DECISION-MAKING IN A RETAILER-LED CLOSED-LOOP SUPPLY CHAIN INVOLVING A THIRD-PARTY LOGISTICS PROVIDER

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ABSTRACT. This paper investigates decisions in a three-echelon closed-loop supply chain composed of one manufacturer, one retailer, and one third-party logistics provider (3PL), with the retailer being dominant. Inspired by game theory, we develop an equilibrium model for a retailer-led, closed-loop supply chain under logistics outsourcing. We derive the optimal forward and reverse logistics decisions of each supply chain member. This article analyzes the effects of market size, consumers’ sensitivity to sales prices, the proportion of logistics costs, consumers’ environmental awareness, and consumers’ sensitivity to recycling prices on decision-making process. Finally, we provide a numerical example to verify the validity of our conclusions. Our results indicate that the higher the manufacturer’s share in the forward logistics cost, the higher the sales price, the wholesale price, and the forward logistics service price, and the lower the order quantity. The higher the manufacturer’s share in the reverse logistics costs, the lower the recycling price, the transfer price, and the recycling amount, and the higher the reverse logistics service price. Whether it is forward logistics or not, the higher the manufacturer’s share in the logistics costs, the lower the profits of each member.

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1. **Introduction.** In recent years, enterprises have increasingly faced challenges related to severe shortages of raw materials and environmental pollution, which has affected their sustainable development. In an attempt to be more sustainable, companies have been paying more attention to the recycling and remanufacturing of their used products. Several changes within these companies have been implemented to achieve this goal, such as: stimulating reverse logistics of used products from consumers to manufacturers [24, 6], and shifting the supply chain system from a traditional forward or reverse supply chain to a closed-loop supply chain system [11, 26]. Enterprises’ implementation of recycling and re-manufacturing strategies not only promotes the reuse of resources and saves costs, but also enhances responsibility in the production system [5]. In practice, manufacturing plays an important role in the closed-loop supply chain. Manufacturers are responsible for recycling, or entrust third party enterprises to recycle, used products so as to set an example in their role as leaders. However, with the increasing concentration of the retail industry, there is also an increasing number of large retail enterprises such as Wal-Mart (U.S.), Carrefour (France), and Suning (China), among others. These retailers are gradually gaining control of sales channels and are occupying dominant positions in the supply chain [27]. Many large retail enterprises not only engage in product sales, but also assume responsibility for the recycling of used products [13]. This has promoted the rapid development of closed-loop supply chains [25].

With competition intensifying, enterprises may attempt to put more of their resources and focus on their main business activities. As a result, many enterprises may outsource part, or all, of their logistical activities that are not core to the business, entrusting them to professional third-party logistics providers [10]. Logistics outsourcing is prevalent, not just in this specific context but, indeed, more broadly. Toshiba (Japan), for example, chooses UPS, a big third-party logistics company in the US, to provide logistics services, as well as to recycle and repair used products. Using UPS for non-core business activities lowers Toshiba’s cost of business and improves its operational efficiency. The participation of professional third-party logistics providers improves business efficiency, and has an impact on the decision-making of supply chain members. In addition, with retailers gaining increasing power in supply chains, closed-loop supply chains dominated by retailers have become increasingly popular in practice, yet their theoretical inner-workings are under-researched. In spite of its prevalence in the manufacturing industry, there is little literature on the closed-loop supply chain involving third-party logistics service providers. In this context, this paper tries to answer the following three questions.

(1) What is the optimal decision-making strategy for the forward and reverse logistics of each closed-loop supply chain member when outsourcing logistics?

(2) What is the optimal equilibrium decision-making strategy in a closed-loop supply chain dominated by retailers?

(3) How do market parameters (such as market size, consumers’ sensitivity to prices, consumers’ environmental awareness, the proportion of logistics costs assumed by different parties, etc.) affect the decisions of forward logistics and reverse logistics supply chain members?

To answer these questions, this paper investigates the balance struck by a closed-loop supply-chain-wide system consisting of a manufacturer, a 3PL provider, and a retailer. In this case, the supply chain is led by the retailer. The products produced by the manufacturer are transferred to final consumers for consumption through the
dominant retailer, which is defined as forward logistics. Consumers’ used products are recycled to manufacturers for remanufacturing through the dominant retailer, which is defined as reverse logistics. In the process of product transfer, logistics services are outsourced to a 3PL provider by the manufacturer or the dominant retailer. This study’s consideration of the dominant retailers’ logistics outsourcing responds to the fact that there are many larger retailers in market, and these larger retailers are willing to outsource their logistics service to the 3PL provider. Walmart (America) and Gome (China), for example, are larger retail chain store operators, and both companies outsource their logistics services to Hercules Logistics & DTW Logistics respectively. Comparing the difference between forward logistics and reverse logistics, this paper measures the effect of the 3PL provider’s logistics service price on supply chain members. This study then reveals the conditions that create the balance. The results show that the logistics service price has an important influence on the balance. Furthermore, we discuss the effect of other factors, such as market size, consumers’ sensitivity to price, consumer environmental awareness etc., on the balance.

The remainder of this paper is organized as follows: Section 2 provides a brief review of the literature. Section 3 presents the problem and describes our assumptions. Section 4 proposes and analyzes our model of the closed-loop supply chain members. In Section 5, we provide numerical examples. Finally, Section 6 presents our conclusions and explores potential future research directions.

2. Literature review. As a result of the increased attention that is being dedicated to environmental protection, and the growing advocacy of sustainable development, closed-loop supply chains have been applied in various industries [1]. In addition, closed-loop supply chains have attracted the attention of many scholars. At present, research on closed-loop supply chains typically focuses on so-called dominant modes, the three primary types being the manufacturer-led mode, the third-party recycler-led mode, and a different enterprises-led mode [8].

Many scholars study the first of these three types, i.e. manufacturer-led closed-loop supply chains. Savaskan et al. [22] analyze three kinds of recycling modes in closed-loop supply chains: manufacturer recycling, retailer recycling, and third-party recycling. Their research results indicate that retailer recycling represents the best recycling mode. Savaskan and Wassenhove [23] study the recycling mode of competitive retailers, and find that the degree of competition among retailers affects the preferred recycling mode. Chuang et al. [2] examine the decisions of members in a high-tech product’s closed-loop supply chain. They consider three alternative reverse channel structures for the manufacturer, and account for their production quantities and profits. Chung et al. [3] discuss the remanufacturing of perishable goods and focus on inventory controls in closed-loop supply chains dominated by manufacturers. Ma et al. [18] investigate two types of closed-loop supply chains dominated by manufacturers, with or without government subsidies for consumer purchases, and conclude that the amount of government subsidies does not affect the member’s decisions. Gong et al. [10] introduce third-party logistics service providers into the closed-loop supply chain system dominated by manufactures. The authors find that, by allocating a reasonable proportion of logistics costs to manufacturers, optimal supply chains can be achieved, and outsourcing decision are made more effectively. Jian et al. [16] use evolutionary game theory to analyze conditions for remanufacturing by manufacturers, and retailer recycling. Finally,
Jian et al. [17] examine the pricing of recycling in closed-loop supply chains with remanufacturing in the presence of a carbon subsidy policy.

As previously mentioned, in order to concentrate on their core businesses, manufacturers and retailers frequently entrust product recycling to third-party enterprises. Some papers study the closed-loop supply chain dominated by third-party recyclers. Huang et al. [14] identify the driving factors of the recycling behaviour displayed by third-party recyclers and the effect of the manufacturer’s and retailer’s positions on the efficiency of a supply chain. Qing et al. [21] explain, through multiple case studies, the reasons for developing remanufacturing activities. Additionally, they discuss the necessity of having third-party recyclers handle the recovery of used products. They contribute new findings by investigating three original equipment manufacturers (OEMs), one logistics enterprise, and three small and medium sized enterprises (SMEs). Zou et al. [34] study two modes of third-party recycler remanufacturing: authorization and outsourcing. They find that if there is high consumer approval of remanufactured products, the outsourcing mode is better. Conversely, the authorization mode is better when there is low consumer acceptance of remanufactured products. Feng et al. [4] explore the decisions of third-party recyclers in a closed-loop supply chain (composed of one third-party recycler, one retailer, and one manufacturer) and model the profits of supply chain members.

Scholarship is also emerging on the topic of closed-loop supply chains dominated by different enterprises. Hong and Yeh [13] compare decision-making and profits in retailer recycling and manufacturer entrusted third-party recycling. The authors find that the retailer recycling mode performs more optimally than the third-party recycling mode. Xiong et al. [29] explore the performance of manufacturer remanufacturing and supplier remanufacturing in a decentralized closed-loop supply chain. Modak et al. [19] construct cooperative and non-cooperative models of a closed-loop supply chain that consists of one manufacturer and duopolistic retailers. In addition, they analyze the model with collusion games. Wang et al. [30] opt for waste electrical and electronic equipment as their case studies, and use principle-agent theory to investigate the decision-making of the closed-loop supply chain in the case where the retailer and the third-party recycler compete over recycling prices. Zhou et al. [33] apply game theory in their exploration of the decisions and coordination problems that exist in manufacturer-led and retailer-led closed-loop supply chains that are centralized. In their model, the authors consider consumer behaviour, and posit that when the service level of new products is lower, the pricing of new and remanufactured products in manufacturer-led supply chains is higher than that in retailer-led scenarios.

Several studies have examined decisions in a retailer-led closed-loop supply chain. Li [15], for example, explores pricing strategies in a retailer-led closed-loop supply chain, and discusses the impact of the recycling prices of used products on wholesale and retail prices. Han [12] describes the decision-making in three recycling channels (retailer recycling, manufacturer recycling, and third-party recycling) in a closed-loop supply chain led by strong retailers under uncertain remanufacturing costs. Gao et al. [7] trace the operation and coordination mechanisms of a closed-loop supply chain dominated by retailers under asymmetric information regarding manufacturers’ remanufacturing costs. Yang et al. [31] develop two models to analyze how the retailers’ service level affects performance and sustainability issues related to remanufacturing operations. Yao et al. [32] examine the effect of fairness preference on pricing strategies in a closed-loop supply chain, as well as the construction
of the profit decision models. They suggest that these have a negative impact on the profit of the retailer-led closed-loop supply chain system. Wang and Xu [28], through the lens of power structure and alliance strategy, consider optimal pricing and the performance of the risk-averse closed-loop supply chain in a manufacturer-led, retailer-led, and manufacturer-retailer power balanced system. Our review of the relevant literature does not yield any studies dedicated to the 3PL provider in a retailer-led closed-loop supply chain.

Methodologically, our paper is closely related to Gong [8] and Li [15], but is distinctly different from their research in the following three aspects. Firstly, although Gong [8] takes logistics outsourcing into account in his model, his research is dedicated to the closed-loop supply chain dominated by manufacturers, whereas our research focuses on a retailer-led closed-loop supply chain. Such closed-loop supply chains dominated by retailers are used by different enterprises, for example Gome (China), a large retail enterprise that outsources its mobile logistics to DTW, which is also responsible for recycling used mobile phones. Secondly, although retailer-led models are employed by some of the cited literature (i.e., Li [15]), logistics outsourcing is not considered in their research. In our paper, we develop a model that incorporates logistics outsourcing, and analyzes the optimal forward and reverse logistics decisions of each supply chain member under logistics outsourcing. Thirdly, we investigate the effect of market size, consumers’ price sensitivity, the proportion of logistics costs assumed by different parties, and the consumers’ environmental awareness on the decision-making of supply chain members. Fourth, Gong’s research proposes selection conditions for the logistics mode under a manufacturer-led and retailer-led supply chain, and uncovers which combination is better. In contrast, our research focuses on the strategic decisions of supply chain members under reverse and forward logistics, and analyzes the influence of market size, the logistics cost ratio, and other factors on these decisions. Li’s results show that “product ordering and pricing decisions are related to product market size, consumer awareness of environmental protection, and consumers’ sensitivity to product sales price and recycling price”, while our research demonstrates that, under logistics outsourcing, in addition to the factors identified in Li’s paper, product ordering and pricing decisions are also closely related to logistics costs. Our approach is inspired by the fact that in China, for example, the logistics costs of small and medium-sized enterprises account for about 30% of their total operating cost. In 2018, the total logistics costs in China were $1.91 trillion, accounting for 14.8% of GDP, of which reverse logistics accounted for about 20% of the total logistics cost. These areas are underrepresented in much of the reviewed research, pointing to a gap in the literature to which our study responds. To the best of our knowledge, our paper appears to be the first to explore decisions in a retailer-led closed-loop supply chain involving a third-party logistics provider.

3. Problem description and assumptions.

3.1. Problem description. Consider a three-echelon supply chain with one manufacturer, one 3PL, and one retailer. The retailers has a dominant position in the channel and faces a stochastic demand market. Their relationship is described in Figure 1, which visually shows that the manufacturer provides products to the retailer, and the retailer sells them to consumers. Moreover, the retailer is responsible for recycling used products. The manufacturer collects the products recycled by the retailer at a certain price, processes the used products, forms the remanufactured
products, and puts them on the market. Finally, the manufacturer sells these products at the same price as new products. From production to sales, and from waste recycling to reproduction, transportation, packaging and other logistics services of the products are completed by the 3PL provider, including forward and reverse logistics. The cost of forward and reverse logistics are shared by the manufacturer and the retailer. As shown in Figure 1, in this supply chain system, the retailer first determines the sales price of the products and the market recycling price of the used products based on the market environment. Second, the manufacturer determines the wholesale price and the transfer price of the used products from the retailer according to the sales price and the market recycling price determined by the retailer. Finally, the 3PL provider determines the forward and reverse logistics service price based on the decisions of the manufacturer and the retailer.

**Figure 1.** Three-echelon closed-loop supply chain system under logistics outsourcing

### 3.2. Model Assumptions

In this paper, we make the following assumptions:

**Assumptions 1.** The 3PL provider, the manufacturer, and the retailer are all risk neutral.

**Assumptions 2.** The manufacturers and the 3PL provider have complete information on the retailer’s needs, the retailer and the manufacturer have complete information on the cost of the 3PL provider, and the 3PL provider and the retailer have complete information on the costs of the manufacturer’s remanufacturing and manufacturing.

**Assumptions 3.** Per extant literature [20, 9], the demand function is \( Q = d - bp \), wherein, \( d \) denotes the maximum possible demand, \( b > 0 \) is the price sensitivity coefficient of products and \( p_r \) denotes the sales price of the retailer’s unit product.

**Assumptions 4.** In line with existing literature [9], the recycling quantity of the used products is determined by the equation: \( \bar{Q} = x + h\bar{p}_r \), wherein, \( x > 0 \) defines the amount of the used products returned by the consumers due to the promotion of environmental awareness when the retailer does not pay the customer to recover the cost, \( h > 0 \) represents the consumer sensitivity to the recycling price and \( \bar{p}_r \) is the market recycling price of unit product paid to consumers by the retailers. Based on literature [13, 22], it is assumed that \( Q > \bar{Q} \).

**Assumptions 5.** The logistics cost of the 3PL provider is \( c_l \), and \( p_t, \bar{p}_t \) define the forward and reverse logistics cost of the 3PL provider respectively.

In addition, we define other symbols in this paper as follows: \( c_m \) is the unit marginal costs for the manufacturer;
\( \bar{c}_m \) is the unit marginal costs for the manufacturer’s remanufacture, and \( \bar{c}_m < c_m \); 
\( c_r \) is the unit marginal sales cost of the retailer; 
\( \bar{c}_r \) is the unit marginal recovery cost of the retailer; 
\( k_1 (0 \leq k_1 \leq 1) \) is the manufacturer’s proportion of the forward logistics service cost; 
\( k_2 (0 \leq k_2 \leq 1) \) is the retailer’s proportion of the forward logistics service cost, and 
\( k_1 + k_2 = 1 \); 
\( l_1 (0 \leq l_1 \leq 1) \) is the manufacturer’s proportion of the reverse logistics service cost; 
\( k_2 (0 \leq k_2 \leq 1) \) is the retailer’s proportion of the reverse logistics service cost, and 
\( l_1 + l_2 = 1 \).

Decision variables are defined as follows:
\( w \) is the wholesale price per unit product of the manufacturer; 
\( \bar{w} \) is the transfer price paid by the manufacturer to the retailer for recycling unit product; 
\( p_l \) is the forward logistics service price of unit products of the 3PL provider; 
\( \bar{p}_l \) is the reverse logistics service price of unit products of the 3PL provider; 
\( p_r \) is the sales price per unit product of the retailer; 
\( \bar{p}_r \) is the market recycling price of a unit product paid to consumers by the retailer.

Based on the above assumptions, the retailer’s profit function \( \pi_r \), the manufacturer’s profit function \( \pi_m \) and the 3PL provider’s profit function \( \pi_l \) can be expressed:

\[
\pi_r = (p_r - w - c_r - k_2 p_l) Q + (w - \bar{p}_r - \bar{c}_r - l_2 \bar{p}_l) \bar{Q} \quad (1)
\]

\[
\pi_m = (w - c_m - k_1 p_l) Q + (c_m - \bar{c}_m - \bar{w} - l_1 \bar{p}_l) \bar{Q} \quad (2)
\]

\[
\pi_l = (p_l - c_l) Q + (\bar{p}_l - c_l) \bar{Q} \quad (3)
\]

Thus, the optimization problem of the closed-loop supply chain members can be expressed as:

\[
\max \pi_r = (p_r - w - c_r - k_2 p_l) Q + (w - \bar{p}_r - \bar{c}_r - l_2 \bar{p}_l) \bar{Q} \\
\text{s.t. } \pi_m = (w - c_m - k_1 p_l) Q + (c_m - \bar{c}_m - \bar{w} - l_1 \bar{p}_l) \bar{Q} \\
\text{s.t. } \pi_l = (p_l - c_l) Q + (\bar{p}_l - c_l) \bar{Q}
\]

In order to solve the optimization problem above, it is assumed that the retailer’s unit sales profit and recovery profit are respectively \( u = p_r - w - c_r - k_2 p_l \), \( \bar{u} = \bar{w} - \bar{p}_r - \bar{c}_r - l_2 \bar{p}_l \). The retailer’s sales price and recycling price are respectively, \( p_r = u + \bar{c}_r + k_2 p_l \) and \( \bar{p}_r = \bar{u} + \bar{c}_r + l_2 \bar{p}_l \).

4. The basic model.

4.1. Optimal decisions for 3PLs. Substituting \( p_r = u + \bar{c}_r + k_2 p_l \) and \( \bar{p}_r = \bar{u} + \bar{c}_r + l_2 \bar{p}_l \) into (3), and solving the first-order condition \( \frac{\partial \pi_l}{\partial p_l} = 0 \) and \( \frac{\partial \pi_l}{\partial \bar{p}_l} = 0 \) for \( p_l \) and \( \bar{p}_l \), the best reaction functions of the 3PL provider are derived as:

\[
p_l = c_l + \frac{d - b (w + c_r + \bar{u})}{2 bk_2} \quad (4)
\]

\[
\bar{p}_l = \frac{c_l}{2} + \frac{x + b (\bar{w} - \bar{u} - \bar{c}_r)}{2 hl_2} \quad (5)
\]

Substituting \( u = p_r - w - c_r - k_2 p_l \), \( \bar{u} = \bar{w} - \bar{p}_r - \bar{c}_r - l_2 \bar{p}_l \) into (4) and (5) and simplifying, (4) and (5) are rewritten as:

\[
p_l = c_l + \frac{d - b p_r}{bk_2} \quad (6)
\]
Proposition 1. With an increase of the sales price, the forward logistics service price of the 3PL provider decreases, and with an increase of the recycling price, the reverse logistics service price of the 3PL provider increases.

Proposition 1 shows that the increase of the sales price will decrease the forward and reverse logistics price of the 3PL provider. This is because the increase of the sales price reduces the market demand, and the decrease of the market demand reduces the profit of the 3PL provider.

On the other hand, an increase in the recycling price will increase the reverse logistics service price of the 3PL provider. The 3PL provider reduces the logistics service price to prevent substantial reduction in the order quantity. The increase of the reverse logistics price increases the recycling quantity, and the 3PL provider can increase the logistics service price without reducing the recycling quantity, therefore the 3PL provider will increase the reverse logistics service price to maximize its profit.

4.2. Optimal decisions for manufacturers. Substituting \( p_r = u + w + c_r + k_2 \bar{p}_l \), \( \bar{p}_r = \bar{u} + \bar{w} + \bar{c}_r + l_2 \bar{p}_l \), (4) and (5) into (2), and solving the first-order condition \( \frac{\partial \pi}{\partial w} = 0 \) and \( \frac{\partial \pi}{\partial \bar{w}} = 0 \) for \( w \) and \( \bar{w} \), the best reaction functions of the manufacturer are derived as:

\[
\frac{\partial \pi}{\partial w} = \frac{(c_m - u - c_r) k_2 - k_1 (u + c_r) b + d (k_2 + k_1)}{2k_2 + k_1} b = 0 \quad (8)
\]

\[
\frac{\partial \pi}{\partial \bar{w}} = \frac{(c_l l_2 + (c_m - \bar{c}_m + \bar{c}_r + \bar{u}) l_2 + l_1 (\bar{u} + \bar{c}_r) h - x (l_2 + l_1))}{2l_2 + l_1} h = 0 \quad (9)
\]

Substituting \( u = p_r - w - c_r - k_2 \bar{p}_l \), \( \bar{u} = \bar{w} - \bar{p}_r - \bar{c}_r - l_2 \bar{p}_l \) into (8) and (9) respectively and simplifying, (8) and (9) are rewritten as:

\[
w = \frac{(c_m - 2p_r + k_1 c_l) k_2 - 2k_1 p_r b + 2d (k_2 + k_1)}{k_2 b} \quad (10)
\]

\[
\bar{w} = \frac{-[c_l l_2 + (c_m - \bar{c}_m - 2\bar{p}_r - l_1 c_l) l_2 - 2l_1 \bar{p}_r] h - 2x (l_2 + l_1)}{l_2 h} \quad (11)
\]

Proposition 2. With the increase of the sales price, the wholesale price decreases; with the increase of the recycling price, the transfer price decreases.

Proposition 2 shows that, different from the logistics service price, the wholesale price and the recycling price of the manufacturer will decrease with the increase of the sales price and the recycling price. This is because the increase of the sales price reduces the market demand and the order quantity of the retailers. Although the 3PL provider reduces the logistic price to prevent the reduction of the order quantity, it cannot make up for its reduction completely. To a certain extent, the price decrease of the 3PL provider reduces cost for the manufacturers and therefore maximizes their profits; the manufacturers reduce the wholesale prices. With the increase of the recycling prices, the retailers’ recycling quantity increase, the manufacturers can reduce the price of the recycling subsidies without reducing the amount of recycling products. In addition, the increase of the reverse logistics service price of the 3PL provider increases costs. Consequently, in order to maximize their profits, the manufacturers decrease their transfer prices.
4.3. Optimal decisions for retailers. Substituting \( p_r = u + w + c_r + k_2p_t, \bar{p}_r = \bar{u} + \bar{w} + \bar{c}_r + l_2\bar{p}_t \) into (3), and solving the first-order condition \( \frac{\partial \pi}{\partial w} = 0 \) and \( \frac{\partial \pi}{\partial \bar{u}} = 0 \) for \( u \) and \( \bar{u} \), the best reaction functions of the manufacturer are derived as:

\[
\begin{align*}
\bar{u} &= \frac{d - b[(k_1 + k_2) c_l + c_m + c_r]}{2b} \\
\bar{u} &= \frac{h [(c_m - \bar{c}_m - \bar{c}_r - (l_1 + l_2) c_l)] + x}{h}
\end{align*}
\]

Substituting \( u = p_r - w - c_r - k_2p_t, \bar{u} = \bar{w} - \bar{p}_r - \bar{c}_r - l_2\bar{p}_t \) into (12) and (13), the optimal sales price and the recycling price are expressed as the following, respectively.

\[
\begin{align*}
p_r &= \frac{bc_1k_2^2 + k_2 [b (c_lk_1 + c_r + c_m) + 7d] + 4dk}{4b (2k_2 + k_1)} \\
\bar{p}_r &= \frac{-h c_1l_2^2 + l_2 [h (c_m - c_l - \bar{c}_r - \bar{c}_m) - 7x] - 4xl_1}{4h (2l_2 + l_1)}
\end{align*}
\]

4.4. Sub game refining Nash equilibrium solution. Substituting \( k_2 = 1 - k_1, l_2 = 1 - l_1 \) into (12) and (13), the margin sales profits and the margin recovery profits of the retailer are expressed as the following, respectively.

\[
\begin{align*}
\bar{w} &= c_m - \bar{c}_m - l_1c_l + \frac{x + h (c_m - c_l - \bar{c}_m - \bar{c}_r)}{2h(2 - l_1)} \\
\bar{p}_t &= c_l + \frac{d - b (c_l + c_m + c_r)}{4b (2 - k_1)} \\
\bar{p}_t &= c_l + \frac{x + h (c_m - c_l - \bar{c}_m - \bar{c}_r)}{4h (2 - l_1)}
\end{align*}
\]

Substituting \( k_2 = 1 - k_1, l_2 = 1 - l_1 \) and (16), (17), (18), (19) into (4) and (5), the optimal forward logistics service price and reverse logistics service price are expressed as the following, respectively.

\[
\begin{align*}
p_t &= c_l + \frac{d - b (c_l + c_m + c_r)}{4b (2 - k_1)} \\
\bar{p}_t &= c_l + \frac{x + h (c_m - c_l - \bar{c}_m - \bar{c}_r)}{4h (2 - l_1)}
\end{align*}
\]

Substituting \( k_2 = 1 - k_1, l_2 = 1 - l_1 \) and (14), (15) into (4) and (5), the optimal sales price and the recycling price are expressed as the following, respectively.

\[
\begin{align*}
p_r &= \frac{d}{b} - \frac{(1 - k_1) [d - b (c_l + c_m + c_r)]}{b (2 - k_1)} \\
\bar{p}_r &= \frac{(1 - l_1) [x + h (c_m - c_l - \bar{c}_m - \bar{c}_r)] - x}{4h (2 - l_1)} - \frac{x}{h}
\end{align*}
\]

Substituting (22), (23) into \( Q = d - bp \) and \( \bar{Q} = d - b\bar{p}_r \), the optimal order quantity and recycling quantity of the retailer are as the following, respectively.

\[
Q = \frac{(1 - k_1) [d - b (c_l + c_m + c_r)]}{(2 - k_1)}
\]
In order to ensure that the above results are of practical significance, they should all be positive values. If (16), (17) are positive, then (18)-(22) and (24), (25) are positive, that is,

\[ d - b(c_l + c_m + c_r) > 0 \]  
\[ x + h(c_m - c_l - \bar{c}_m - \bar{c}_r) > 0 \]

Formulas (26) and (27) indicate when the product is sold at the system cost price, the sale quantity is positive, and the recycling quantity is positive when the system is recovered at zero profit.

In order to ensure that (23) is positive, the proportion of the reverse logistics cost undertaken by the manufacturer should be satisfied.

\[ l_1 < \frac{h(c_m - c_l - \bar{c}_m - \bar{c}_r) - 7x}{h(c_m - c_l - \bar{c}_m - \bar{c}_r) - 3x}, \text{ and } l_1 \leq 1 \]  

**4.5. Model analysis.** Formulas (18)-(25) show that the market size \( d \), the consumers' sensitivity to sales price \( b \) and the proportion of the forward logistics cost undertaken by the manufacturer \( k_1 \) only affect the forward logistics decisions, while the consumers' environmental awareness \( x \) and the proportion of the reverse logistics cost undertaken by the manufacturer \( l_1 \), the consumers' sensitivity to recycling price \( h \) only affect the reverse logistics decisions. Therefore, this section analyzes the impact of \( d, b, k_1 \), and \( x, l_1, h \) on the forward logistics decisions and reverse logistics decisions respectively.

**4.5.1. Forward logistics decision analysis**

**Proposition 3.** With the expansion of the market size, the sales price, the wholesale price, the forward logistics service price and the order quantity increase accordingly.

The first derivative of (18), (20), (22) and (24) for \( d \) can be obtained by simplifying the formulas:

\[ \frac{\partial p_l}{\partial d} = \frac{1}{4b(2 - k_1)} > 0, \quad \frac{\partial w}{\partial d} = \frac{1}{2b(2 - k_1)} > 0, \]
\[ \frac{\partial p_r}{\partial d} = \frac{7 - 3k_1}{4b(2 - k_1)} > 0, \quad \frac{\partial Q}{\partial d} = \frac{1 - k_1}{4(2 - k_1)} > 0 \]

Proposition 3 shows that the expansion of the market size has a positive impact on all forward logistics decisions of the products. The expansion of the market scale prompts an increase on the demand for the products and therefore the order quantity of the retailer increases. The increase of the demand also gives the retailer a chance to raise prices, that is, they can increase the price without reducing the demand. The increase of the demand quantity and the sales price also increases the wholesale price and the forward logistics service price.

**Proposition 4** With the increase of consumers’ sensitivity to sales price, the sales price, the wholesale price, the forward logistics service price and the order quantity decrease accordingly.
The first derivative of (18), (20), (22) and (24) for can be obtained by simplifying the formulas:

\[
\frac{\partial p_l}{\partial b} = \frac{-d}{4b^2 (2 - k_1)} < 0, \quad \frac{\partial v}{\partial b} = \frac{-d}{2b^2 (2 - k_1)} < 0,
\]

\[
\frac{\partial p_r}{\partial b} = \frac{-(7 - 3k_1)d}{4b^2 (2 - k_1)} < 0, \quad \frac{\partial Q}{\partial b} = \frac{-(1 - k_1)(c_r + c_m + c_1)}{4(2 - k_1)} < 0
\]

Proposition 4 shows that the consumers’ sensitivity to sales prices has a negative impact on forward logistics decisions. The higher the consumer’s sensitivity to sales price, the more the sales price decreases with each additional unit of demand. This happens because in an attempt to maintain high demand, the retailer reduces the sales price but still cannot offset the decrease of the order quantity caused by the increase in consumers’ sensitivity to product price, therefore the order quantity decreases accordingly. In addition, the reduction of the order quantity and the sales price sees the 3PL provider and the manufacturer reducing their forward logistics service price, and the wholesale price, respectively in order to maximize their own profits.

**Proposition 5.** With the increase of the proportion of the forward logistics cost assumed by the manufacturer, the sales price, the wholesale price and the forward logistics service price increases while the order quantity decreases.

**Proof.** The first derivative of (18), (20), (22) and (24) for can be obtained by simplifying the formulas:

\[
\frac{\partial p_l}{\partial k_1} = \frac{d - b(c_r + c_m + c_1)}{4b(2 - k_1)^2} > 0, \quad \frac{\partial w}{\partial k_1} = \frac{d - b(c_r + c_m + c_1)}{2b(2 - k_1)^2} > 0,
\]

\[
\frac{\partial p_r}{\partial k_1} = \frac{d - b(c_r + c_m + c_1)}{4b(2 - k_1)^2} > 0, \quad \frac{\partial Q}{\partial k_1} = \frac{-(d - b(c_r + c_m + c_1))}{4b(2 - k_1)^2} < 0
\]

Proposition 5 shows that the increase of the proportion of the forward logistics cost assumed by the manufacturer makes all members raise their prices in the forward supply chain. The increase of the price will reduce the order quantity of the retailer. This happens because the manufacturer increases the wholesale price to compensate for the cost increase brought about by the increase of the proportion of the forward logistics cost. The increase of the wholesale price makes the sales price increase and the order quantity decrease, while the decrease of the order quantity reduces the profit of the 3PL provider, therefore the 3PL provider increases its forward logistics service price to maximize its profits.

4.5.2. Reverse logistics decision analysis

**Proposition 6.** With the enhancement of consumers’ environmental awareness, the recycling price and transfer price decrease. On the other hand, the reverse logistics service price and the recycling quantity increases.

**Proof.** The first derivative of (19), (21), (23) and (25) for can be obtained by simplifying the formulas:

\[
\frac{\partial \bar{p}_l}{\partial x} = \frac{1}{4h(2 - k_1)} > 0, \quad \frac{\partial \bar{w}}{\partial x} = \frac{-1}{2h(2 - k_1)} < 0,
\]

\[
\frac{\partial \bar{p}_r}{\partial x} = \frac{-(7 - 3k_1)}{4h(2 - l_1)} < 0, \quad \frac{\partial \bar{Q}}{\partial x} = \frac{1 - l_1}{4(2 - l_1)} > 0
\]
Proposition 6 shows that the higher the consumers’ environmental awareness, the lower the recycling price and the transfer price, and the higher the reverse logistics service price. Furthermore, the recycling quantity increases with higher consumer environmental awareness. This happens because the enhancement of consumers’ environmental awareness has increased the quantity of used products voluntarily returned by consumers free of charge. The retailer does not need to pay for these products, therefore, the quantity of used products that the retailer needs to pay for is relatively small. In order to maximize its profits, the retailer will decrease the recycling price, the decrease of the recycling price reduces the quantity of the recovery product in the market, but the enhancement in consumers’ environmental awareness leads to the final increase in the recycling quantity. The lower recycling price makes the manufacturer’s transfer price decrease. For the 3PL provider, the increase of the recycling quantity provides the opportunity to raise the price, so the reverse logistics service price increases accordingly.

**Proposition 7.** With the increase of consumers’ sensitivity to recycling price, the recycling price, the transfer price and the recycling quantity increases, and the reverse logistics service price decreases.

**Proof.** The first derivative of (19), (21), (23) and (25) for can be obtained by simplifying the formulas:

\[
\frac{\partial \bar{p}_l}{\partial h} = \frac{-x}{4h^2 (2 - k_1)} < 0, \quad \frac{\partial \bar{w}}{\partial h} = \frac{x}{2h^2 (2 - k_1)} > 0, \quad \frac{\partial \bar{p}_r}{\partial h} = \frac{x (7 - 3l_1)}{4h (2 - l_1)} > 0, \quad \frac{\partial \bar{Q}}{\partial h} = \frac{(1 - l_1) (c_m - c_l - \bar{c}_r - \bar{c}_m)}{4 (2 - l_1)} > 0
\]

Proposition 7 shows that the higher the sensitivity of consumers to recycling price, the higher the recycling price and the transfer price will be, the more the recycling quantity, and the lower the reverse logistics service price. This is because the increase of the consumer’s sensitivity to recycling price means that the more consumers return used products, each unit’s recycling price increased. Therefore, in order to maximize profits, the retailer increases the recycling price. The increase of the recycling price and the consumer’s sensitivity to recycling price in turn increases the order quantity, and the increase of the recycling price also makes the transfer price of the manufacturer increase, but the increase of the order quantity gives the opportunity of the 3PL provider to reduce the price. In order to maximize its profit, the 3PL provider reduces the reverse logistics service price.

**Proposition 8.** With the increase of the proportion of the reverse logistics cost undertaken by the manufacturer, the recycling price, the transfer price, and the recycling quantity decrease, while the reverse logistics service price increases.

**Proof.** The first derivative of (19), (21), (23) and (25) for can be obtained by simplifying the formulas:

\[
\frac{\partial \bar{p}_l}{\partial l_1} = \frac{(x + h (c_m - c_l - \bar{c}_r - \bar{c}_m))}{4h (2 - l_1)^2} > 0, \quad \frac{\partial \bar{w}}{\partial l_1} = -\frac{c_l - (x + h (c_m - c_l - \bar{c}_r - \bar{c}_m))}{2h (2 - l_1)^2} < 0, \\
\frac{\partial \bar{p}_r}{\partial l_1} = -\frac{(x + h (c_m - c_l - \bar{c}_r - \bar{c}_m))}{4h (2 - l_1)^2} < 0, \quad \frac{\partial \bar{Q}}{\partial l_1} = \frac{-(x + h (c_m - c_l - \bar{c}_r - \bar{c}_m))}{4 (2 - l_1)^2} < 0
\]

Proposition 8 shows that the higher the proportion of the reverse logistics cost undertaken by the manufacturer, the higher the recycling price, the transfer price,
and the recycling quantity. On the other hand, in this scenario the reverse logistics service price is lowered. This is because the increase in the proportion of the reverse logistics cost undertaken by the manufacturer reduces the retailer’s recovery costs. In response, the retailer reduces its own recycling prices, the recycling quantity decreases, and the reduction of the recycling price reduces the transfer price. Ultimately, the reduction of the recycling quantity reduces the profits of the 3PL provider and in order to maximize its own profits, the 3PL provider raises its logistics service price.

5. **Numerical analysis.** From the above results and analysis, we demonstrate that $d$, $b$ and $k_1$ only affect the forward logistics decisions and profits, while $x$, $h$ and only $l_1$ affect the reverse logistics decisions and profits. In order to examine the effect of these parameters on the forward and reverse logistics decisions, we proceed as follows. The cost parameters are given by $c_m = 20$, $c_m = 2$, $c = 2$, $c_r = 1$, $c_r = 4$, the demand parameters are given by $h = 5$, $b = 1$, $x = 6$, $d = 200$, the cost share parameters are given by $k_1 = l_1 = 0.5$, $\pi^f$, $\pi^r$ and $\pi^m$ denote the forward logistics profits of the 3PL provider, the retailer and the manufacturer respectively, $\pi^y_l$, $\pi^y_r$ and $\pi^y_m$ denote the reverse logistics profits of the 3PL provider, the retailer and the manufacturer respectively. Tables 1 and 2 showcase the optimal decisions and profits for supply chain members under the three-echelon closed-loop supply chain dominated by the retailer involving the 3PL provider system.

| $P_l$  | $w$  | $P_r$  | $Q$  | $\bar{p}_l$  | $\bar{w}$  | $\bar{p}_r$  | $Q$  |
|--------|------|--------|------|---------------|-------------|-------------|------|
| 31.00  | 79.00 | 185.45 | 14.50 | 4.60          | 11.80       | 0.70        | 13.00|

| $\pi^f$ | $\pi^r$ | $\pi^m$ | $\pi^y_l$ | $\pi^y_r$ | $\pi^y_m$ |
|----------|----------|----------|------------|------------|------------|
| 420.50   | 1261.50  | 630.75   | 33.80      | 101.40     | 50.70      |

5.1. **Sensitivity analysis of market size.** According to (26), we know that if the market size is in the range $[200, 250]$, $d - b(c_l + c_m + c_r) \geq \min[d - b(c_l + c_m + c_r)] = 174 > 0$ is satisfied, as shown in Figure 2a and Figure 2b. Figure 2a demonstrates that with the market size expansion, so do the sales price, the wholesale price and the forward logistics service price increase. Figure 2b indicates that the order quantity also increases the expansion of the market size. The findings presented in these figures are consistent with proposition 3. Figure 2c shows that the expansion of the market size increases the profits of supply chain members.

The profits of the supply chain members are increased because initially the increase of the market size augments the forward logistics service price. The increase of demand due to the growth in market size increases the order quantity, which increases the profit of the 3PL provider. For manufacturers, although the increase of the forward logistics service price enhances the cost of the 3PL provider, the marginal sales profit of the manufacturer increases. Therefore, the final profit of the manufacturer increases with the increase of the order quantity. Manufacturer profit ultimately is higher due to the fact that the increase of the wholesale price...
is greater than that of the forward logistics service price. The cost increase of the retailer, caused by the surging of the forward logistics service price and the wholesale price, is less than that of its sales price. As a result, the retailer’s marginal sales profit increases, in addition, the order quantity enhances, so the retailer’s final profit grows. From figure 2a, the increase of the wholesale price is smaller than that of the sales price, but larger than that of the forward logistics service price. Figure 2c shows that the increase of the manufacturer’s profit is smaller than that of the retailer, but larger than that of the 3PL provider.

**Figure 2.** The effect of market size on decisions and profits

**Note.** FLP, WP and SP are short for the forward logistics service price, the wholesale price and the sales price respectively. RPs, MPs and 3PLPs are short for the retailer’s profits, the manufacturer’s profits and the 3PL provider’s profits respectively. In Figure 3 and Figure 4, the meaning of the letters is the same as Figure 2.

5.2. **Sensitivity analysis of consumers to sales price.** According to (26), we know that if the sensitivity coefficient of consumers to sales price is in the range $[1, 5]$, $d - b(c_l + c_m + c_r) \geq \min[d - b(c_l + c_m + c_r)] = 174 > 0$ is satisfied, as shown in Figure 3a and Figure 3b. Figure 3a indicates that, with the increase of the sensitivity coefficient of consumers to the sales price, the sales price, the wholesale price and the forward logistics service price decrease accordingly. Figure 3b indicates the order quantity decrease with the increase of the sensitivity coefficient of consumers
to the sales price. In Figure 3c, the increase of consumer’s sensitivity to sales price reduces the profit of the supply chain members. This is because the decrease of the forward logistics service price and order quantity reduces the profit of the 3PL provider. For the manufacturer, although the reduction of the forward logistics service price reduces its cost, the marginal sales profit of the manufacturer decreases because the reduction of the wholesale price is greater than that of the forward logistics service price, in addition, the order quantity decreases, the final profit of the manufacturer decreases. For the retailer, its marginal sales profit decreases because the cost reduction caused by the decrease of the forward logistics service price and the wholesale price is less than that of the sales price. In addition, the order quantity decreases, the final profit of the retailer decreases. Figure 3c shows that the reduction of the manufacturer’s profits is smaller than that of the retailer’s profits, but compared with the profits of the 3PL provider, the decrease of the manufacturer’s profits is greater.

Figure 3. The effect of consumers’ sensitivity to sales prices on decisions and profits

5.3. Sensitivity analysis of proportion of forward logistics cost undertaken by manufacturers. Figure 4a indicates that with the increase of the proportion of the forward logistics cost assumed by the manufacturers, the sales price, the wholesale price and the forward logistics service price also increase. Figure 4b shows that the order quantity decreases with the increase of the proportion. Figure
4c shows that an increase in the proportion of the forward logistics cost assumed by the manufacturers also reduces the profits of supply chain members. This is because for the 3PL provider, the profits brought by the increase of the forward logistics service price cannot compensate for the profit loss caused by the decrease of the order quantity. Therefore, the net profit of the 3PL provider decreases. For the manufacturers, the increase of the forward logistics service price augments their cost, the manufacturer’s marginal sales profit rises because the increase of the wholesale price is greater than that of the forward logistics service price (as can be seen from the proof process of proposition 5). However, the increase of the marginal sales profit cannot compensate for the profit loss caused by the reduction of the order quantity, so the manufacturer’s final profit decreases. For the retailer, the increase of the cost coursed by the forward logistics service price and the wholesale price is more than that of the profit brought by the higher sales price, so the marginal sales profit of the retailer decreases. In addition, the order quantity decreases, so the net profit of the retailer decreases.

Per Figure 4a, the growing proportion of the forward logistics cost undertaken by the manufacturer see a rapid increase of the wholesale price is increasing. That is, with each extra unit of the proportion of the forward logistics cost assumed by the manufacturer, the wholesale price increases. The augmenting of the sales price and the forward logistics service price are always the same, and both are smaller than that of the wholesale price. Figure 4c also shows that with the increase of the proportion of the forward logistics cost assumed by the manufacturer, the reduction rate of the manufacturer’s profits is less than that of the retailer, but greater than that of the 3PL provider. Moreover, the profit reduction of the manufacturer is smaller than that of the retailer, but larger than that of the 3PL provider.

5.4. Sensitivity analysis of consumers’ environmental awareness. Formula (27) shows that if consumers’ environmental awareness is in the range $[6, 10]$, $x + h(c_m - c_l + \bar{c}_m - \bar{c}_r) \geq \min[x + h(c_m - c_l + \bar{c}_m - \bar{c}_r)] = 81 > 0$ is satisfied. As shown in Figure 5a, with the increase of consumers’ environmental awareness, the recycling price and the transfer price decrease, while the reverse logistics service price increases. Figure 5b reveals that recycling quantity increases with the expansion of consumers’ environmental awareness. Figure 5c shows that the enhancement of consumers’ environmental awareness makes supply chain members’ reverse profits increase. This is because the increase of the reverse logistics service price and the recycling quantity makes the reverse profit of the 3PL provider grow. For the retailer, the marginal profit brought by the reduction of the reverse logistics service price compensates for the marginal profit loss caused by the increase of the reverse logistics service price and the decrease of the transfer price. The marginal profit increases with the growth of the order quantity, so the final profit of the retailer augments. For the manufacturer, the marginal profit brought by the reduction of the transfer price make up for the marginal profit losses caused by the increase of the reverse logistics service price. Therefore, the marginal profit and the reverse profit of the manufacturer increase with size of the recycled quantity. Figure 5a also shows that with the change of consumers’ environmental awareness, the change rate of the transfer price is smaller than that of the recycling price, but larger than that of the reverse logistics service price. Figure 5c visually represents that with the enhancement of consumers’ environmental awareness, the retailer’s profits increase the most, followed by the manufacturer, and finally by the 3PL provider.
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Figure 4. The effect of the proportion of forward logistics cost assumed by manufacturers on decisions and profits

Note that. RLP, TP, and RP are short for the reverse logistics service price, the transfer price, and the recycling price, respectively. RPs, MPs, and 3PLPs are short for the retailer’s profits, the manufacturer’s profits and the 3PL provider’s profits, respectively. The same abbreviations are used in Figures 6 and 7.

5.5. Sensitivity analysis of consumers to recycling price. Formula (27) shows that when the consumer’s sensitivity to recycling price is in the range of \([10, 15]\), \(x + h(\bar{c}_m - c_f + \bar{c}_m - \bar{c}_r) \geq \min[x + h(\bar{c}_m - \alpha + \bar{c}_m - \bar{c}_r)] = 156 > 0\) is satisfied. As shown in Figure 6a, the increase of the consumer’s sensitivity to recycling price, prompts recycling price and the transfer price to rise, and the reverse logistics service price to decrease. Figure 6b indicates that the recycling quantity increases with heightened sensitivity. Figure 6c shows that the increase of consumer’s sensitivity to recycling price augments supply chain members’ profits. This is because the profit brought by the increase of the recycling quantity compensates for the profit loss caused by the decrease of the reverse logistics service price, so the profit of the 3PL provider grows. For the retailer, according to the proof process of proposition 7, we know that the marginal profit brought by the increase of the transfer price and the decrease of the reverse logistics service price compensates for the marginal profit loss caused by a higher recycling price. Therefore, the marginal profit of the retailer increases. In addition, the order quantity increases, meaning that the final profit
Figure 5. The effect of consumers’ environmental awareness on decisions and profits.

of the retailer also rises. For the manufacturer, the marginal profit brought by the decrease of the reverse logistics service price cannot compensate for the marginal profit loss caused by the increase of the transfer price. Therefore, the marginal profit of the manufacturer decreases, but the profit brought by expanding the recycled quantity compensates for the profit loss caused by the marginal profit loss, so the final profit of the manufacturer increases. Figure 6a also indicates that with the increase of the consumers’ sensitivity to recycling price, the change range of the transfer price is smaller than that of the recycling price, but larger than that of the reverse logistics service price. This is consistent with the proof process of proposition 7. Figure 6c shows that the increase of the retailer’s profit with the expansions of the consumers’ sensitivity to recycling price is the largest, followed by the manufacturer, and finally by the 3PL provider.

Formula (28) shows that when the proportion of the reverse logistics cost assumed by the manufacturer is in the range $[0, 0.8]$, $l_1 < \frac{h(c_m - c_l + \bar{c}_m - \bar{c}_r) - \bar{c}_r}{h(c_m - c_l + \bar{c}_m - \bar{c}_r) - \bar{c}_r} = \frac{9}{11} \approx 0.82 < 1$ is satisfied. As shown in Figure 7a, with the increase of the proportion of the reverse logistics cost assumed by the manufacturer, the recycling price and the transfer price decrease, and the reverse logistics service price increases. Figure 7b indicates that the recycling quantity decrease with the increase of the proportion. Figure 7c shows that the increase in the proportion reduces supply chain members’ profits. This is because the profit brought by the increase of the reverse logistics service price for the 3PL provider cannot compensate for the profit loss brought by the reduction
of the recycling quantity, so the profit of the 3PL provider is reduced. For the retailer, according to the proof process of proposition 8, the marginal profit brought by the reduction of the recycling price cannot compensate for the marginal profit loss caused by the reduction of the transfer price and the increase of the reverse logistics service price. Therefore, the marginal profit decreases with the reduction of the order quantity, and the final profit of the retailer in turn lessens. For the manufacturer, although the marginal profit brought by the reduction of the transfer price compensates for the marginal profit loss caused by the increase of the reverse logistics service price, the profit brought by the augmenting of marginal profit cannot compensate for the profit loss caused by the increase of the recycling quantity, so the final profit of the manufacturer falls. Figure 7a also shows that with the increase of the proportion of the reverse logistics cost undertaken by the manufacturer, the change range of the transfer price is smaller than that of the recycling price, but larger than that of the reverse logistics service price. This finding is consistent with the proof process of proposition 8. Figure 7c shows that with the increase of the proportion of the reverse logistics cost undertaken by the manufacturer, the profit of the retailer declines the most, followed by the manufacturer, and finally by the 3PL provider.

6. Conclusions. In this paper, a 3PL provider is introduced into a retailer-led closed-loop supply chain decision-making model. Through game theory, we obtain
the optimal pricing strategies of the supply chain members and the optimal purchasing and recycling strategies of the retailer. Additionally, we analyze the effects of market size, consumers’ sensitivity to sales prices, and the proportion of the forward logistics cost assumed by the manufacturer on the decision-making and the profit of the forward supply chain members. Finally, we discuss the effect of consumers’ environmental awareness, consumer sensitivity to recycling prices, the proportion of the reverse logistics cost assumed by the manufacturer on the decision-making and the profits of the reverse supply chain members.

Our results show that an expansion in market size increases the profits of all members in the closed-loop supply chain. Similarly, enhancements in consumers’ environmental awareness optimize the performance of all supply chain members. Consumers’ sensitivity to sales prices and recycling prices has differential effects on the performance of the supply chain members. That is, when consumers’ sensitivity to sales prices increases, the performance of the supply chain members will decrease. In contrast, when consumers’ sensitivity to recycling prices increases, the performance of the supply chain members decreases. Whether it is the reverse logistics or the forward logistics, the higher the proportion of logistics costs assumed by the manufacturer, the lower the profits of the supply chain members. The retailer’s profits increase the most among all supply chain members due to its dominant position.
With the continued expansion of a consumer society, the dominance of retail enterprises such as Wal Mart (America), Gome (China), Jingdong (China) in the supply chain is being consolidated. In addition, the refinement of social division makes the professional third-party logistics enterprises develop rapidly. In China, logistics outsourcing is becoming more popular with increased consumption consciousness. At present, Gome (China) and Jingdong (China) have launched many initiatives to promote the recycling of waste products, as their own logistics services are outsourced to professional third party logistics enterprises. In response to the government’s call to protect the environment, besides Gome (China) and Jingdong (China), many other large retail enterprises also recycle their products. This study provides decision-making suggestions for the closed-loop supply chain enterprises with logistics outsourcing led by retailers. Our research results also provide the basis for these enterprises to cope with market changes and predict market trends. For example, in the closed-loop supply chain of logistics outsourcing led by retailers, which factors are related to enterprise decision-making and how do such enterprises make decisions? What is the impact of sales price and recycling price on logistics price? How does logistics costs affect the decision-making of manufacturers and retailers? How do manufacturers and retailers allocate logistics costs to improve corporate profits? When market size, consumers’ environmental awareness, and consumers’ sensitivity to product price and recovery price change, enterprises should change their decision-making to adapt to such changes. In order to adapt, how do they adjust their decision-making, and what is the impact of changes in market parameters on enterprise profits? All these questions can be found in this paper.

Although we contribute new findings, there are several possible extensions to our research. First, we draw the conclusions presented in this paper based on assumed information symmetry, while in reality, the majority of the information in a given supply chain is private. The question whether asymmetric information would affect the decisions of the members in a retailer-led closed-loop supply chain with logistics outsourcing thus calls for further investigations. Secondly, this paper does not analyze the effects of possible coordination among the supply chain members. Coordination in a closed-loop supply chain is an important topic, therefore in future research, it may be worthwhile to explore coordination mechanisms that consider the 3PL provider’s role. Finally, we assume that all supply chain members are risk-neutral. Future work may expand on our findings by incorporating the risk attitudes of decision-makers in the model.

**Data availability.** The data used to support the findings of this study are available from the corresponding author upon request.

**Conflicts of interest.** The authors declare that there are no conflicts of interest regarding the publication of this paper.

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