of β and η on the retailer's expected profit.

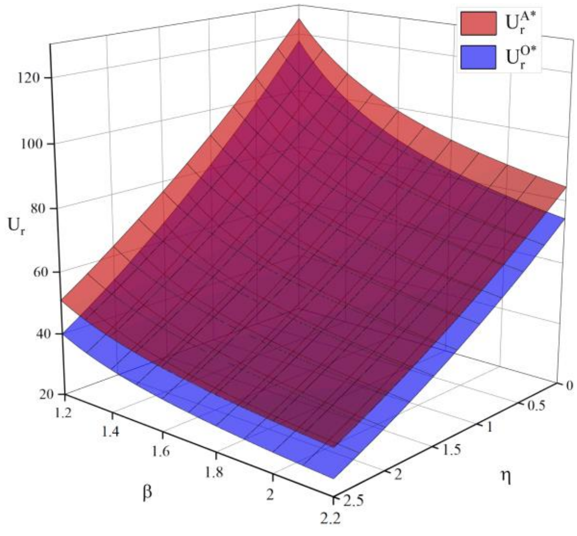


Figure 20. Effects of β and η on the retailer's utility.

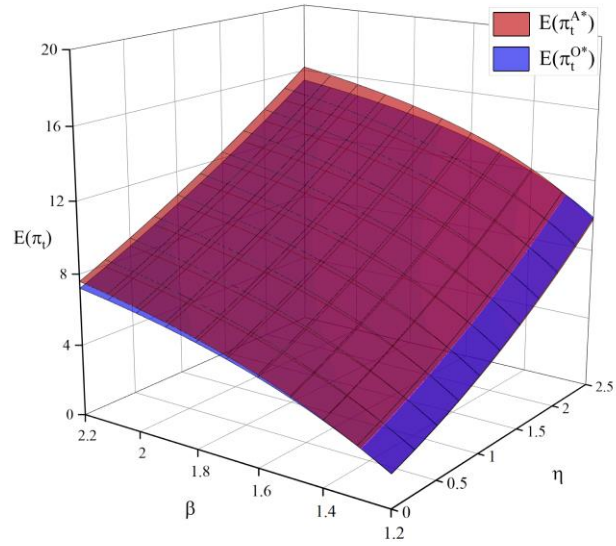


Figure 21. Effects of β and η on the TPR's expected profit.

Finally, we analyze how parameter variations affect the expected environmental impacts under different remanufacturing models. By setting relevant parameter values as $\phi = 40$, $c_n = 4$, $c_r = 2$, $\sigma = 4$, $\delta = 0.75$, $k = 1$, $\lambda_u = 0.12$, $\lambda_r = 0.73$, and $\theta = 1$, we show the variation of the expected environmental impacts with β and η in Figure 22. It can be seen that both β and η have an inverse relationship with expected environmental impacts. Moreover, when β is larger, Model A is more environmentally friendly. By setting the relevant parameter values as $\phi = 40$, $c_n = 4$, $c_r = 2$, $\sigma = 4$, $\delta = 0.75$, $\theta = 1$, $\beta = 2$ $\eta = 1.5$, and $\lambda_u = 0.12$, Figure 23 shows the variation of the expected environmental impacts with k and λ_r. The increase in expected environmental impacts due to the increase in λ_r is more pronounced in Model O. When λ_r exceeds a certain threshold, the expected environmental impact under Model O exceeds that under Model A. At lower λ_r values, k is directly proportional to the expected environmental impact. At higher λ_r values, the increase in k reduces the environmental burden. Therefore, in addition to the environmental performance of products, recycling and service efficiency are also important factors affecting the environment. When formulating environmental policies, the government needs to consider the impact of these factors on the expected profits and risk aversion utilities of supply chain enterprises, so as to guide supply chain members to make decisions conducive to sustainable development.

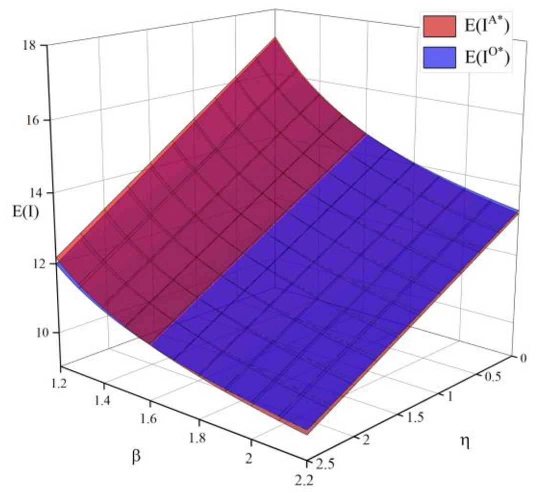


Figure 22. Effects of β and η on the expected environmental impacts.

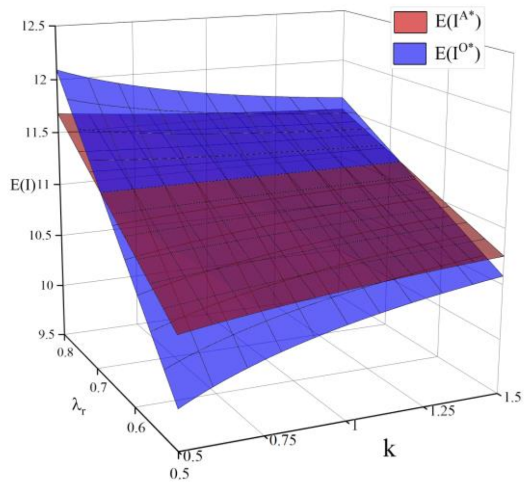


Figure 23. Effects of k and λ_r on the expected environmental impacts.

7. Conclusions

This study considers a CLSC consisting of an OEM, a risk-averse retailer, and a TPR. We analyze the decision-making of the authorized remanufacturing model (Model A) and the outsourcing remanufacturing model (Model O). Our main findings are summarized as follows:

(1) As the risk aversion degree of the retailer increases, the OEM will raise the outsourcing fee to encourage the TPR to produce more remanufactured products while setting lower wholesale prices. The retailer's risk aversion diminishes enthusiasm for selling new products and providing retail services, while simultaneously contributing to the growth of the remanufactured products market and the TPR's expected profit. For the OEM, the negative impact of risk aversion, shrinking the new product market, outweighs its positive effect on the expected remanufacturing channel revenue, thereby adversely affecting total expected benefits. Interestingly, when the risk aversion degree falls below a certain threshold, sacrificing the benefits of the OEM can actually be beneficial for the expected benefits of the retailer. Additionally, by suppressing the production of new products and incentivizing remanufacturing, risk aversion can be advantageous for environmental improvement.

(2) Retail service scale cost parameter is negatively correlated with the quantity and price of new products as well as the service level, and positively correlated with the quantity and price of remanufactured products. The increase in retail service difficulty will prompt the OEM to raise the outsourcing remanufacturing fee to provide greater support for remanufacturing channel. The increase in difficulty of retail service inhibits the sales of new products, which brings higher expected profit to the remanufacturing business but is unfavorable for the expected profits of the OEM and the retailer, as well as the retailer utility. Moreover, high retail service difficulty yields high recovery rates and less expected environmental impact from new products, thereby improving CLSC environmental performance.

(3) The increase in recycling scale cost coefficient suppresses remanufacturing activity but benefits the new product market. As recycling difficulty rises, the retailer sells more products at higher prices and service levels, thereby increasing expected profit and utility. In the outsourcing remanufacturing model, the OEM raises the authorization fee to incentivize remanufacturing by the TPR with low recycling efficiency; however, an increase in recycling difficulty consistently undermines the OEM's expected profit. Under certain parameter conditions, an increase in recycling difficulty may elevate the expected profit of TPR due to the raised outsourcing fee. Additionally, when the unit environmental impact of remanufactured products is relatively high, the increase in difficulty of recycling can reduce the number of remanufactured products with poor environmental performance, thereby lowering the expected environmental impact of CLSC. When the

environmental impact of unit remanufactured products is relatively low, or when the environmental impact of unit unrecycled waste products is high, the recycling difficulty's increase will lead to significant waste pollution and exacerbate the expected overall environmental impact.

(4) Model A has more new products, greater retail service effort, higher new product price, and less remanufactured products; therefore, it benefits the new product business and enables the retailer to achieve higher expected profit and utility. In Model O, the supply chain operations focus shifts on remanufacturing, with the OEM responsible for selling remanufactured products and securing greater expected profits. For the TPR, the preference for different remanufacturing models is influenced by parameter variations. Model O becomes more profitable for the TPR only when both the market acceptance of remanufactured products and the recycling scale cost coefficient exceed certain thresholds. Additionally, Model O is more environmentally friendly when the unit environmental impact of remanufactured products falls below a specific threshold; otherwise, the opposite holds true.

We now summarize some valuable managerial implications from the model analysis results.

First, the OEM should adopt the outsourcing remanufacturing model, which takes charge of remanufactured product sales, and adjust the outsourcing fee based on changes in retailer risk aversion, service, and recovery efficiency. This approach enables better control over the remanufacturing channel and optimizes expected profit compared to Model A. While Model A can generate higher expected profit from the new product channel, the profit from remanufacturing in Model O is more notable. In other words, the OEM needs to collaborate with the TPR, which can accept the outsourcing remanufacturing model. When establishing the third-party remanufacturing supply chain, the OEM should select a TPR with high recovery efficiency and a new product retailer with high service efficiency and low risk aversion. Additionally, the OEM can provide technical and promotional support to the retailer's retail services, including promotional items, product knowledge training, and marketing materials. By enhancing product durability design to increase recycling difficulty and actively promoting remanufactured products to boost market recognition, the TPR can be encouraged to adopt the outsourcing remanufacturing model that benefits the OEM.

Second, for the retailer, service efficiency should be improved to increase risk-aversion utility and expected profit, such as strengthening employee training and introducing AI sales consultants to raise the consumer experience. From a profit-maximization perspective, the retailer should maintain appropriate risk aversion, which avoids overly high service levels while making the OEM lower the wholesale price to stimulate the new product market, thereby securing more favorable expected channel profit distribution for the retailer. Enhancing retail service efficiency may make the TPR more willing to pursue the authorized remanufacturing model, which is more conducive to the retailer's expected profit and utility. While optimizing service costs, it is crucial to recognize that an excessively low service scale cost coefficient may make the TPR more inclined to accept the model O, which is unfavorable to the retailer. Therefore, gaining a thorough and timely understanding of the bargaining power held by the OEM and the TPR in negotiations over model selection is important to the retailer.

Third, in Model A, TPR should enhance recovery efficiency. However, in Model O, when the retailer service cost parameter for new products is relatively high, and consumers have low acceptance of remanufactured products, the TPR should avoid pursuing excessively high recovery efficiency and optimize profitability through low production and high unit margins. We suggest that the TPR carefully selects remanufacturing cooperation models based on varying recycling efficiency, market recognition degree of remanufactured products, and the service cost of the competitor. When the recognition degree is high, the TPR, encountering serious difficulties in improving recycling efficiency, should pursue the outsourcing remanufacturing model in CLSC operation.

Fourth, for policymakers, considering how these factors affect supply chain enterprises' profits can guide supply chain members in making decisions that promote sustainable development. We recommend that the government support the TPR in enhancing recycling efficiency while encouraging the new product retailer to improve the effectiveness of services. Moreover, the call for consumers to accept remanufactured products may prevent the TPR from choosing the authorized remanufacturing model when the outsourcing remanufacturing model is more environmentally friendly. The government should also consider the impact of retailer services on the environmental performance of different remanufacturing models, using conditional subsidies for specific, more environmentally friendly remanufacturing models to guide the supply chain toward a greener structure. For instance, when the retailer service cost coefficient is low, and the environmental burden per unit of remanufactured product is high, implementing a subsidy for the TPR that produces and sells remanufactured products could encourage the CLSC to adopt a relatively eco-friendly authorization remanufacturing pattern rather than the outsourcing remanufacturing.

However, this study also has some limitations. We analyze the outsourcing and authorized remanufacturing models, but do not consider the scenario where the OEM is responsible for producing the remanufactured products. Second, this study only considers the risk aversion of a retailer, while future research could consider the risk preferences of multiple members. Additionally, the issue regarding different quality levels of recycled products is also worth analyzing in the third-party remanufacturing supply chain model.

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Use of Generative-AI tools declaration

The authors declare that they did not utilize any artificial intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors certify that none of their known financial conflicts of interest or personal relationships might have appeared to influence the research presented in this study.

References

1. J. M. Framinan, An analysis of the supply chain dynamics of remanufacturing with multiple collectors, *Int. J. Product. Econ.*, **267** (2024), 109071. https://doi.org/10.1016/j.ijpe.2023.109071
2. J. Xu, Q. Bai, Z. Li, L. Zhao, Maximizing the profit of omnichannel closed-loop supply chains with mean–variance criteria, *Comput. Ind. Eng.*, **113** (2024), 109030. https://doi.org/10.1016/j.compeleceng.2023.109030
3. Y. Chen, F. Chen, On the competition between two modes of product recovery: Remanufacturing and refurbishing, *Prod. Oper. Manag.*, **28** (2019), 2983−3001. https://doi.org/10.1111/poms.13082

4. J. Zhao, C. Wang, L. Xu, Decision for pricing, service, and recycling of closed-loop supply chains considering different remanufacturing roles and technology authorizations, *Comput. Ind. Eng.*, **132** (2019), 59−73. https://doi.org/10.1016/j.cie.2019.04.019
5. C. P. Baldé, R. Kuehr, T. Yamamoto, R. McDonald, E. D'Angelo, S. Althaf, et al., *Global E-waste Monitor 2024*, International Telecommunication Union (ITU) and United Nations Institute for Training and Research (UNITAR), 2024. Available from: https://ewastemonitor.info/the-global-e-waste-monitor-2024/.
6. X. Wu, Y. Zhou, Buyer-specific versus uniform pricing in a closed-loop supply chain with third-party remanufacturing, *Eur. J. Oper. Res.*, **273** (2019), 548−560. https://doi.org/10.1016/j.ejor.2018.08.028
7. Y. Zhang, W. Chen, Q. Li, Third-party remanufacturing mode selection for a capital-constrained closed-loop supply chain under financing portfolio, *Comput. Ind. Eng.*, **157** (2021), 107315. https://doi.org/10.1016/j.cie.2021.107315
8. Z. B. Zou, J. J. Wang, G. S. Deng, H. Chen, Third-party remanufacturing mode selection: Outsourcing or authorization? *Transport. Res. Part E: Logist. Transport. Rev.*, **87** (2016), 1−19. https://doi.org/10.1016/j.tre.2015.12.008
9. J. Ding, X. Pu, W. Zhang, Outsourcing vs. authorization remanufacturing and differential vs. uniform pricing: A supply chain perspective, *Transport. Res. Part E: Logist. Transport. Rev.*, **192** (2024), 103777. https://doi.org/10.1016/j.tre.2024.103777
10. Suning, *Suning.com Max Store Integrates Deepseek! LingSi AI Store Assistant Officially Launches*, 2025. Available from: http://www.suning.cn/cms/latestNews/26973.htm.
11. Z. Liu, L. Hu, W Yeh, Risk-averse two-stage stochastic programming-based closed-loop supply chain network design under uncertain demand, *Appl. Soft Comput.*, **147** (2023), 110743. https://doi.org/10.1016/j.asoc.2023.110743
12. J. Gao, H. Han, L. Hou, H. Wang, Pricing and effort decisions in a closed-loop supply chain under different channel power structures, *J. Clean. Prod.*, **112** (2016), 2043−2057. https://doi.org/10.1016/j.jclepro.2015.01.066
13. S. Qu, L. Shu, J. Yao, Optimal pricing and service level in supply chain considering misreport behavior and fairness concern. *Comput. Ind. Eng.*, **174** (2022), 108759. https://doi.org/10.1016/j.cie.2022.108759
14. D. Gong, H. Gao, L. Ren, X. Yan, Consumers' free riding: Pricing and retailer service decisions in a closed-loop supply chain, *Comput. Ind. Eng.*, **181** (2023), 109285. https://doi.org/10.1016/j.cie.2023.109285
15. K. Cai, Z. He, Y. Lou, S. He, Risk-aversion information in a supply chain with price and warranty competition. *Ann. Oper. Res.*, **287** (2020), 61−107. https://doi.org/10.1007/s10479-019-03386-w
16. M. Liu, E. Cao, C. K. Salifou, Pricing strategies of a dual-channel supply chain with risk aversion, *Transport. Res. Part E: Logist. Transport. Rev.*, **90** (2016), 108−120. https://doi.org/10.1016/j.tre.2015.11.007
17. X. Xia, W. Chen, B. Liu, Optimal production and financing strategies for capital-constrained closed-loop supply chain under risk aversion, *Kybernetes*, **52** (2023), 2770−2809. https://doi.org/10.1108/K-09-2021-0923
18. J. Ding, Y. Wang, T. Tuerxun, The impact of risk aversion on remanufacturing supply chain decisions under quality uncertainty, *Kybernetes*. **55** (2026), 806–824. https://doi.org/10.1108/K-07-2024-1976
19. Q. Zhou, C. Meng, KF. Yuen, Remanufacturing authorization strategy for competition among OEM, authorized remanufacturer, and unauthorized remanufacturer, *Int. J. Product. Econ.,* **242** (2021), 108295. https://doi.org/10.1016/j.ijpe.2021.108295

20. N. Wang, Y. Zhang, J. Li, Carbon emission reduction and coordination in a closed-loop supply chain with outsourcing remanufacturing, *Kybernetes,* **51** (2022), 3366−3393. https://doi.org/10.1108/K-11-2020-0800
21. X. Xia, M. Lu, W. Wang, Emission reduction and outsourcing remanufacturing: A comparative study under carbon trading, *Expert Syst. Appl.*, **227** (2023), 120317. https://doi.org/10.1016/j.eswa.2023.120317
22. Z. Liu, J. Ren, M. Wan, J. Cao, Financing strategies for a textile and apparel remanufacturing supply chain with the delay in disbursement subsidies, *J. Clean. Prod.*, **437** (2024), 140745. https://doi.org/10.1016/j.jclepro.2024.140745
23. G. Esenduran, M. Jin, Y. Zhou, Laissez-Faire vs. Government Intervention: Implications of Regulation Preventing Nonauthorized Remanufacturing, *Manuf. Serv. Oper. Manag.*, **27** (2025), 588−606. https://doi.org/10.1287/msom.2023.0128
24. P. Ma, M. Li, Operational and financing decisions of original equipment manufacturers under third-party remanufacturing modes, *Comput. Ind. Eng.*, **183** (2023), 109508. https://doi.org/10.1016/j.cie.2023.109508
25. B. Li, J. Tang, Z. Liu, B. Gong, Remanufacturing mode selection considering uncertain EOL products' quality and differential consumers' WTP, *Kybernetes*, **53** (2024), 358−383. https://doi.org/10.1108/K-03-2022-0428
26. X. Xia, J. Chen, W. Wang, H. Wang, Impact of differentiated carbon taxes on remanufacturing mode selection, *Energy Econ*., **140** (2024), 107955. https://doi.org/10.1016/j.eneco.2024.107955
27. H. Qiao, X. Xu, Replacement program decision-making and remanufacturing model selection considering consumer segmentation, *J. Ind. Manag. Optim*., **21** (2025), 1145−1175. https://doi.org/10.3934/jimo.2024119
28. Y. Xia, T. Xiao, G. P. Zhang, Service investment and channel structure decisions in competing supply chains, *Serv. Sci.*, **11** (2019), 57−74. https://doi.org/10.1287/serv.2018.0235
29. S. Zhang, B. Dan, M. Zhou, After-sale service deployment and information sharing in a supply chain under demand uncertainty, *Eur. J. Oper. Res.*, **279** (2019), 351−363. https://doi.org/10.1016/j.ejor.2019.05.014
30. Z. Guan, X. Zhang, M. Zhou, Y. Dan, Demand information sharing in competing supply chains with manufacturer-provided service, *Int. J. Product. Econ.*, **220** (2020), 107450. https://doi.org/10.1016/j.ijpe.2019.07.023
31. Y. Zhang, M. S. Han, K. Wang, Symmetric or asymmetric? Value-added service design for new and remanufactured products under competition, *Int. J. Product. Econ.*, (2025), 109682. https://doi.org/10.1016/j.ijpe.2025.109682
32. X. Hong, L. Wang, Y. Gong, W. Chen, What is the role of value-added service in a remanufacturing closed-loop supply chain? *Int. J. Product. Res.*, **58** (2020), 3342−3361. https://doi.org/10.1080/00207543.2019.1702230
33. R. Shan, L. Luo, R. Kou, Cost-sharing strategy for recycling and service investment in a closed-loop supply chain, *RAIRO Oper. Res.*, **55** (2021), 2963−2990. https://doi.org/10.1051/ro/2021143
34. W. Shi, H. Chen, X. Zhang, C. Ma, Optimal Alliance Strategy and Its Impact in a Closed-Loop Supply Chain by considering Greenness and Service Effort, *Math. Probl. Eng.*, **1** (2021), 6676482. https://doi.org/10.1155/2021/6676482
35. R. Gong, J. Xue, R. Liu, J. Zhou, L. Zhao, A closed-loop supply chain decision model considering corporate social responsibility and value-added services, *Manag. Decis. Econ.*, **43** (2022), 1704−1720. https://doi.org/10.1002/mde.3481

36. J. Zhang, What is the role of product services in the dual-channel closed-loop supply chain? *RAIRO Oper. Res.*, **58** (2024), 3637−3658. https://doi.org/10.1051/ro/2023183
37. W. Deng, Sustainable development: Impacts of consumers' risk aversion on remanufacturing model selection and environmental performance, *Sustain. Dev.*, **28** (2020): 1564−1574. https://doi.org/10.1002/sd.2105
38. B. Niu, H. Xu, L. Chen, Creating all-win by blockchain in a remanufacturing supply chain with consumer risk-aversion and quality untrust, *Transport. Res. Part E: Logist. Transport. Rev.*, **163** (2022), 102778. https://doi.org/10.1016/j.tre.2022.102778
39. J. Xu, Q. Bai, Q. Luo, Energy conservation strategy and coordination of a closed-loop supply chain with risk-averse members under carbon tax regulation, *Oper. Res.*, **23** (2023), 52. https://doi.org/10.1007/s12351-023-00793-7
40. H. Song, Q. Li, Decision-making in closed-loop supply chains: Effects of government subsidies and risk aversion, *Int. Rev. Financ. Anal.*, **96** (2024), 103566. https://doi.org/10.1016/j.irfa.2024.103566
41. B. Gong, Z. Li, J. Cheng, X. Zhang, Closed-loop supply chain decisions considering carbon tax policy under the recycler's risk aversion, *Ann. Oper. Res.*, **55** (2025), 1851–1876. https://doi.org/10.1007/s10479-025-06671-z
42. F. Zhou, C. Zhang, S. Tiwari, X. Huang, S. Pratap, Decision and coordination of WEEE closed-loop supply chain with risk aversion under the cap-and-trade regulation, *Int. J. Product. Econ.*, **280** (2025), 109477. https://doi.org/10.1016/j.ijpe.2024.109477
43. X. Xia, Y. Nan, Pricing Decision and Financing Approach Selection of Fund-Deficient Closed-Loop Supply Chain under Distributor's Risk Aversion, *Math. Probl. Eng.*, **1** (2022), 3077833. https://doi.org/10.1155/2022/3077833
44. J. Cao, Q. Shao, Outsourcing and authorized remanufacturing under voluntary emission reduction mechanism. *Flex. Serv. Manuf. J.*, **37** (2024), 776–815. https://doi.org/10.1007/s10696-024-09555-9
45. B. Niu, Z. Zou, Better demand signal, better decisions? Evaluation of big data in a licensed remanufacturing supply chain with environmental risk considerations, *Risk Anal.*, **37** (2017), 1550–1565. https://doi.org/10.1111/risa.12796
46. B. Zheng, L. Jin, Relicensing scheme selection in closed-loop supply chains with differentiated new and remanufactured products, *Comput. Ind. Eng.*, **171** (2022): 108443. https://doi.org/10.1016/j.cie.2022.108443
47. X. Xia, W. Chen, B. Liu, Optimal production decision and financing strategy for a capital-constrained closed loop supply chain under fairness concern, *J. Clean. Prod.*, **376** (2022), 134256. https://doi.org/10.1016/j.jclepro.2022.134256