INVESTIGATING A GREEN SUPPLY CHAIN WITH PRODUCT RECYCLING UNDER RETAILER’S FAIRNESS BEHAVIOR

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Abstract. Due to the rapid increment of environmental pollution and advancement of society, recently many manufacturing firms have started greening their products and focusing on product remanufacturing. The retailing firms are also taking several efforts for marketing those products and thinking more about the fairness of the business. Keeping this in mind, this study investigates the effect of recycling activity and the retailer’s fairness behavior on pricing, green improvement, and marketing effort in a closed-loop green supply chain. In the forward channel, the manufacturer sells the green product through the retailer while in the reverse channel, either the manufacturer or the retailer or an independent third-party collects used products. The centralized model and six decentralized models are developed depending on the retailer’s fairness behavior and/or product recycling. The optimal results are derived and compared analytically. The analytical results are verified by exemplifying a numerical example. A restitution-based wholesale price contract is developed to resolve the channel conflicts and coordinate the supply chain. Our results reveal that (i) the manufacturer never selects the third-party as a collector of used products under fair-neutral retailer, (ii) the fairness behavior of the retailer improves her profitability but it diminishes the manufacturer’s profit, and (iii) if the manufacturer does not pay much transfer price, then the collection through the third-party is preferable to the fair-minded retailer.

1. Introduction. In recent years, rising environmental pollution, government legislations, changes in consumers’ purchasing and returning practices, and a competitive business environment are compelling more and more manufacturers to employ in product remanufacturing. Remanufacturing is a large-scale industrial process of collecting used products and reusing them to generate extra qualities (Huang et al. [17]). It not only lessens environmental pollution but also improves the profit of the manufacturer by lowering the utilization of fresh raw materials and saving the production cost. Cost-saving goals may vary from industry to industry. For example, Volkswagen saves 70% from the reuse of used car engines and parts; Xerox saves 40-65% by reusing parts of returned products; Kodak saves 40-60% by using parts of returned cameras, etc. (Genc and De Giovanni [10]). Now, one question may arise - who should collect used products from customers? Generally, manufacturers

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1For the rest of the paper, the manufacturer will be treated as ‘he’ and the retailer as ‘she’.
directly collect used products. For instance, Xerox, HP, etc., perform the used product collection activities by themselves (Mondal and Giri [31]). Guide [13] suggested that 82% of manufacturers prefer to collect used products directly from customers. But retailers have a close relationship with customers and third-parties are specialists in collecting used products. So, the impact of collection through retailers or third-parties cannot be avoided. For instance, Kodak contracts with retailers while Dell and Acer contract with third-parties for collecting used products (Savaskan et al. [38]). Therefore, how to design a suitable reverse channel for collecting used products and mutual agreement or contract between channel individuals are crucial decisions in the closed-loop supply chain (CLSC).

Besides product remanufacturing, green innovation is another important area of research in supply chain management. As social and environmental problems such as global warming, earthquake, the rise of sea level, ozone layer hole, desert storm, untimely rain, etc. are increasing day by day, the governments of developed countries are executing many rules and regulations to reduce greenhouse gas (GHG) emissions. Further government pressure and growing consumers’ environmental awareness have forced many manufacturers to engage in green innovation. A 2014 Nielsen Global Corporate Social Responsibility Survey exhibits that more than 50% of customers prefer environment-friendly products while purchasing, and they are willing to pay more for these products. According to the report of the Solar Energy Industries Association (SEIA), many top US companies (Target Corporation, Wal-Mart, Prologis, Apple, etc.) have enhanced their solar usage by 240%\(^2\). To reduce the environmental impact, Dell and HP have promoted the safe disposal of their products. Further, they are committed to use renewable energy sources and follow zero-waste manufacturing technologies (Chen and Akmalul’Ulya [4]). Xerox reduced 20% energy consumption and 28% emissions by 2016 from a baseline of 2012. It has targeted to reduce GHG emissions and energy consumption 25% by 2025 from the 2016 baseline\(^3\). Canon and Kodak have also made several initiatives to reduce emissions and conserve energy. Coca-Cola has partnered with third-party recyclers to reduce carbon footprint (Giri et al. [12]). The leading automakers Ford, BMW, Honda and Volkswagen have reached a voluntary agreement with the state of California and agreed to improve the average efficiency of their fleet by 3.7% per year starting from the 2022 model year (Shama [39]). Besides manufacturers, retailers should also exert effort while selling their products. To attract customers, some retailers such as Tesco, Casino and Patagonia have begun to attach the carbon footprint label with the products, which helps the customers to follow every step of the manufacturing process. Some retailers pay attention in promotional advertisements, in-store and out-store banners (Jian et al. [18]) while some retailers focus on time-sensitivity of consumers (Zhang et al. [53]). Thus, the CLSC needs to study the effect of the manufacturer’s green innovation efforts and the retailer’s marketing efforts.

In recent years, researchers and academicians have focused on the effect of behavioral factors in many cases. In order to substantiate the research in terms of reality, this study assumes that the retailer is concerned about the fairness of the business. In CLSC, the manufacturers are the key members of the supply chain, and they are mainly responsible for product remanufacturing and product greening activities. Sometimes the strong position of the manufacturers in the business may

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\(^2\)[https://www.business.com/articles/rise-of-green-business-innovation.]
\(^3\)[https://www.xerox.com/en-in/about/ehs/carbon-footprint-reduction.]
constrain them to make decisions that are favorable to themselves. For instance, the manufacturers may intentionally increase the wholesale price of the product, forcing retailers to think that there is something inappropriate treatment with the business (Zhou et al. [58]). This behavior can reduce the retailer’s motivation for exerting effort in marketing those green and remanufactured products. Consequently, the collection rate of used products may decrease. On the other hand, some retailers are as greedy as demanding more profits than manufacturers, which may be considered as another sort of fairness concern (Du et al. [7]). Furthermore, this notion of injustice not only hinders the raise of profits from product remanufacturing and product greening but also deranges sustainable cooperation among CLSC members (Zheng et al. [56]). If the manufacturer does not take care of the retailer’s fairness concern and rearrange his strategy, it will adversely affect the manufacturer’s long-term development. At the same time, it hurts their businesses by weakening mutual relationships. For instance, China’s largest sock manufacturer Langsha Group terminated its partnership with Wal-Mart in 2007 due to unfair allocation of benefits. In 2010, a similar situation was noticed between Xuzhou Wanjiz Trading of China and P&G (Nie and Du [34]). Unfairness between Gree Inc., a specialized air-conditioner manufacturer in China and Gome, a household appliance retailer in China also affected their businesses (Liu et al. [21], Zheng et al. [57]). So, it is important to explore the effect of the retailer’s fairness concern in the supply chain.

Inspired by the above issues, this article considers a two-tier supply chain, where the manufacturer puts effort into product greening and the retailer exerts effort into marketing those products, under product recycling and retailer’s fairness concern. Depending on the retailer’s fairness behavior, two decentralized models are developed, each of which is again subdivided into three models under consideration of different options of used product collection. The centralized model is presented as a benchmark case. Finally, a restitution-based wholesale price contract is proposed for channel coordination. The main goal of this article is to find the answer to the following research questions:

- What will be the optimal pricing, greening level, and marketing effort of different models under consideration?
- Which is the best reverse channel from the manufacturer, the retailer, and the customers’ perspective?
- What are the effects of the retailer’s fairness concern on the optimal decisions and profitability of the channel members?
- Is the proposed contract able to coordinate the supply chain perfectly?

While responding to the above inquiries and trying to provide some managerial insights, this study creates the proposed green CLSC models. The novelty of the current study is summarized as follows. Firstly, this study considers a CLSC in which the manufacturer thinks about its economic goal as well as environmental goal by taking care of unit emission reduction during production through green innovation and the retailer thinks about its marketing effort while selling those products. Secondly, it considers several options for collecting used products viz. collection through the manufacturer, collection through the retailer and collection through the third-party, and investigates which collection options are beneficial for the channel individuals, consumers and environment. Thirdly, most of the previous literatures on product remanufacturing assumed that all the remanufactured products become like-new. But in reality, it is not always possible to convert all the used products into a like-new state. Thus, this study considers a fraction of
remanufactured products become like-new and are sold in the primary market with the new one while the remaining fraction of remanufactured products is sold in the secondary market at a comparatively lower price. Fourthly, how retailer’s fairness concern affects the product recycling activities and other decisions are also investigated. Finally, a restitution-based wholesale price contract is developed for achieving better performance and providing a win-win situation to the channel individuals under the retailer’s fairness concern. Apparently, none of the past studies explored various collection options of used products under retailer’s fairness concern and channel coordination issue cooperatively in a closed-loop green supply chain.

The rest of the article is arranged as follows: The related literatures are summarized and reviewed in the next section. Section 3 describes the problem under consideration and presents the required notations and assumptions for developing the proposed models. The mathematical models are developed and optimal results are derived in Section 4. In Section 5, the optimal results are compared analytically and a restitution-based wholesale price contract is established. Numerical experiment and sensitivity analyses are conducted in Section 6. Section 7 concludes the article with some meaningful managerial insights and further research aspects.

2. Literature review. In this section, we review the most relevant literature across four research streams - different collection modes in CLSC, supply chain model considering fairness concern, CLSC models considering both product recycling and fairness concern, and strategies in green supply chain (GSC) and channel coordination.

2.1. Different collection modes in CLSC. Due to the rapid depletion of conventional energy sources, product remanufacturing has become an important issue for both policymakers and researchers. There is a huge literature on product remanufacturing in CLSC. Savaskan et al. [38] developed three decentralized models considering different collectors of used products, namely, manufacturer, retailer and third-party. They showed that collection through the retailer gives the best channel performance. Maiti and Giri [27] presented five models viz. centralized, Nash game, and three Stackelberg games ruled by manufacturer, retailer, and third-party with the third-party as a collector of used products. They found that the decentralized policy ruled by the retailer is more receivable. Hong et al. [15] investigated the effect of advertising investment on used product collection (namely, M-collection, R-collection, TPL-collection). They revealed that the R-collection model is the most effective one. Liu et al. [20] analyzed the pricing and the best reverse channel choice issue in a CLSC consisting of a manufacturer (OEM), a retailer, and a third-party with different collection channels viz. OEM and retailer, retailer and third-party, and OEM and third-party. They suggested that the OEM and retailer collection model is the best option for the OEM. Based on single forward dual recycling model (SD model) and dual forward dual recycling model (DD model), Taleizadeh et al. [42] explored pricing strategies, product quality, sales, and collection effort decisions in a CLSC. They found that the DD model is the best for the manufacturer while the retailer’s optimal decisions depend on the market share. Under the Stackelberg game setting, Modak et al. [30] analyzed a two-echelon CLSC for pricing, product quality, and recycling management under consideration of three possible collection options of used products viz. third-party led collection, retailer led collection and manufacturer led collection. They revealed that the collection through the third-party is always incommodeous. Chen et al. [5] investigated the impacts of
marketing activities and product quality improvement in CLSC under remanufacturing through formulating one centralized and three decentralized models based on collection options of used products. Using social work donation as corporate social responsibility (CSR) practice, Modak et al. [29] developed three decentralized models viz. Model-M, Model-R, and Model-T and showed that the manufacturer prefers the collection of used products through the retailer. To deal with consumers’ environmental awareness and government regulations, Chen and Akmalul’Ulya [4] studied the effect of reward-penalty mechanism considering the centralized model (Model-C) and three decentralized models (Model-M, Model-R, and Model-3P) depending on different collection options of used products. They suggested that the reward-penalty mechanism helps in improving the greening effort and return rate of used products. To get more advantage of product remanufacturing, Liu et al. [22] focused on the product-design strategies in a two-tier CLSC and found that adjustment of these strategies has a great impact on product remanufacturing and profitability of the channel members. Mondal and Giri [31] considered a two-period CLSC model to investigate the pricing and used products collection strategies viz. the manufacturer collects used products, the retailer collects used products, and both the manufacturer and the retailer collect used products under selling price, greening level, and marketing effort dependent demand. Their results revealed that the inclusion of greening level and marketing effort can promote the performance of the supply chain. Ranjbar et al. [37] studied the effect of dual recycling (through retailer and third-party) on pricing and collecting decisions in a three-level CLSC under different channel powers. They showed that the retailer-led decentralized model is the most efficient CLSC model. In a dual-channel CLSC, Zhang et al. [51] investigated different government policies by using dynamic game theory. They obtained that although different government policies can reduce carbon emission and enhance social welfare, they hurt retailers and consumers. In a capital-constraint CLSC, Zhang et al. [54] aimed to focus on financing strategies and operational decisions and found that whether the manufacturer engages in partial remanufacturing or full remanufacturing depends on initial working capital and financing cost. Zhang et al. [50] explored the pricing and remanufacturing mode in a waste electrical and electronic equipment (WEEE) CLSC where the manufacturer may remanufacture used products himself or he can outsource it to the retailer. They revealed that which remanufacturing mode provides better outcome depends on government fund policy. Liu et al. [23] introduced dual regulation characterized by minimal collection rate of used products and deposit-refund policy in a two-level CLSC comprising of a brand owner and an original equipment manufacturer (OEM), and investigated the impacts of dual regulation on optimal operations. Recently, Mondal et al. [33] integrated CSR in a CLSC and investigated the effects of government subsidy and various recycling policies. They showed that government subsidy helps in improving channel performance and the manufacturer-led collection provides the best possible outcome. Contrary to the above literatures, this study focuses on the retailer’s fairness concern under different collection modes.

2.2. Supply chain model considering fairness concern. The evolution of the fairness model within the structure of operations management is a recent field of research. Cui et al. [6] initiated this innovative work by considering a two-echelon supply chain consisting of a fair-minded manufacturer and a retailer. Under consideration of linear demand function, they showed that a simple wholesale price
contract can acquire the goal of maximizing channel profit and utility. Caliskan-Demirag et al. [3] extended the work of Cui et al. [6] by introducing non-linear demand function. Their study revealed that an exponential demand function helps to attain channel coordination easily. Yang et al. [48] further extended the work of Cui et al. [6] to investigate the cooperative advertising problem. Based on an affine transformation, Du et al. [8] studied the wholesale price contract in a newsvendor problem taking account of both fair-minded manufacturer and retailer. They noted that channel coordination faces more difficulty under fairness concern. Nie and Du [34] investigated the effect of quantity discount contract in a supply chain consisting of one supplier and two fairness concerned retailers. They demonstrated that a quantity discount contract can’t coordinate the supply chain under fairness concern. Liu et al. [24] considered a supply chain in which both the manufacturer and the retailer are fairness concerned. Their results showed that fairness hurts the profit of the manufacturer and the whole supply chain. Song et al. [41] emphasized on the retailer’s fairness concern and the supplier’s mental accounting in a dual-channel supply chain. Their results demonstrated that there is no impression of fairness in enhancing the retailer’s profit and mental accounting undermines the supplier’s motivation to set up direct sales channels to discourage the retailer. Wang et al. [46] studied the coordination problem of an e-commerce supply chain with a fair-minded manufacturer. They indicated that the fairness behavior diminishes the efficiency of the system. Zhang et al. [49] focused on the effect of the retailer’s fairness concern and consumers’ environmental awareness on the pricing decision in a two-echelon supply chain. Their study illustrated that the retailer’s benefit depends on the retailer’s power and degree of fairness concern. In order to provide some insights to the managers on pricing decisions, Zhen et al. [55] established a Stackelberg game under the fairness concern of both the manufacturer and the multi-channel retailer. They found that the performance of the supply chain depends on whether the manufacturer is concerned about advantageous or disadvantageous inequity. Under consideration of the e-commerce supply chain, Wang et al. [45] studied the decision and coordination strategy under fair-minded manufacturer. Their results showed that the centralized policy provides better service but charges a higher selling price. Qian et al. [35] considered a two-echelon sustainable supply chain consisting of a social-concerned manufacturer and a fair-minded retailer to study the channel coordination problem under the cap-and-trade policy. They found that the fairness concern improves the retailer’s profit but it reduces the sustainability level, profits of the manufacturer and the entire supply chain. Du and Zhao [9] investigated a dual-channel supply chain under retailer’s fairness concern. They suggested that the manufacturer should not neglect the retailer’s fairness preference. Zhang et al. [52] introduced the retailer’s horizontal and vertical fairness behavior in a dual-channel CLSC and investigated under which situation the manufacturer opens a direct channel. Unlike the above literatures, the present study investigates the impacts of different collection modes of used products under retailer’s fairness concern.

2.3. CLSC models under recycling and fairness concern. Nowadays, some researchers have started focusing on the fairness concern under product recycling. Ma et al. [25] introduced fairness concern in CLSC and analyzed the pricing decision under retailer’s marketing effort and fairness concern. They found that the retailer’s fairness concern improves her profitability only. Using both cooperative and non-cooperative gaming approaches, Zheng et al. [57] investigated a three-echelon CLSC
comprising a manufacturer, a distributor, and a fairness concerned retailer. Their results showed that the retailer’s fairness concern diminishes the profit of the decentralized model. In another study, Zheng et al. [56] considered a CLSC in which the manufacturer allows a third-party to remanufacture used products. They revealed that the performance of the supply chain depends on the retailer’s fairness concern as well as consumers’ willingness to buy remanufactured products. Recently, Jian et al. [18] analyzed the decision-making of both the centralized and the decentralized models in a CLSC under consideration of the manufacturer’s fairness concern and the retailer’s sales effort. They obtained that the manufacturer’s fairness concern forces to enhance selling price, diminishes sales effort and damages the benefit of the supply chain.

2.4. Strategies in green supply chain and channel coordination. The key to advancing the sustainable development of any business lies in determining appropriate strategies in line with consumers’ environmental awareness and the implementation of an effective contract strategy between business members. That’s why, recently, academicians and practitioners are showing their interest in channel coordination in green supply chain (GSC). In addition to sharing business-related risks across channels, channel coordination can improve profits and reduce costs. Several contracts viz. wholesale price, revenue sharing, profit sharing, cost sharing, two-part tariff (TPT), etc. have been studied so far for coordinating GSC. Ghosh and Shah [11] concentrated on green cost sharing contract and developed two types of cost sharing contracts viz. retailer-led cost sharing and bargaining cost sharing contracts. Their results exhibited that bargaining may reduce the retailer’s profit. Wang et al. [43] focused on the issue of carbon emission reduction in a two-echelon supply chain under a low-carbon environment and demonstrated that retailer under wholesale price premium and cost-sharing contract could arrive at the objective of lessening carbon emissions and animate the manufacturer to improve its carbon emission reduction rate and the profit of the supply chain. Bai et al. [1] studied a bi-level supply chain model comprising of a manufacturer and a retailer for perishable goods under the cap-and-trade policy and proposed a TPT contract and a revenue and promotional cost-sharing contract to coordinate this system. They showed that both the contracts assist with accomplishing perfect coordination while the TPT contract is stronger. Basiri and Heydari [2] examined the issue of GSC coordination for substitutable products within a two-tier supply chain with selling price, green quality and sales effort dependent demand. They revealed that their proposed contract can improve the profit of the entire supply chain and guarantees higher benefits for both channel individuals than the decentralized scenario. In a two-echelon green CLSC, Giri et al. [12] employed a revenue sharing contract under selling price, warranty period, and greening level-dependent market demand. They revealed that the proposed contract could improve the warranty period, greening level, and profits of channel members. Song and Gao [40] set up two kinds of revenue sharing contract, such as retailer-led and bargaining revenue sharing contract in a two-echelon GSC. They presumed both the contracts could effectively enhance the greening level, profits of the manufacturer and the entire supply chain but the bargaining revenue sharing reduces the retailer’s profit. Considering various coordination contracts, Hong and Guo [16] studied the environmental performance of a GSC where the manufacturer produces the green product, the retailer promotes it through green marketing and customers are environmental-conscious. They found that the coordination may not always benefit all members. Ranjan and Jha [36]
addressed the pricing and coordination mechanism in a dual-channel supply chain under price, greening level, and sales effort dependent market demand. They expressed that a collaborative model provides a higher green product. Wang and Choi [44] investigated the Pareto-efficient coordination under consideration of revenue sharing, cost sharing, and TPT contracts in a make-to-order supply chain under flexible cap-and-trade emission policy. They found that Pareto improvement encourages the channel members; revenue sharing and TPT contracts improve the greening level and profitability. Wu et al. [47] investigated pricing, environmental responsibility investment and product recycling strategies in an environmentally responsible CLSC under the Stackelberg gaming approach. They showed that a bargaining revenue sharing contract is an efficient mechanism for resolving channel conflicts. Heydari et al. [14] analyzed the GSC coordination issue in a two-tier supply chain by proposing a hybrid greening cost and revenue sharing (HGRS) contract. Their study revealed that the proposed HGRS contract is capable of stimulating market demand through reducing selling price and improving the greening level of the product. Moreover, both the channel individuals acquire more benefit than non-cooperative scenario. Although the above literatures studied channel coordination issues in GSC, they didn’t consider the fairness issue of the channel individuals. So, the present study focuses on the GSC coordination issue under retailer’s fairness concern.

2.5. Research gaps and contributions. Table 1 represents the position of the present study with respect to the relevant existing literatures. It illustrates that there are diverse studies addressing product recycling, fairness concern, and channel coordination in GSC separately. There are plenty of studies focusing only on various collection options of used products in traditional CLSC. Only a few studies e.g. Chen et al. [5], and Mondal and Giri [31] investigated different collection options of used products under the manufacturer’s quality improvement and the retailer’s marketing effort. But they eschewed the effect of the retailer’s fairness behavior. Even, Chen et al. [5] didn’t consider channel coordination issue. Although Ma et al. [25] considered the retailer’s fairness concern and product recycling, they refrained from considering the effect of the manufacturer’s greening effort and channel coordination. Recently, Jian et al. [18] analyzed the manufacturer’s greening effort, retailer’s marketing effort in a CLSC under consideration of the manufacturer’s fairness concern. But they abstained from the consideration of retailer’s fairness concern and various collection options of used products. Except Maiti and Giri [28], almost every literature assumed that all the returned products can be converted into a new product. In this article, besides considering a fraction of returned products can be converted into a new one, we emphasize on the manufacturer’s greening effort, fair-minded retailer’s marketing effort, different options for used products collection, and channel coordination issue. First, we develop the centralized model and two decentralized models depending on whether the retailer is fair-neutral or fair-minded. Each decentralized model is again subdivided into three models depending on various collection options of used products. Then, the optimal decisions are compared analytically and a new restitution-based wholesale price contract is proposed for improving channel performance. Finally, we perform numerical illustration of the developed models and investigate the effects of some key parameters on the profitability of the channel individuals and carbon emissions. To the best of our knowledge, we are the first to develop such a model, and we
believe that this study will assist policymakers by providing new insights on product recycling, fairness concern and channel coordination in GSC.

### Table 1. A comparison of the present study with related existing literatures.

| Author(s)          | Demand sensitivity | Carbon Collector | Retailer’s Loop type | Channel coordination |
|--------------------|--------------------|------------------|----------------------|----------------------|
| Maiti and Giri [27] | ✓                  | ✓                | ✓                    | ✓                    |
| Hong et al. [15]   | ✓                  | ×                | ✓                    | ✓                    |
| Nie and Du [34]    | ✓                  | ×                | ✓                    | ×                    |
| Liu et al. [24]    | ✓                  | ×                | ✓                    | ×                    |
| Ma et al. [25]     | ✓                  | ✓                | ✓                    | ×                    |
| Chen et al. [6]    | ✓                  | ✓                | ✓                    | ×                    |
| Modak et al. [30]  | ✓                  | ×                | ✓                    | ✓                    |
| Song et al. [4]    | ✓                  | ✓                | ×                    | ✓                    |
| Chen and Akmalul’Ulya [4] | ✓     | ✓                | ✓                    | ×                    |
| Modak et al. [29]  | ✓                  | ×                | ✓                    | ✓                    |
| Zhang et al. [9]   | ✓                  | ×                | ✓                    | ✓                    |
| Zheng et al. [57]  | ✓                  | ×                | ×                    | ✓                    |
| Zheng et al. [56]  | ✓                  | ×                | ×                    | ✓                    |
| Mondal and Giri [31]| ✓              | ✓                | ×                    | ✓                    |
| Zhang et al. [38]  | ✓                  | ×                | ×                    | ✓                    |
| Qian et al. [35]   | ✓                  | ✓                | ×                    | ✓                    |
| Jian et al. [18]   | ✓                  | ✓                | ×                    | ×                    |
| Du and Zhao [9]    | ✓                  | ✓                | ×                    | ×                    |
| Mondal et al. [33] | ✓                  | ×                | ✓                    | ✓                    |
| Present study      | ✓                  | ✓                | ✓                    | ✓                    |

Note: M - Manufacturer; R - Retailer; T - Third-party.

Here, quality includes greening level, sustainability level, emission reduction level, etc. and effort includes sales, marketing, greening, CSR effort, etc.

### 3. Problem description.** This study considers a CLSC comprising a manufacturer, a fair-minded retailer, and/or an independent third-party. The manufacturer can increase the market demand by improving the greening level and the retailer can enhance the market demand through promoting marketing efforts like an advertisement, labeling carbon footprint, etc. Firstly, the manufacturer produces the green product with a greening level \( \theta \) at manufacturing cost \( c_m \) per unit and supplies it to the retailer at a wholesale price of \( w \) per unit. The retailer then sells it to the primary market at a selling price of \( p \) per unit with a marketing effort \( e \). In the reverse channel, the collector (the manufacturer or the retailer or the third-party) collects the used products from customers by paying an acquisition price of \( A \) per unit. After collection, the manufacturer remanufactures it at \( c_r \) per unit. Only a fraction \( (\rho) \) of the remanufactured product is available for selling in the primary market with the brand new product. The remaining product is sold in the secondary market with a lower price of \( w_1 \) per unit. The manufacturer, the retailer, and the collector incur some costs for green innovation, marketing effort, and collection of used products, respectively. So, we take quadratic cost functions \( \lambda \theta^2 \) for green innovation (Ghosh and Shah [11], Giri et al. [12]), \( \eta e^2 \) for marketing effort (Ma et al. [26], Mondal and Giri [31]) and \( \mu \tau^2 \) for collection of used products (Savaskan et al. [38]). We formulate the centralized model as the benchmark case and three decentralized models with different options for collecting used products. Before discussing our main models i.e. models under fairness behavior (see Fig. 1), we first discuss the models without retailer’s fairness behavior. In all the proposed models, the manufacturer as the Stackelberg leader first decides his decisions. After that, the retailer and/or the third-party simultaneously decide their decisions. The notations used throughout the paper are given in Table 2.
3.1. Notations and assumptions. The required notations used for establishing the proposed models are presented in Table 2.

Table 2. Decision variables and parameters.

| Notations | Description |
|-----------|-------------|
| **Decision variables** | |
| $w$ | unit wholesale price of the manufacturer. |
| $p$ | unit selling price of the retailer. |
| $\theta$ | level of green innovation. |
| $e$ | marketing effort level of the retailer. |
| $\tau$ | collection rate of used products. |
| **Parameters** | |
| $D$ | market demand. |
| $D_r$ | return quantity. |
| $c_m(c_r)$ | unit manufacturing (remanufacturing) cost of the new (returned) product. |
| $D_0$ | basic market demand. |
| $E_0$ | basic carbon emission during production. |
| $E_t(E_{t})$ | unit (total) carbon emission during production. |
| $\rho$ | fraction of remanufactured products available for selling in the primary market. |
| $w_1$ | unit selling price of the remanufactured product in the secondary market. |
| $\lambda$ | green investment-related cost coefficient. |
| $\eta$ | marketing effort-related cost coefficient. |
| $\mu$ | collection cost coefficient. |
| $A$ | unit price paid to the customer for used products. |
| $B$ | unit transfer price of the used products ($B > A$). |
| $\Pi_i^j$ | profit function where superscript $j$ denotes the supply chain models ($j = C, M, N, R, T, M, F, R, T, F, C, O$) while the subscript $i$ denotes the supply chain members and the entire supply chain, respectively ($i = m, r, t, w$). |
| $(.)^j$ | optimal decisions under model $j$. |
The following assumptions are made for developing the proposed models:

1. The market demand at the retailer’s end is deterministic and negatively related to the selling price while positively related to the greening level of the product and the marketing effort of the retailer. So, the market demand takes the form

$$D(p, \theta, e) = D_0 - \alpha p + \beta \theta + \gamma e,$$

where $\alpha$, $\beta$ and $\gamma$ are the price sensitivity factor, the greening level sensitivity factor and the marketing effort sensitivity factor of the market demand, respectively (Chen and Akmalul’Ulya [4], Mondal and Giri [31]). For the rest of the paper, $D(p, \theta, e)$ and $D$ will be interchangeable.

2. In general, it is not always possible to collect all the used products. So, the return quantity is taken as a fraction of total demand i.e.

$$D_r = \tau D,$$

where $0 < \tau < 1$ (Savaskan et al. [38]).

3. The unit manufacturing cost of a new one from fresh raw materials is more expensive than the unit remanufacturing cost of a returned product i.e. $c_m > c_r$. Not all remanufactured products become like-new. Only a fraction ($\rho$) of the remanufactured products passes for being sold with the new one in the primary market. The rest of the remanufactured products is sold at a lower price $w_1$ in a secondary market (Maity and Giri [28]). This situation is more clearly depicted in Fig. 2. Therefore, the unit cost saving from product remanufacturing is

$$X = \rho c_m + (1 - \rho)w_1 - c_r.$$

For instance, Dell has a separate website (http://www.delloutlet.com) for selling low-quality refurbished computers and accessories. Toyota sells and leases its under-standard used/remanufactured automobiles to an international secondary market. BMW, Ford, and Mercedes-Benz use trade-in programs to collect used automobiles and sell them in a secondary market after refurbishing and/or remanufacturing (Li et al. [19]).

4. The manufacturer engages in product remanufacturing only when unit cost savings from product remanufacturing is higher than the unit price paid to customers for used products i.e. $X > A$. It is also assumed that the manufacturer outsources the collection activity to the retailer or the third-party only when the unit cost savings from the product remanufacturing exceeds the transfer price i.e. $X > B$ (Savaskan et al. [38]).

5. Unit carbon emission during production is assumed to be dependent on the greening level of the product and it is given by

$$E_u = E_0 - \delta \theta,$$

where $E_0$ is the basic emission and $\delta$ is the adjustment factor (Qian et al. [35]). Since there is no distinction in the greening levels of new and remanufactured products in this study, in order to avoid complexity in calculation, it is assumed that unit emission due to manufacturing is the same as that of remanufacturing. So, the total emission is

$$E_t = (D - D_r)E_u + D_rE_u$$

(i.e. $E_t = DE_u$ (Mondal and Giri [32]).

6. In order to ensure the positivity of the optimal results, the parameters $\lambda, \eta,$ and $\mu$ are so chosen that

$$\lambda > \frac{\beta^2}{2\alpha}, \quad \eta > \frac{\gamma^2}{2\alpha}, \quad \mu > \frac{\alpha(X - A)^2}{2}$$

and

$$\lambda(2\alpha \eta - \gamma^2) - \eta \beta^2 > 0.$$

4. Model development and analysis. In this section, we develop our proposed models and analyze the optimal decisions. In the following, we first develop the centralized model as a benchmark case.

4.1. The centralized model (Model-C). In the centralized model, all the supply chain members work as a single decision-making entity whose goal is to elevate the entire supply chain’s profit with respect to all the decisions viz. selling price $p$,
greening level \( \theta \), marketing effort \( e \), and collection rate of used products \( \tau \). As the single decision-making entity is handling all decisions, the internal transfer prices \( w \) and \( B \) have no role in this model (see Fig. 1(a)). So, the single decision-making entity produces the green product of greening level \( \theta \) and fulfills the primary market demand through selling it at a selling price \( p \) per unit with a marketing effort \( e \). The collection activity is also maintained by the same entity with a collection rate of \( \tau \) per unit. Hence, the objective function of Model-C is given by

\[
\max_{(p, \theta, e, \tau)} \Pi^C_w = pD - c_m(D - \rho D_r) - (c_r + A)D_r + w_1(1 - \rho)D_r \\
- \lambda \theta^2 - \eta e^2 - \mu \tau^2
\]  

(1)

Here, the first term is the sales revenue obtained from selling the green product in the primary market. The second and third terms are respectively the manufacturing and the remanufacturing (including acquisition price) costs. The fourth term is the revenue obtained from selling low standard remanufactured products in the secondary market and the remaining terms are respectively green investment cost, marketing effort-related cost, and collection-related cost.

Lemma 4.1. The profit function \( \Pi^C_w \) of Model-C is jointly concave in \( p, \theta, e \) and \( \tau \).

Proof. See Appendix A1.

Since the profit function is jointly concave, optimal decisions of Model-C (which can be obtained through utilizing the first order necessary conditions for optimality of the objective function (1)) are given as follows:

\[
p^C = \frac{D_0 \eta \lambda (2 \mu - \alpha(X - A)^2) + \mu c_m (\lambda (2 \alpha \eta - \gamma^2) - \eta \beta^2)}{\mu (\lambda (4 \alpha \eta - \gamma^2) - \eta \beta^2) - \alpha^2 \eta \lambda (X - A)^2},
\]

\[
\theta^C = \frac{\beta \eta \mu (D_0 - c_m \alpha)}{\mu (\lambda (4 \alpha \eta - \gamma^2) - \eta \beta^2) - \alpha^2 \eta \lambda (X - A)^2},
\]

\[
e^C = \frac{\gamma \lambda \mu (D_0 - c_m \alpha)}{\mu (\lambda (4 \alpha \eta - \gamma^2) - \eta \beta^2) - \alpha^2 \eta \lambda (X - A)^2},
\]

\[
\tau^C = \frac{\alpha \eta \lambda X (D_0 - c_m \alpha)}{\mu (\lambda (4 \alpha \eta - \gamma^2) - \eta \beta^2) - \alpha^2 \eta \lambda (X - A)^2}.
\]

With these values of optimal decisions, the optimal market demand, return quantity, the profit of the entire supply chain and emission during production are given by
Corollary 1. The assumption 6 ensures the positivity of the optimal results but it does not guarantee that \( \tau < 1 \). In order to satisfy the condition \( \tau^C < 1 \), the collection cost coefficient should be large enough such that \( \mu > \frac{\alpha \eta \lambda \lambda(X-A)}{\lambda(4\alpha \eta - \gamma) - \eta \beta^2} \).

Corollary 2. The optimal decisions of Model-C follow the following properties:

(i) \( \frac{\partial \theta^C}{\partial \tau} > 0; \frac{\partial \theta^C}{\partial \alpha} > 0; \frac{\partial \theta^C}{\partial \gamma} > 0; \frac{\partial \theta^C}{\partial \mu} > 0. \)

(ii) \( \frac{\partial \theta^C}{\partial \tau} > 0; \frac{\partial \theta^C}{\partial \alpha} > 0; \frac{\partial \theta^C}{\partial \gamma} > 0; \frac{\partial \theta^C}{\partial \mu} > 0. \)

(iii) \( \frac{\partial \theta^C}{\partial \alpha} < 0; \frac{\partial \theta^C}{\partial \tau} < 0; \frac{\partial \theta^C}{\partial \gamma} < 0; \frac{\partial \theta^C}{\partial \mu} < 0. \)

(iv) \( \frac{\partial \theta^C}{\partial \gamma} < 0; \frac{\partial \theta^C}{\partial \tau} < 0; \frac{\partial \theta^C}{\partial \gamma} < 0; \frac{\partial \theta^C}{\partial \mu} < 0. \)

(v) \( \frac{\partial \theta^C}{\partial \mu} < 0; \frac{\partial \theta^C}{\partial \tau} > 0; \frac{\partial \theta^C}{\partial \gamma} < 0; \frac{\partial \theta^C}{\partial \mu} < 0. \)

Corollary 2 illustrates that the greening level and the marketing effort sensitivity coefficients have a positive effect on the optimal decisions of Model-C. It is conspicuous that if the customers are more sensitive towards the greening level of the product and the marketing effort of the retailer, they abdicate the product with a lower greening level from the retailer who applies less effort in marketing that product. So, the greening level of the product and the marketing effort of the retailer increase. Higher greening level and marketing effort demand higher selling price. It is also observed that the collection rate of used products also enhances with these coefficients. If the channel members invest more for improving their respective efforts then they require to put less efforts. So, when green innovation and marketing effort-related costs increase, optimal decisions of the channel members tend to decrease. Similar to the green innovation and marketing effort-related costs, if the used products collection cost increases, the collection rate also decreases. At the same time, greening level and marketing effort also drop. Due to the higher collection price, in this case, the centralized decision-maker charges a higher selling price to maintain the profitability of the entire supply chain.

4.2. Decentralized models. In the decentralized scenario, members of the supply chain work independently and optimize their decisions by maximizing their individual profits. The manufacturer first destines the wholesale price and the greening level, and the downstream member(s) (retailer, third-party) comply with the decisions of the manufacturer to determine their decisions. In the following, we develop two models (each contains three models) depending on the fairness behavior of the retailer.

4.2.1. The retailer is not concerned about fairness behavior.

4.2.1.1 Used product collection through the manufacturer (Model-MN).

In Model-MN, besides producing and selling the green product to the retailer in the forward channel, the manufacturer directly collects used products from end-customers through reverse channel. The retailer sells those products in the primary market (see Fig. 1(b)). This type of collection activity is commonly adopted by companies like Xerox, Canon, Apple, etc. Xerox and Canon provide prepaid mailboxes (Savaskan et al. [38]) while Apple provides Gift Card to collect used products (Mondal and Giri [31]). Hence, the objective functions of the manufacturer and the
retailer in Model-MN are given by
\[
\max_{(w, \theta, \tau)} \Pi_{MN}^{m} = wD - c_m(D - \rho D_r) - (c_r + A)D_r + w_1(1 - \rho)D_r
- \lambda \theta^2 - \mu \tau^2, \tag{2}
\]
\[
\max_{(p, e)} \Pi_{MN}^{r} = (p - w)D - \eta e^2. \tag{3}
\]

**Lemma 4.2.** For given \(w, \theta\) and \(\tau\), the profit function \(\Pi_{MN}^{r}\) of the retailer in Model-MN is jointly concave in \(p\) and \(e\).

**Proof.** See Appendix A2. \(\square\)

There exist unique values of \(p\) and \(e\), which can be obtained from utilizing first order necessary conditions for optimality. So, optimal decisions of the retailer are
\[
p(w, \theta) = \frac{2\eta(D_0 + \alpha w + \beta \theta) - w_\gamma^2}{4\alpha \eta - \gamma^2},
\]
\[
e(w, \theta) = \frac{\gamma(D_0 - \alpha w + \beta \theta)}{4\alpha \eta - \gamma^2}.
\]

**Corollary 3.** The optimal selling price and the marketing effort obey the following properties:

(i) \(\frac{\partial p}{\partial w} > 0; \frac{\partial e}{\partial \theta} > 0\).

(ii) \(\frac{\partial p}{\partial \theta} < 0; \frac{\partial e}{\partial w} > 0\).

Corollary 3 indicates that an increase in both the wholesale price and the greening level of the product increases the selling price, which is quite obvious. An increase in the greening level implies that the manufacturer has to invest more in green innovation. In order to maintain profitability, he has to enhance the wholesale price of the product. A higher wholesale price of the product forces the retailer to set a higher selling price. As the manufacturer exerts more effort in green innovation, the retailer also promotes the marketing effort. Again, if the retailer has to buy the product by paying a higher wholesale price, she shows less interest in enhancing the marketing effort. The increasing (decreasing) rate of the marketing effort depends on the greening level (selling price) sensitivity coefficient of the market demand.

After getting these reactions of the retailer, the manufacturer determines his decisions by optimizing the objective function (2) and it leads to the following lemma:

**Lemma 4.3.** The profit function \(\Pi_{MN}^{m}\) of the manufacturer in Model-MN is jointly concave in \(w, \theta\) and \(\tau\).

**Proof.** See Appendix A2. \(\square\)

The optimal values of the manufacturer’s decision variables can be obtained by utilizing the first order necessary conditions for optimality of the manufacturer’s objective function. The optimal decisions of the manufacturer and the retailer are summarized as follows:
\[
w_{MN} = \frac{D_0 \lambda [\mu(4\alpha \eta - \gamma^2) - \alpha^2 \eta \lambda(X - A)^2] + \mu \omega_m \omega [\lambda(4\alpha \eta - \gamma^2) - \eta \beta^2] - \beta \mu_D(D_0 - c_m \alpha)}{\alpha [\mu(2\lambda(4\alpha \eta - \gamma^2) - \eta \beta^2) - \alpha^2 \eta \lambda(X - A)^2]},
\]
\[
g_{MN} = \frac{\beta \mu_D(D_0 - c_m \alpha)}{\mu(2\lambda(4\alpha \eta - \gamma^2) - \eta \beta^2) - \alpha^2 \eta \lambda(X - A)^2},
\]
\[
e_{MN} = \frac{\alpha \eta \lambda(X - A)(D_0 - c_m \alpha)}{\mu(2\lambda(4\alpha \eta - \gamma^2) - \eta \beta^2) - \alpha^2 \eta \lambda(X - A)^2}.
\]
For collecting disposable cameras, Kodak pays a fixed payment to the retailer in return for transfer price $B$. During production for Model-MN are given by

$$\Pi^{MN} = \frac{\mu}{\alpha \eta \lambda (D_0 - c_m \alpha)}, \quad \Pi^{MN} = \frac{\mu}{\alpha \eta \lambda (D_0 - c_m \alpha)}$$

With these optimal decisions, the optimal market demand, return quantity and profits of the manufacturer, the retailer and the entire supply chain, and emission during production for Model-MN are given by

$$D^{MN} = \frac{2 \lambda \mu (D_0 - c_m \alpha)}{\alpha \eta \lambda (D_0 - c_m \alpha)}, \quad D^{MN} = \frac{2 \lambda \mu (D_0 - c_m \alpha)}{\alpha \eta \lambda (D_0 - c_m \alpha)}$$

$$\Pi^{MN} = \frac{\mu}{\alpha \eta \lambda (D_0 - c_m \alpha)} \frac{\mu}{\alpha \eta \lambda (D_0 - c_m \alpha)} \frac{\mu}{\alpha \eta \lambda (D_0 - c_m \alpha)}$$

$$\Pi^{MN} = \frac{\mu}{\alpha \eta \lambda (D_0 - c_m \alpha)} \frac{\mu}{\alpha \eta \lambda (D_0 - c_m \alpha)} \frac{\mu}{\alpha \eta \lambda (D_0 - c_m \alpha)}$$

$$E^{MN} = (E_0 - \delta \theta^{MN}) D^{MN}.$$

Corollary 4. The optimal wholesale price, profits of the manufacturer and the retailer in Model-MN obey the following properties:

(i) $\frac{\partial w^{MN}}{\partial \beta} > 0; \quad \frac{\partial \Pi^{MN}}{\partial \beta} > 0; \quad \frac{\partial \Pi^{MN}}{\partial \beta} > 0.$

(ii) $\frac{\partial w^{MN}}{\partial \gamma} > 0; \quad \frac{\partial \Pi^{MN}}{\partial \gamma} > 0; \quad \frac{\partial \Pi^{MN}}{\partial \gamma} > 0.$

(iii) $\frac{\partial w^{MN}}{\partial \eta} < 0; \quad \frac{\partial \Pi^{MN}}{\partial \eta} < 0; \quad \frac{\partial \Pi^{MN}}{\partial \eta} < 0.$

(iv) $\frac{\partial w^{MN}}{\partial \eta} < 0; \quad \frac{\partial \Pi^{MN}}{\partial \eta} < 0; \quad \frac{\partial \Pi^{MN}}{\partial \eta} < 0.$

(v) $\frac{\partial w^{MN}}{\partial \mu} > 0; \quad \frac{\partial \Pi^{MN}}{\partial \mu} < 0; \quad \frac{\partial \Pi^{MN}}{\partial \mu} < 0.$

Different model parameters have a similar effect on the optimal decisions of Model-MN as described in Model-C. So, in this case, we omit those results. We know that when customers are more sensitive towards the greening level and the marketing effort, the greening level and the marketing effort increase. As green innovation needs more investment, the manufacturer has to increase the wholesale price of the product. A higher wholesale price improves the manufacturer’s earning, and a higher greening level and a higher marketing effort promote the market demand. As a result, profits of the manufacturer and the retailer increase. But higher green investment costs, marketing effort and collection effort costs pull the profits of the channel members.

4.2.1.2 Used product collection through the retailer (Model-RN). In Model-RN, the retailer has a dual job, one in the forward logistics and another in the reverse logistics. In the forward logistics, the retailer purchases the green product from the manufacturer and sells it in the primary market. In reverse logistics, she collects used products from end-customers at $A$ per unit and transfers them to the manufacturer in return for transfer price $B$ per unit (see Fig. 1(c)). This type of collection strategy can be seen in automobile, furniture and refrigerator stores where the customers can sell their used products that they bought previously from those stores. For collecting disposable cameras, Kodak pays a fixed payment to the retailers (Savaskan et al. [38]).

The objective functions of the manufacturer and the retailer for Model-RN are given by

$$\max_{(w, \theta)} \Pi^{RN}_{m} = wD - c_m (D - \rho D_r) - (c_r + B) D_r + w_1 (1 - \rho) D_r - \lambda \theta^2,$$

$$\max_{(p, e, \tau)} \Pi^{RN}_{r} = (p - w) D + (B - A) D_r - \eta e^2 - \mu \tau^2$$
Lemma 4.4. For given \( w \) and \( \theta \), the profit function \( \Pi^R_N \) of the retailer in Model-RN is jointly concave in \( p, e \) and \( \tau \).

Proof. The proof is omitted as it is similar to Lemma 4.2. \( \square \)

There exists unique values of \( p, e \) and \( \tau \), which can be obtained from the first order necessary conditions for optimality. The optimal decisions of the retailer are

\[
p(w, \theta) = \frac{\eta(D_0 + \beta \theta) [2\mu - \alpha(B - A)^2] + \mu w (2\alpha \eta - \gamma^2)}{\mu (4\alpha \eta - \gamma^2) - \alpha^2 \eta (B - A)^2},
\]

\[
e(w, \theta) = \frac{\gamma \mu (D_0 - \alpha w + \beta \theta)}{\mu (4\alpha \eta - \gamma^2) - \alpha^2 \eta (B - A)^2}, \quad \tau(w, \theta) = \frac{\alpha \eta (B - A)(D_0 - \alpha w + \beta \theta)}{\mu (4\alpha \eta - \gamma^2) - \alpha^2 \eta (B - A)^2}.
\]

After getting these reactions of the retailer, the manufacturer determines his decisions through optimizing the objective function (4) and it leads to the following lemma:

Lemma 4.5. The profit function \( \Pi^R_m \) of the manufacturer in Model-RN is jointly concave in \( w \) and \( \theta \).

Proof. The proof is omitted as it is similar to Lemma 4.3. \( \square \)

The optimal decisions of the manufacturer and the retailer are summarized as follows:

\[
w^R_N = \frac{D_0 \lambda [\mu (4\alpha \eta - \gamma^2) - \alpha^2 \eta (B - A) (2X - B - A)]}{\beta \eta \mu (D_0 - c_m \alpha) + c_m \alpha \mu [\lambda (2\alpha \eta - \gamma^2) - \eta \beta^2]),}
\]

\[
\theta^R_N = \frac{\beta \eta \mu (D_0 - c_m \alpha)}{\mu (2\lambda (4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda (X - A)(B - A)},
\]

\[
p^R_N = \frac{D_0 \lambda [\mu (6\alpha \eta - \gamma^2) - 2\alpha^2 \eta (B - A)(X - A)] + c_m \alpha \mu [(\lambda (2\alpha \eta - \gamma^2) - \eta \beta^2])}{\alpha [\mu (2\lambda (4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda (X - A)(B - A)]},
\]

\[
e^R_N = \frac{\gamma \lambda \mu (D_0 - c_m \alpha)}{\mu (2\lambda (4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda (X - A)(B - A)},
\]

\[
\tau^R_N = \frac{\alpha \eta \lambda (B - A)(D_0 - c_m \alpha)}{\mu (2\lambda (4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda (X - A)(B - A)}.
\]

With the above values of the decision variables, the optimal market demand, return quantity and profits of the manufacturer, the retailer and the entire supply chain, and emission during production for Model-RN are given by

\[
D^R_N = \frac{2\alpha \lambda \eta \mu (D_0 - c_m \alpha)}{\mu (2\lambda (4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda (X - A)(B - A)}.
\]

\[
D^R_r = \frac{2\alpha^2 \lambda^2 \eta^2 \mu (B - A)(D_0 - c_m \alpha)^2}{[\mu (2\lambda (4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda (X - A)(B - A)]^2},
\]

\[
\Pi^R_m = \frac{\lambda \mu [(D_0 - c_m \alpha)^2]}{\mu (2\lambda (4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda (X - A)(B - A)},
\]

\[
\Pi^R_r = \frac{\lambda^2 \eta \mu [(\lambda (4\alpha \eta - \gamma^2) - \eta \beta^2) - \alpha^2 \eta (B - A)^2)(D_0 - c_m \alpha)^2}{[\mu (2\lambda (4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda (X - A)(B - A)]^2},
\]

\[
\Pi^R_w = \frac{\lambda \eta \mu (D_0 - c_m \alpha)^2 [\mu (2\lambda (4\alpha \eta - \gamma^2) - \eta \beta^2) - \alpha^2 \eta (B - A)(2X + B - A)]}{[\mu (2\lambda (4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda (X - A)(B - A)]^2},
\]

\[
E_t^R = (E_0 - \delta \theta^R_N) D^R_N.
\]
4.2.1.3 Used product collection through the third-party (Model-TN). In Model-TN, instead of the retailer, the manufacturer outsources the collection activity to an independent third-party. In this case, in the forward logistics, the manufacturer produces and sells the green product to the retailer and the retailer then sells it in the primary market. In reverse logistics, the third-party collects used products from end-customers by paying a price of $A$ per unit and transfers it to the manufacturer at a transfer price of $B$ per unit (see Fig. 1(d)). This type of collection activity is common in metal, plastic, paper, and glass industries. Sometimes, for collecting used desktop and laptops, companies like Dell and Acer also make contract with a third-party.

The objective functions of the manufacturer, the retailer and the third-party for Model-TN are given by

$$\max_{(w, \theta)} \Pi_{m}^{TN} = wD - c_m(D - \rho D_r) - (c_r + B)D_r + w_1(1 - \rho)D_r - \lambda \theta^2, \quad (6)$$

$$\max_{(p, e)} \Pi_{r}^{TN} = (p - w)D - \eta \epsilon^2, \quad \text{and}$$

$$\max_{(\tau)} \Pi_{t}^{TN} = (B - A)D_r - \mu \tau^2 \quad (8)$$

Similar to Model-MN, in this case also the retailer determines her optimal decisions (selling price and marketing effort) through maximizing her own profit. Based on this, the third-party ascertains the optimal collection effort. The optimal values of $p$ and $e$ can be obtained from the first order necessary conditions for optimality of (7) and that of $\tau$ (since $\frac{\partial^2 \Pi_{T}^{TN}}{\partial \tau^2} = -2\mu < 0$) can be obtained from the first order necessary conditions for optimality of (8).

The optimal decisions of the retailer and the third-party are given by

$$p(w, \theta) = \frac{2\eta(D_0 + \alpha w + \beta \theta) - w \gamma^2}{4\alpha \eta - \gamma^2}, \quad e(w, \theta) = \frac{\gamma(D_0 - \alpha w + \beta \theta)}{4\alpha \eta - \gamma^2},$$

$$\tau(w, \theta) = \frac{\alpha \eta(B - A)(D_0 - \alpha w + \beta \theta)}{4\alpha \eta - \gamma^2}.$$

After getting these reactions of the retailer and the third-party, the manufacturer determines his optimal decisions by optimizing the objective function (6). The optimal decisions of the manufacturer, the retailer and the third-party are summarized as follows:

$$w^{TN} = \frac{D_0 \lambda [\mu(4\alpha \eta - \gamma^2) - 2\alpha^2 \eta(B - A)(X - B)] + c_m \alpha \mu (\lambda(4\alpha \eta - \gamma^2) - \eta \beta^2)}{\alpha [\mu(2\lambda(4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda(X - B)(B - A)]},$$

$$\theta^{TN} = \frac{\beta \eta \mu(D_0 - c_m \alpha)}{\mu(2\lambda(4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda(X - B)(B - A)},$$

$$p^{TN} = \frac{D_0 \lambda [\mu(6\alpha \eta - \gamma^2) - 2\alpha^2 \eta(B - A)(X - B)] + c_m \alpha \mu (\lambda(2\alpha \eta - \gamma^2) - \eta \beta^2)]}{\alpha [\mu(2\lambda(4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda(X - B)(B - A)]},$$

$$e^{TN} = \frac{\gamma \lambda \mu(D_0 - c_m \alpha)}{\mu(2\lambda(4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda(X - B)(B - A)},$$

$$\tau^{TN} = \frac{\alpha \eta \lambda(B - A)(D_0 - c_m \alpha)}{\mu(2\lambda(4\alpha \eta - \gamma^2) - \eta \beta^2) - 2\alpha^2 \eta \lambda(X - B)(B - A)}. $$
Then the optimal demand market, return quantity and profits of the manufacturer, the retailer and the entire supply chain, and emission during production for Model-TN are given by

\[ D_{TN}^r = \frac{2\alpha^2\lambda^2\mu(\alpha\eta - \gamma^2 - \gamma^2)}{\mu(2\lambda(4\alpha\eta - \gamma^2 - \gamma^2) - 2\alpha^2\eta\lambda(X - B)(B - A))}, \]

\[ D_{TN}^m = \frac{2\alpha^2\lambda^2\mu^2(\alpha\eta - \gamma^2 - \gamma^2)}{\mu(2\lambda(4\alpha\eta - \gamma^2 - \gamma^2) - 2\alpha^2\eta\lambda(X - B)(B - A))}, \]

\[ \Pi_{TN}^r = \frac{\lambda^2\mu^2(\alpha\eta - \gamma^2 - \gamma^2)}{\mu(2\lambda(4\alpha\eta - \gamma^2 - \gamma^2) - 2\alpha^2\eta\lambda(X - B)(B - A))}, \]

\[ \Pi_{TN}^m = \frac{\lambda^2\mu^2(\alpha\eta - \gamma^2 - \gamma^2)}{\mu(2\lambda(4\alpha\eta - \gamma^2 - \gamma^2) - 2\alpha^2\eta\lambda(X - B)(B - A))}, \]

\[ E_{TN}^r = (E_0 - \delta^r TN)D_{TN}^r, \]

4.2.2. The retailer is concerned about fairness behavior. In this subsection, we consider the situation when the retailer is concerned about the fairness of the business. That means, she does not prefer any decision which produces either higher or lower profit than her desired equitable reference point. Here we assume that \( \epsilon \Pi_m > \Pi_r \), it will be disadvantageous inequality while \( \epsilon \Pi_m < \Pi_r \) will be an advantageous inequality for the retailer. In our model, as the manufacturer is the leader, we consider only disadvantageous inequality. Therefore, following Wang et al. [46], the utility function of the fairness concerned retailer is taken as

\[ U_r = \Pi_r - \xi \Pi_m = (1 + \xi \Pi_r - \xi \Pi_m), \]

where \( \xi > 0 \) is the fairness concern parameter. A large value of \( \xi \) implies that the retailer is more concerned about fairness behavior. It is noteworthy that the fairness behavior of the retailer can reduce the profit margin between the manufacturer and the retailer (Zheng et al. [56]). In order to avoid complexity in calculation, following Qian et al. [35], we consider \( \xi = \frac{\xi_1\epsilon}{\xi_1\epsilon} \). Then the utility function of the retailer will take the form

\[ U_r = \frac{\xi_1\epsilon}{\xi_1\epsilon} = \Pi_r - \xi \Pi_m, \]

where \( 0 \leq \xi \leq 1 \). The optimal results for different models under retailer’s fairness concern i.e. Model-MF, Model-RF and Model-TF are presented in Table 3.

5. Comparative analysis of the proposed models. This section compares the optimal outcomes of the proposed models to get some insights. Comparing the optimal results of the different models, we get the following propositions.

Proposition 1. If the condition \( B \geq \frac{\mu X(2\lambda(4\alpha\eta - \gamma^2) - \gamma^2) + \alpha^2\eta\lambda X(\alpha - A)^2}{\mu(2\lambda(4\alpha\eta - \gamma^2) - \gamma^2) + \alpha^2\eta\lambda(\alpha - A)^2} \) holds, then the optimal collection rate of used products follows the pattern \( \tau^C > \tau^{MN} \geq \tau^{TN} \geq \tau^{MN} > \tau^{MN} > \tau^{MN} \).

Proof. See Appendix B1. □

From Proposition 1, it is observed that the collection rate of used products is higher in the centralized model. Due to the fact of joint decision-making, the collector can exert more effort into collecting used products. Among three decentralized
models, Model-TN has the lowest collection rate of used products, as the marginal benefit of the third-party from collecting used products in Model-TN is lower than that of the manufacturer in Model-MN (i.e., \( B - A < X - A \)). Which one of Model-MN and Model-RN can collect a higher amount of used products that depends on how much transfer price the manufacturer pays to the retailer. If the manufacturer pays a lower amount of transfer price, then the manufacturer should manipulate the collection activity himself rather than transferring it to the retailer. But a higher amount of transfer price encourages the retailer in collecting used products as it can improve her profitability. As a result, the collection rate of used products becomes higher in Model-RN than that in Model-MN when the transfer price is greater than a threshold value.

**Proposition 2.** If the condition \( \beta \geq \sqrt{\frac{2\alpha\lambda(B - A)(X - A)}{\mu}} \) holds, then the optimal wholesale price of the brand new product follows the pattern \( w^{RN} \geq w^{TN} > w^{MN} \); otherwise, \( w^{TN} > w^{RN} > w^{MN} \).

**Proof.** See Appendix B2.

Proposition 2 reveals that among three decentralized models, the manufacturer sets a lower wholesale price in Model-MN. The reason behind this outcome is that the manufacturer wants to boost the market demand by setting a comparatively lower wholesale price. According to our assumption, when the consumers are more sensitive towards the green product, the market demand increases (i.e., \( \frac{\partial D}{\partial \alpha} > 0 \)). The more the market demand, the more the return will be. In Model-RN, the retailer can earn from both selling the new product (i.e., \( p - w \)) and collecting used products (i.e., \( (B - A)D_r \)). But in Model-TN, the retailer can earn only from selling the new product. So, the retailer gains more profit in Model-RN. Hence, in a market with more environmental-conscious consumers, the manufacturer sets a higher wholesale price in Model-RN than Model-TN. When the consumers are less sensitive towards the green product, the manufacturer charges a higher wholesale price in Model-TN. This is because, in the case of Model-TN, the manufacturer has to deal with two different persons: one for selling a new product and another for collecting used products. Without taking any risk, the manufacturer charges a higher wholesale price.
Proposition 3. If the condition $B \geq \frac{(X+A)}{2}$ holds, then
(i) the optimal greening level of the product follows the pattern $\theta^C > \theta^RN > \theta^MN > \theta^TN$; otherwise, $\theta^C > \theta^MN > \theta^RN > \theta^TN$.
(ii) the optimal marketing effort of the retailer follows the pattern $e^C > e^RN \geq e^MN > e^TN$; otherwise, $e^C > e^MN > e^RN > e^TN$.
(iii) the optimal selling price of the product follows the pattern $p^TN > p^MN \geq p^RN > p^C$; otherwise, $p^TN > p^RN > p^MN > p^C$.

Proof. See Appendix B3.

Proposition 3 shows that the greening level and the marketing effort are higher in Model-C. This is due to joint decision-making. As Model-C is free from the double-marginalization effect, the selling price is lower than the decentralized models. As the collection rate is lower in Model-TN, the manufacturer reduces the greening level of the product. Due to the lower greening level, the retailer also decreases the marketing effort. The higher wholesale price in Model-TN forces the retailer to set a higher selling price. In Model-MN, the manufacturer can promote the market demand by only setting a lower wholesale price, but in Model-RN, the transfer price also plays as a stimulant for enhancing market demand indirectly. So, in Model-RN, if the manufacturer has to pay a higher transfer price, due to the fact of higher market demand, he increases the greening level of the product. Higher greening level and higher transfer price help the retailer in selling the product with lower selling price and higher marketing effort. The opposite situation holds when the manufacturer pays a lower transfer price. Therefore, under a higher transfer price, Model-RN is beneficial from the consumers’ perspective. As a result, the market demand also tends to increase in Model-RN.

Proposition 4. The optimal profits of the manufacturer and the retailer have the following relationships.
(i) If the condition $B \geq \frac{(X+A)}{2}$ holds, then the optimal profit of the manufacturer follows the pattern $\Pi^RN_m \geq \Pi^MN_m \geq \Pi^TN_m$; otherwise, $\Pi^MN_m > \Pi^RN_m > \Pi^TN_m$.
(ii) If the condition $B \geq A + \sqrt{2\mu(X-B)^2\left(2\lambda(4\alpha\eta-\gamma^2)-\beta^2\eta\right) - \alpha^2\eta(X-A)^4} \eta \left[2\beta^2\mu(2\lambda(4\alpha\eta-\gamma^2)-\beta^2\eta) - \alpha^2\eta(X-A)^2\left(2\beta^2\mu+\alpha^2\lambda(X-A)^2\right)\right]$ holds, then the optimal profit of the retailer follows the pattern $\Pi^RN_r \geq \Pi^MN_r \geq \Pi^TN_r$; otherwise, $\Pi^MN_r > \Pi^RN_r > \Pi^TN_r$.

Proof. See Appendix B4.

A higher selling price, and lower greening level and marketing effort diminish the market demand in Model-TN. The collection rate of used products is also lower in Model-TN. Lower market demand and lower collection rate remit the profit of the manufacturer, which is summarized in Proposition 4. In Model-RN, a higher transfer price can encourage the retailer in collecting more used products. The more the used products, the less the production cost will be. Therefore, in that situation the profit of the manufacturer is higher in Model-RN; otherwise, it will be higher in Model-MN.

In Model-TN, the retailer can earn only from selling a new product, but she has to pay a higher wholesale price. So, the profit of the retailer is lower in Model-TN. As we have mentioned before, the transfer price plays a provoking role in rising the market demand, a higher amount of transfer price in Model-RN can promote the market demand as well as the earning of the retailer from collecting used products. Hence, the profit of the retailer becomes higher.
From the above discussions, we learn that if the manufacturer agrees to pay a higher transfer price then Model-RN is beneficial to all the channel members including the customers. Otherwise, Model-MN gives the best possible outcome. In the following, we’ll investigate how the fairness behavior of the retailer affects the optimal decisions and profitability of the channel members under different collection options of used products.

**Proposition 5.** A comparison between the optimal results of fairness model and without fairness model gives the following relationships.

(i) \( w^N_i > w^F_i; \ p^N_i > p^F_i; \ \theta^N_i > \theta^F_i; \ e^N_i > e^F_i; \ \tau^N_i > \tau^F_i. \)

(ii) \( \Pi^N_m > \Pi^F_m; \ \Pi^N_r < \Pi^F_r; \ \Pi^N_w > \Pi^F_w, \ i = M, R, T. \)

**Proof.** See Appendix B5.

Proposition 5 demonstrates that the fairness behavior of the retailer harms green innovation, marketing effort, and product recycling. As the retailer takes care of the utility in addition to thinking about her profit, in this case, the manufacturer does not take any risk to improve the greening level of the product. Due to the lower greening level, he also charges a lower wholesale price. Lower wholesale price and greening level force the retailer to sell the product with lower selling price and lower marketing effort. The collector also shows less interest in collecting used products. Although the selling price decreases, due to lower greening level and marketing effort, the market demand becomes worse, which lessens the profit of the manufacturer and the entire supply chain. Since the retailer thinks about her utility, the fairness behavior can only elevate the profit of the retailer.

**Proposition 6.** If the condition \( B \geq \frac{(\sqrt{\xi}X + A)}{1 + \sqrt{\xi}} \) holds, then

(i) \( p^{TF} \geq p^{RF}; \ \theta^{RF} \geq \theta^{TF}; \ e^{RF} \geq e^{TF}; \) otherwise the pattern will be reversed.

(ii) \( \Pi^{RF}_m \geq \Pi^{TF}_m; \) otherwise, the pattern will be reversed.

**Proof.** See Appendix B6.

Propositions 3 and 4 suggest that the transfer price \( (B) \) does not affect the optimal decisions and profitability of the channel members in Model-TN under a fair-neutral retailer. However, Proposition 6 displays an interesting finding that under fair-minded retailer, the transfer price influences the optimal decisions and profitability of the channel members. If the retailer is concerned about the fairness of the business, the manufacturer prefers to transfer the collection activity to the third-party, since in this case, he has to pay less transfer price. The payment of less transfer price helps him to exert more effort in green innovation, which can promote his profitability through improving the market demand. It can also be shown that when the manufacturer pays a lower transfer price, the collection of used products through the third party is also preferable for the retailer (due to algebraic complexity, we will show this result numerically).

5.1. **Restitution-based wholesale price contract (Model-CO).** From the above comparative analysis, we note that, if the transfer price is greater than a threshold value, then the used product collection through the retailer is more profitable for all members of the supply chain including customers. Again, the fairness behavior of the retailer improves the profit of the retailer but it lessens the profit of the manufacturer. So, in this subsection, we consider a restitution-based wholesale price contract for the collection of used products through the retailer. In this contract, the manufacturer and the retailer are willing to engage in integrated planning.
and adopt the central decision-making framework. The manufacturer sets a new wholesale price \( w_{CO} \) depending on whether his profit is lower or higher than that of Model-RN. If his profit in the coordinated structure is lower than that of Model-RN, then he will charge higher wholesale price from the retailer to restitute his profit loss, while in other situation, i.e. when his profit in the coordinated structure is higher than that of Model-RN, then he will reduce the wholesale price to restitute the profit loss of the retailer. So, the demand and return function of Model-RN under coordinated structure will convert from \( D_{RN} \) to \( D_{C} \) and from \( D_{rRN} \) to \( D_{rC} \), respectively. A lower selling price, and higher greening level and marketing effort obviously increase the market demand, which in turn improves the profitability. Therefore, profits of the manufacturer and the retailer under this contract become

\[
\Pi_{m}^{CO} = w_{m}^{CO}D_{C} - c_{m}(D_{C} - \rho D_{rC}) - (c_{r} + B)D_{rC}^2 + w_{1}(1 - \rho)D_{rC} - \lambda(\theta C)^2 \tag{9}
\]
\[
\Pi_{r}^{CO} = (p - w_{r}^{CO})D_{C} - \eta(\epsilon C)^2 + (B - A)D_{rC} - \mu(\tau C)^2 \tag{10}
\]

The manufacturer will participate in the contract if his profit becomes greater than or equal to that of Model-RN, and the retailer will participate in the contract if her profit becomes greater than or equal to that of Model-RF. From the manufacturer’s condition, we get

\[
\Pi_{m}^{CO} \geq \Pi_{m}^{RN} \Rightarrow w_{m}^{CO} \geq \frac{\Pi_{m}^{RN} + c_{m}D_{C} + \lambda(\theta C)^2 - (X - B)D_{rC}}{D_{C}} \quad (= w_{min})
\]

From the retailer’s condition, we get

\[
\Pi_{r}^{CO} \geq \Pi_{r}^{RF} \Rightarrow w_{r}^{CO} \leq \frac{pC_{C} + (B - A)D_{C} - \eta(\epsilon C)^2 - \mu(\tau C)^2 - \Pi_{r}^{RF}}{D_{C}} \quad (= w_{max})
\]

Under these conditions, the profit of the entire supply chain becomes \( \Pi_{w}^{CO} = \Pi_{m}^{CO} + \Pi_{r}^{CO} = \Pi_{w}^{C} \). Thus we have the following proposition.

**Proposition 7.** If the manufacturer sets the wholesale price \( w_{CO} \in [w_{min}, w_{max}] \), then the proposed restitution-based wholesale price contract can coordinate the supply chain.

If the proposed contract coordinates the supply chain then there will be some surplus profit \( \Delta = \Pi_{w}^{CO} - \Pi_{m}^{RN} - \Pi_{r}^{RF} \) which can be divided between the channel members according to their bargaining powers. Without any loss of generality, we assume that the manufacturer and the retailer have the same bargaining power (i.e. symmetric bargaining power). So, their profits under the contract are given by

\[
\Pi_{m}^{CO} = \Pi_{m}^{RN} + \frac{1}{2}\Delta \quad \text{and} \quad \Pi_{r}^{CO} = \Pi_{r}^{RF} + \frac{1}{2}\Delta.
\]

Also, under symmetric bargaining, the optimal wholesale price is

\[
w_{CO} = \frac{(pC_{C} + c_{m})D_{C} + (2B - X - A)D_{C} - \eta(\epsilon C)^2 - \mu(\tau C)^2 + \Pi_{m}^{RN} - \Pi_{r}^{RF}}{2D_{C}}
\]

6. **Numerical analysis.** This section deals with numerical analysis of the optimal results for the developed models and presents some meaningful managerial insights. Due to difficulty in accessing the actual industry data, we suppose the following hypothetical parameter-values in accordance with the assumptions of our study: \( D_{0} = 100; \alpha = 0.11; \beta = 0.85; \gamma = 0.3; c_{m} = 150; c_{r} = 55; A = 40; B = 70; \lambda = 100; \eta = 90; \mu = 1500; w_{1} = 100; \rho = 0.8; \xi = 0.12 \) in appropriate units. The optimal results of different models are summarized in Table 4.
Table 4 displays that the manufacturer charges a lower wholesale price in Model-MN. But Model-RN is beneficial from consumers’ perspective since it provides a higher green product with lower selling price and higher marketing effort. The collection rate of used products is higher in Model-MN, which contradicts the result of Ma et al. [25] who showed that the collection rate of used products is higher in Model-RN. The reason behind the contrasting outcome of our study lies in the value of transfer price. The manufacturer prefers the collection through the retailer while the retailer prefers the collection through the manufacturer. This outcome is similar to that of Chen et al. [5]. The total profit of the entire supply chain is higher in Model-RN and lower in Model-TN, which negates the outcome of Chen et al. [5] who suggested that the total profit will be higher in Model-MN. The reason behind this outcome is also similar to that of the collection rate. A higher greening level in Model-RN decreases unit carbon emission during production while that under Model-TN is higher due to lower green product. However, total emission during production is higher in Model-RN and that in Model-TN is lower due to variation of market demand. While comparing these results with those of the models with the retailer’s fairness concern, one can notice that the fairness behavior only improves the profit of the retailer. But it decreases the values of other decision variables, profits of the manufacturer and the entire supply chain. It is also observed that the trends of the optimal results follow a similar pattern that of without the retailer’s fairness concern. Thus, from the comparison of decentralized models, we conclude that the collection through the third-party provides the worst performance while the collection through the retailer is beneficial to the manufacturer and the entire supply chain.

Although the retailer’s fairness concern promotes the retailer’s profit or Model-RN gives higher profit to the manufacturer, all these decentralized models fail to compete with the centralized model. It is noted that the selling price in Model-C is lower than those of the decentralized models, but the greening level, marketing effort and collection rate of used products are more than double. The profit of the entire supply chain is 35.5% higher than that of Model-RN, which illustrates the significance of channel coordination. The proposed restitution-based wholesale price contract can perfectly coordinate the supply chain and both the channel members can achieve a win-win situation (see Fig. 3).

Table 5 represents the optimal results of the proposed models when $\rho = 0$ i.e. none of the remanufactured products are like-new and are sold in the secondary

| Optimal results | Without fairness | With fairness | | Model-C | Model-CO |
|---|---|---|---|---|
| $w$ | 525.499 | 529.530 | 529.530 | 484.279 | 488.405 | 488.222 | - | 372.201 |
| $p$ | 720.948 | 719.742 | 722.926 | 720.817 | 719.514 | 722.601 | - | 522.136 |
| $\theta$ | 0.83066 | 0.83599 | 0.82193 | 0.73948 | 0.74459 | 0.73247 | 0.66997 | 0.66997 |
| $\tau$ | 0.32249 | 0.21637 | 0.21274 | 0.28709 | 0.26299 | 0.21233 | 0.66327 | 0.66327 |
| $\Pi_m$ | 8160.02 | 8212.36 | 8074.27 | 7642.77 | 7314.53 | 7195.46 | - | 9973.38 |
| $\Pi_r$ | 4192.51 | 4176.24 | 4104.85 | 5060.96 | 5048.37 | 4967.26 | - | 6809.43 |
| $\Pi_t$ | - | - | 67.8844 | - | 67.6264 | - | - |
| $\Pi_w$ | 12352.5 | 12388.6 | 12247.0 | 12325.2 | 12362.9 | 12230.3 | 16782.8 | 16782.8 |
| $E_u$ | 0.83587 | 0.83280 | 0.83561 | 0.85211 | 0.85108 | 0.85351 | 0.65831 | 0.65831 |
| $E_t$ | 17.9277 | 18.0196 | 17.7764 | 18.2658 | 18.3701 | 18.1225 | 29.1094 | 29.1094 |
Figure 3. Win-win situation for the manufacturer and the retailer.

Table 5. Optimal results of the proposed models when $\rho = 0$.

|                       | Without fairness | With fairness |
|-----------------------|------------------|--------------|
|                       | Model-MN | Model-RN | Model-TN | Model-MF | Model-RF | Model-TF | Model-C | Model-CO |
| $w$                   | 537.597     | 537.592   | 537.853   | 491.302  | 497.210   | 496.564   | -       | 385.472  |
| $p$                   | 724.435     | 723.963   | 727.008   | 723.929  | 723.400   | 726.202   | 536.602  | 536.602  |
| $\theta$              | 0.81527     | 0.81375   | 0.80391   | 0.72725  | 0.72933   | 0.71833   | 1.64546  | 1.64456  |
| $c$                   | 0.31971     | 0.32053   | 0.31525   | 0.31942  | 0.32033   | 0.31550   | 0.64493  | 0.64493  |
| $\tau$                | 0.03517     | 0.21155   | 0.28067   | 0.03137  | 0.23256   | 0.20623   | 0.07094  | 0.07094  |
| $\Pi_m$               | 8008.80     | 8029.26   | 7897.21   | 7144.19  | 7164.59   | 7056.50   | -       | 9672.70  |
| $\Pi_r$               | 4038.56     | 3992.09   | 3926.80   | 4895.02  | 4839.26   | 4772.80   | -       | 6482.72  |
| $\Pi_t$               | -           | 64.9398   | -         | -        | 65.0397   | -         | -       | -       |
| $E_u$                 | 0.83695     | 0.83653   | 0.83922   | 0.83643  | 0.85413   | 0.85278   | 0.67109  | 0.67109  |
| $E_t$                 | 17.6604     | 17.6967   | 17.4616   | 18.0154  | 18.0581   | 17.8315   | 28.5650  | 28.5650  |

Table 6. Optimal results of the proposed models when $\rho = 1$.

|                       | Without fairness | With fairness |
|-----------------------|------------------|--------------|
|                       | Model-MN | Model-RN | Model-TN | Model-MF | Model-RF | Model-TF | Model-C | Model-CO |
| $w$                   | 521.843     | 527.354   | 527.391   | 480.679  | 486.584   | 486.085   | -       | 360.962  |
| $p$                   | 719.155     | 718.656   | 721.876   | 719.221  | 718.735   | 721.678   | 514.474  | 514.474  |
| $\theta$              | 0.83858     | 0.84078   | 0.82656   | 0.74574  | 0.74766   | 0.73010   | 1.74226  | 1.74226  |
| $c$                   | 0.32885     | 0.32972   | 0.32414   | 0.32754  | 0.32838   | 0.32331   | 0.68324  | 0.68324  |
| $\tau$                | 0.39791     | 0.21761   | 0.21393   | 0.35836  | 0.19506   | 0.21383   | 0.82672  | 0.82672  |
| $\Pi_m$               | 8237.79     | 8259.44   | 8119.78   | 7325.84  | 7344.61   | 7231.05   | -       | 10141.5  |
| $\Pi_r$               | 4272.81     | 4224.26   | 4151.26   | 5147.11  | 5091.53   | 5017.71   | -       | 6973.61  |
| $\Pi_t$               | -           | -        | -         | -        | 68.2972   | -         | -       | -       |
| $E_u$                 | 0.83228     | 0.83184   | 0.83469   | 0.85085  | 0.85413   | 0.85634   | 0.67109  | 0.67109  |
| $E_t$                 | 18.0642     | 18.1021   | 17.4616   | 18.0154  | 18.0581   | 17.8315   | 28.5650  | 28.5650  |

In this situation, the wholesale price and the selling price increase to maintain the profitability while the other decision variables and profits of the channel members and the entire supply chain decrease compared to the results shown in Table 4. The collection rates of used products under the manufacturer-led collection and Model-C are highly affected. The collection rate in each model is decreased by almost 89%. Since the greening level decreases, unit emission increases while the market demand decreases. As a result, the total emission also decreases.

Table 6 illustrates the optimal results of different models when $\rho = 1$ i.e., all the remanufactured products are like-new product and are sold in the primary market. This situation has a positive effect on all the optimal results i.e. the wholesale price
Table 7. Optimal results of the proposed models when \( w_1 = 0 \).

| Optimal results | Without fairness | With fairness |
|-----------------|------------------|--------------|
| \( w \)         | 530.503          | 533.738      |
| \( p \)         | 723.403          | 721.876      |
| \( \theta \)     | 0.5306           | 0.5473       |
| \( \tau \)       | 0.17682          | 0.21393      |
| \( \Pi_m \)      | 8053.58          | 7984.76      |
| \( \Pi_r \)      | 4083.84          | 4014.35      |
| \( \Pi_t \)      | 1237.44          | 12063.5      |
| \( E_u \)        | 17.7398          | 17.6177      |

and the selling price decrease while other decision variables and profits of the channel members and the entire supply chain enhance. Similar to the previous case, in this situation also, the collection rates of used products under the manufacturer-led collection and Model-C are highly affected compared to the other models. Since the greening level increases, unit emission decreases while the market demand increases. As a result, the total emission also increases.

Table 7 demonstrates the situation when \( w_1 = 0 \) i.e., the low standard remanufactured products have no value in the secondary market. So, those products are abandoned. The optimal results of different models follow the same pattern of the case \( \rho = 0 \) but are less affected than those of the case \( \rho = 0 \).

Comparing the analytical results, we note that the transfer price \( B \) is very important in optimal decision-making. So, in the following, we’ll visualize the effect of \( B \) on optimal decisions and profit of the channel members.

6.1. Effect of the transfer price \( B \). Fig. 4 exposes the following insights:
(i) An increase in transfer price \( B \) decreases the selling price of the product under the retailer-led collection. The rate of decrement is higher under the fairness behavior of the retailer. As the fair-minded retailer thinks about her utility, it can improve her profitability. So, when the manufacturer pays a higher transfer price, she decreases the selling price. In the case of collection through third-party, the selling price decreases up to a certain value of \( B \) similar to that of the retailer. After that, it tends to increase. The reason is that if the manufacturer has to transfer a higher price for collecting used products, to maintain profitability he increases the wholesale price, which forces the retailer to set the higher selling price. It is noticed from Fig. 4(a) that for lower values of \( B \), the fair-minded retailer charges a higher selling price under its own collection process than that of the third-party, which validates the result of Proposition 6.

(ii) In the case of retailer-led collection, the retailer can earn from both selling the new product and collecting used products. So, when \( B \) increases, she promotes her effort in marketing the product. But in the case of collection through the third-party, the retailer earns only from selling the new product. Increasing \( B \) has no direct effect on the retailer’s profit. So, she diminishes her effort for a higher value of \( B \). It is also noted from Fig. 4(b) that for lower \( B \), the fair-minded retailer puts less effort in Model-RF than Model-TF. Similar to the marketing effort, the greening level of the product also increases with \( B \) (see Fig. 4(c)).

(iii) The more the transfer price, the more the collection rate of used products will be. Similar to other decision variables, for lower \( B \), the collection rate of used
products is higher in Model-TF than that of Model-RF under fair-minded retailer. The fairness concerned retailer exerts more effort in collecting used products only when $B$ is greater than some threshold value; otherwise, she shows no interest in collecting used products (see Fig. 4(d)).

(iv) On one hand, a lower selling price, and higher greening level and marketing effort increase the market demand. On the other hand, a higher collection rate collects more used products. The more the used products, the less the production cost will be. As a result, the profit of the manufacturer increases by $B$. The fairness behavior of the retailer reduces the profit of the manufacturer. For a lower value of $B$, the profit of the manufacturer follows the sequence $\Pi^\text{MF}_m > \Pi^\text{TF}_m > \Pi^\text{RF}_m$. After some threshold value of $B$, the sequence changes to $\Pi^\text{MF}_m > \Pi^\text{RF}_m > \Pi^\text{TF}_m$. Finally, for higher value of $B$, the sequence becomes $\Pi^\text{RF}_m > \Pi^\text{MF}_m > \Pi^\text{TF}_m$. The reason behind this result is similar to the one described previously. The fair-minded retailer puts more effort into collecting used products only when $B$ is higher. So, for a lower value of $B$, the manufacturer wants to transfer the collection activity to the third-party in a market with fairness concerned retailer (see Fig. 4(e)).

(v) Fig. 4(f) shows that fairness behavior and $B$ can improve the profit of the retailer. As we have already mentioned previously, for a lower value of $B$, the third-party puts more effort into collecting used products than the retailer. The fair-minded retailer also prefers the collection through the third-party for lower $B$. When $B$ exceeds a threshold value, the profit of the retailer in Model-RF becomes higher than that in Model-MF.

(vi) Since unit carbon emission is negatively related to the greening level of the product, Fig. 4(g) depicts that the unit emission follows the trend opposite to that of greening level i.e. for a lower value of $B$, unit emission under Model-TF is lower than that of Model-RF. But, for a higher value of $B$, the opposite situation occurs. It also depicts that unit emissions under fair-neutral cases are lower than those of fair-minded cases. Again, the total emission is proportional to the market demand. So, it follows the similar trend of the greening level. However, higher unit emission forces to emit much under retailer's fairness behavior than that under the fair-neutral case (see Fig. 4(h)).

6.2. Effect of the fairness concern parameter $\xi$. Fig. 5 discloses the following insights:

(i) $\xi$ is the parameter that measures how much the retailer is concerned about the fairness of the business i.e. the fairness of the profit distribution. For a higher value of $\xi$, the retailer is more concerned about the fairness of the profit distribution. Fig. 5(a) depicts the decreasing trend of the selling price with $\xi$. The reason is that the retailer wants to increase the market demand by decreasing the selling price.

(ii) Fig. 5(b) displays that the profit of the manufacturer decreases with $\xi$. This is because, under the retailer’s strong fairness behavior, the manufacturer takes no risk in improving the greening level. At the same time, he decreases the wholesale price of the product. A lower wholesale price generates a lower profit for the manufacturer.

(iii) Although the retailer decreases the selling price of the product, the rate of decrement of the selling price is lower than that of the wholesale price. A lower wholesale price helps the retailer to improve her profit (see Fig. 5(c)). Although the profit of the retailer increases but the rate of decrement of the manufacturer’s profit is higher than the increment of the retailer’s profit. As a result, the profit of the entire supply chain decreases (see Fig. 5(d)).
INVESTIGATING A GREEN SUPPLY CHAIN WITH PRODUCT RECYCLING

Figure 4. Sensitivity of optimal results w.r.t. $B$. 

(a) $B$ vs selling price. 

(b) $B$ vs marketing effort. 

(c) $B$ vs greening level. 

(d) $B$ vs collection rate. 

(e) $B$ vs manufacturer’s profit. 

(f) $B$ vs retailer’s profit. 

(g) $B$ vs unit emission. 

(h) $B$ vs total emission.
(iv) As we have mentioned earlier, under the retailer’s strong fairness behavior the manufacturer reduces the greening level of the product, the unit emission tends to increase. It is lower in Model-RF and higher in Model-TF (see Fig. 5(e)). However, the total emission follows the pattern $E_{RF}^t > E_{MF}^t > E_{TF}^t$ due to the trend in market demand (see Fig. 5(f)).

7. Managerial insights and conclusions. This study focuses on the issue of product recycling and the retailer’s fairness concern in a closed-loop green supply chain in which the manufacturer can improve the greening level of the product and the retailer puts effort into marketing those green products. Under consideration of fair-neutral and fair-minded retailer, this study exhibits three decentralized
models relying upon various collection options of used products through utilizing the Stackelberg game setting with the manufacturer as the Stackelberg leader and other individuals as followers. The centralized model is developed as the benchmark case. The equilibrium values of all the decision variables and profits of all the channel members are derived and compared analytically. Finally, a restitution-based wholesale price contract is proposed to investigate the channel coordination issue.

From the comparison and discussion of the optimal results, various meaningful managerial insights are derived. Firstly, in the case of a fair-neutral retailer, the used products collection through the third-party results in lower greening level, marketing effort, the collection rate of used products and profits of the channel members. So, under a fair-neutral retailer, the used product collection through the third-party seems to be disadvantageous for all the channel members. Secondly, the unit transfer price plays a provoking role in determining whether the manufacturer or the retailer performs the used products collection activity. If the manufacturer denies paying much transfer price then collection through the manufacturer is profitable; otherwise, the collection through the retailer is preferable under a fair-neutral retailer. Thirdly, the fairness behavior of the retailer only improves the profit of the retailer while decreases the optimal values of the decision variables, and profits of the manufacturer and the entire supply chain. Fourthly, when all the remanufactured products become like-new products, it is profitable for all the channel members including the consumers. It is also beneficial to the environment, since it encourages the collector to collect more used products and it decreases unit emission during production. Fifthly, if transferring the collection activity becomes a preferred strategy for collecting used products and the manufacturer refuses to pay too much transfer price, then the collection through the third-party is favorable for the manufacturer under the retailer’s fairness concern. Even the fair-minded retailer also prefers the third-party led collection when the manufacturer refuses to pay much transfer price. Finally, the proposed contract encourages the retailer to sell the higher green product with a lower selling price and a higher marketing effort. Thus, it helps in creating an operating environment built on trust, commitment and mutual benefits (social). Furthermore, it can improve the collection rate of used products and reduce unit emission during production by increasing the greening level of the products. These outcomes help in rising environmental sustainability. Moreover, the proposed contract enhances the profits of the channel members and the entire supply chain. Hence it is beneficial from an economic perspective. In this manner, the proposed restitution-based wholesale price contract elevates all three dimensions of sustainability.

In light of the above insights, we propose the following practical implications that business managers can use to improve their management results.

- Consumers’ environmental awareness, producing green product, exerting effort in marketing and retailer’s fairness concern have a noteworthy impact on the pricing policies, greening and marketing strategies, profits of the channel members, and emission during production. With the help of these effects, business managers can get an idea of how to make the appropriate decisions and which model gives the better potential results for the development of their economic and environmental objectives.
- If selling prices for a similar type of product tend to be almost the same, the service level as an indicator of marketing effort, is considered an important factor in attracting consumers in the retail store. In this situation, in order
to acquire a competitive advantage in the market and establish a good corporate image, it is indispensable for the retailing managers, as service providers for consumers, to commit themselves in improving their service levels and guaranteeing that consumers have good shopping experiences.

- Building up mutual trust and information sharing between channel individuals are beneficial to both the supply chain and the environment in terms of profit and unit carbon emission during production. While signing a contract with the manufacturer, if the retailer accepts that the manufacturer will think about green improvement and its profit allocation, and at the same time not take any adverse decision in her favor, it will be easier to achieve a win-win situation by alleviating all the negative effects of the retailer’s fairness concern.

- Due to the fact that when all the remanufactured products are available for selling in the primary market, it is beneficial from both economic and environmental viewpoints. The supply chain managers should force the manufacturers in utilizing more advanced technology so that they can turn all the used products into brand new products. At the same time, the collectors should check the quality of used products during collection.

- To instigate manufacturers in making the best attempt to control carbon emissions, the government sector may impose a cap on emissions during production and offer a cap-and-trade policy.

Although this investigation displays some significant insights, it can be extended in various ways. The current study considers that the market demand is deterministic and the information is known to all the channel members. However, in reality, several factors can affect the market demand and all the information may not be available to all the channel members. So, consideration of stochastic demand under information asymmetry can be an extension of the current study. This study only considers the manufacturer-led Stackelberg scenario for decentralized models. Different power structures viz. retailer-led, third party-led Stackelberg and Nash game setting can be considered in further research. In this era of advanced technology, e-commerce is getting more attention. So, the present model can be extended to consider a dual-channel structure. In practice, there exist multiple manufacturers and multiple retailers for trading a single product and collecting used products. Accordingly, the effect of competition among them can be investigated in future studies. Additionally, the current study can be extended by instigating the effect of different contracts on optimal decisions.

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Appendix A1. Proofs of Model-C

The profit function in the centralized model is given by

$$
\Pi^C_w = pD - c_m(D - \rho D_r) - (c_r + A)D_r + w_1(1 - \rho)D_r - \lambda \theta^2 - \eta e^2 - \mu \tau^2
$$

Now,

$$
\frac{\partial \Pi^C_w}{\partial p} = D_0 - 2\alpha p + \beta \theta + \gamma e + \alpha[c_m - \tau(X - A)]; \quad \frac{\partial^2 \Pi^C_w}{\partial p^2} = -2\alpha < 0,
$$
The corresponding Hessian matrix is given by
\[ H^C = \begin{pmatrix}
-2\alpha & 2\beta & \gamma & -\alpha(X - A) \\
2\beta & -2\lambda & 0 & \beta(X - A) \\
\gamma & 0 & -2\eta & \gamma(X - A) \\
-\alpha(X - A) & \beta(X - A) & \gamma(X - A) & -2\mu
\end{pmatrix} \]
The principal minors are: \(|M_1| = -2\beta < 0, \ |M_2| = 4\alpha\lambda - \beta^2 > 0, \) as \( \lambda > \frac{\beta^2}{4\alpha}, \ |M_3| = -2(4\alpha\lambda - (\lambda\gamma^2 + \eta\beta^2)) < 0, \) as \( 2\alpha\lambda - (\lambda\gamma^2 + \eta\beta^2) > 0 \) and \(|H^C| = 4\mu(\lambda(4\alpha\eta - \gamma^2) - \eta\beta^2) = \omega(\lambda(4\alpha\eta - \gamma^2) - \eta\beta^2) - \alpha^2\eta\lambda(X - A)^2 > 0, \) as \( \mu(\lambda(4\alpha\eta - \gamma^2) - \eta\beta^2) = \alpha\lambda(2\alpha - \alpha(X - A))^2 + \mu(2\alpha\lambda - (\lambda\gamma^2 + \eta\beta^2)) > 0. \) Therefore, the Hessian matrix \( H^C \) is negative definite i.e. the profit function \( \Pi_i^C \) is jointly concave with respect to \( p, \theta, e \) and \( \tau, \) which proves Lemma 4.1.

Now, solving \( \frac{\partial \Pi^C}{\partial p} = 0, \frac{\partial \Pi^C}{\partial \theta} = 0, \frac{\partial \Pi^C}{\partial e} = 0 \) and \( \frac{\partial \Pi^C}{\partial \tau} = 0, \) simultaneously, we can get unique optimal decisions of the centralized supply chain.

Appendix A2.

Proofs of Model-MN

The profit functions of the manufacturer and the retailer in Model-MN are given by
\[ \Pi^M_M = wD - c_m(D - \rho D_r) - (c_r + A) D_r + w_1(1 - \rho) D_r - \lambda\theta^2 - \mu \tau^2, \]
\[ \Pi^M_r = (p - w)D - \eta e^2 \]
The retailer’s reaction
\[ \frac{\partial \Pi^M_M}{\partial p} = D_0 - 2\alpha p + \beta e + \gamma e + \alpha w; \quad \frac{\partial^2 \Pi^M_M}{\partial p^2} = -2\alpha < 0, \]
\[ \frac{\partial \Pi^M_M}{\partial e} = \gamma(p - w) - 2\eta e; \quad \frac{\partial^2 \Pi^M_M}{\partial e^2} = -2\eta < 0; \quad \frac{\partial^2 \Pi^M_M}{\partial e \partial p} = \gamma < 0. \]
The Hessian matrix of \( \Pi^M_M \) is given by
\[ H^M_M = \begin{pmatrix}
-2\alpha & \gamma & -2\eta \\
\gamma & -2\eta
\end{pmatrix} \]
The principal minors are: \(|M_1| = -2\alpha < 0 \) and \(|H^M_M| = 4\alpha\eta - \gamma^2 > 0, \) as \( \eta > \frac{\gamma^2}{4\alpha}. \) Therefore, the Hessian matrix \( H^M_R \) is negative definite i.e. the profit function \( \Pi^M_M \) is jointly concave in \( p \) and \( e, \) which proves Lemma 4.2.

The manufacturer’s reaction

With the optimal decisions of the retailer, the profit function of the manufacturer becomes
\[ \Pi_{m}^{MN} = \frac{2\alpha \eta (D_{0} - \alpha w + \beta \theta)(w - c_{m} + \tau (X - A))}{4\alpha \eta - \gamma^{2}} - \lambda \theta^{2} - \mu \tau^{2} \]

Now, \( \frac{\partial^{2} \Pi_{m}^{MN}}{\partial w^{2}} = -\frac{4\alpha^{2} \eta}{4\alpha \eta - \gamma^{2}} < 0; \) \( \frac{\partial^{2} \Pi_{m}^{MN}}{\partial \theta^{2}} = -2\lambda < 0; \) \( \frac{\partial^{2} \Pi_{m}^{MN}}{\partial \tau^{2}} = -2\mu < 0, \)

The Hessian matrix of \( \Pi_{m}^{MN} \) is given by

\[
H_{MN}^{M} = \begin{pmatrix}
-\frac{4\alpha^{2} \eta}{4\alpha \eta - \gamma^{2}} & \frac{2\alpha \beta \eta}{4\alpha \eta - \gamma^{2}} & -\frac{2\alpha^{2} \eta (\lambda - A)}{4\alpha \eta - \gamma^{2}} \\
\frac{2\alpha \beta \eta}{4\alpha \eta - \gamma^{2}} & -\frac{2\alpha \beta \eta (X - A)}{4\alpha \eta - \gamma^{2}} & 0 \\
-\frac{2\alpha^{2} \eta (X - A)}{4\alpha \eta - \gamma^{2}} & 0 & -\frac{2\mu}{4\alpha \eta - \gamma^{2}}
\end{pmatrix}
\]

The principal minors are: \( |M_{1}| = -\frac{4\alpha^{2} \eta}{4\alpha \eta - \gamma^{2}} < 0; \) \( |M_{2}| = \frac{4\alpha^{2} \eta [2(4\alpha \eta - \gamma^{2}) - \eta \beta^{2}]}{(4\alpha \eta - \gamma^{2})^{2}} > 0 \)
and \( |H_{MN}^{M}| = \frac{8\alpha \eta \mu}{(4\alpha \eta - \gamma^{2})^{2}} < 0. \) Under these conditions, the Hessian matrix \( H_{MN}^{M} \) becomes negative definite i.e. the profit function \( \Pi_{m}^{MN} \) is jointly concave in \( w, \theta \) and \( \tau \), which proves Lemma 4.3.

Thus, the optimal decisions can be obtained by using the first order optimality conditions.

**Appendix B1.**

**Proof of Proposition 1**

\[
\tau^{C} - \tau^{RN} = \frac{\alpha \eta \lambda (D_{0} - c_{m} \alpha)}{\mu (\lambda (4\alpha \eta - \gamma^{2}) - \eta \beta^{2}) + \alpha^{2} \eta \lambda (X - A)(X - A)} > 0.
\]

\[
\tau^{RN} - \tau^{MN} = \frac{\alpha \eta \lambda (D_{0} - c_{m} \alpha)(\lambda (X - B) - \eta \beta^{2}) - \alpha^{2} \eta \lambda (X - A)(X - A)\lambda (X - A)}{\mu (\lambda (4\alpha \eta - \gamma^{2}) - \eta \beta^{2}) + \alpha^{2} \eta \lambda (X - A)\lambda (X - A)} > 0.
\]

If \( B > \frac{\mu X (2(4\alpha \eta - \gamma^{2}) - \eta \beta^{2}) + \alpha^{2} \eta \lambda (X - A)^{2}}{\mu (\lambda (4\alpha \eta - \gamma^{2}) - \eta \beta^{2}) + \alpha^{2} \eta \lambda (X - A)^{2}} \) then

\[
\tau^{MN} - \tau^{T} = \frac{\alpha \eta \lambda (D_{0} - c_{m} \alpha)(\lambda (X - B) - \eta \beta^{2}) - \alpha^{2} \eta \lambda (X - A)^{2}}{\mu (\lambda (4\alpha \eta - \gamma^{2}) - \eta \beta^{2}) + \alpha^{2} \eta \lambda (X - A)^{2}} > 0.
\]

**Appendix B2.**

**Proof of Proposition 2**

\[
w^{RN} - w^{T} = \frac{\alpha \eta ^{2} \lambda (B - A)^{2}(D_{0} - c_{m} \alpha)\beta \mu - 2\alpha \lambda (B - A)(B - A)}{\mu (\lambda (4\alpha \eta - \gamma^{2}) - \eta \beta^{2}) - \alpha^{2} \eta \lambda (X - A)(B - A)} > 0.
\]

If \( \beta > \sqrt{\frac{2\alpha^{2} \lambda (B - A)(B - A)}{\mu}} \) then

\[
w^{T} - w^{MN} = \frac{\alpha \eta \lambda (D_{0} - c_{m} \alpha)[(X - B)^{2} + \eta \beta^{2}] - \alpha^{2} \eta \lambda (X - A)(X - A)}{\mu (\lambda (4\alpha \eta - \gamma^{2}) - \eta \beta^{2}) - \alpha^{2} \eta \lambda (X - A)^{2}} > 0.
\]

**Appendix B3.**

**Proof of Proposition 3**

(i) For the greening level

\[
\theta^{C} - \theta^{RN} = \frac{\beta \eta \lambda \mu (D_{0} - c_{m} \alpha)(\lambda (4\alpha \eta - \gamma^{2}) - \alpha^{2} \eta (2B - X)(X - A))}{\mu (\lambda (4\alpha \eta - \gamma^{2}) - \eta \beta^{2}) - \alpha^{2} \eta \lambda (X - A)^{2}} > 0.
\]
\[ g_{RN} - g_{MN} = \frac{\beta \eta \mu (D_0 - c_m \alpha)}{\mu (2\lambda (4\alpha \theta - \gamma^2) - \eta \beta^2)} \frac{\alpha^2 \eta (2B - \gamma^2)(X - A)}{(X - A)} \]
\[ > 0, \text{ if } B > \frac{X + A}{2}. \]
\[ g_{MN} - g_{TN} = \frac{\alpha^2 \eta \lambda \mu (D_0 - c_m \alpha)}{\mu (2\lambda (4\alpha \theta - \gamma^2) - \eta \beta^2)} \frac{2(2B + (X - B))^2}{2(2B + (X - B))^2} \]
\[ > 0. \]

(ii) For the marketing effort
\[ e^C - e_{RN} = \gamma \lambda (2\alpha \theta (D_0 - c_m \alpha)) \frac{\alpha (4\alpha \theta - \gamma^2) - \alpha^2 \eta (2B - \gamma^2)(X - A)}{(X - A)} \]
\[ > 0, \text{ if } B > \frac{X + A}{2}. \]
\[ e_{RN} - e_{MN} = \frac{\alpha^2 \eta \lambda \mu (D_0 - c_m \alpha)}{\mu (2\lambda (4\alpha \theta - \gamma^2) - \eta \beta^2)} \frac{(2B - A)^2}{2(2B - A)^2} \]
\[ > 0, \text{ if } B > \frac{X + A}{2}. \]
\[ e_{MN} - e_{TN} = \frac{\alpha^2 \eta \lambda \mu (D_0 - c_m \alpha)}{\mu (2\lambda (4\alpha \theta - \gamma^2) - \eta \beta^2)} \frac{(B - A)^2}{2(2B - A)^2} \]
\[ > 0. \]

(iii) For the selling price
\[ p_{TN} - p_{MN} = \frac{\alpha \eta \lambda \mu (D_0 - c_m \alpha)}{\mu (2\lambda (4\alpha \theta - \gamma^2) - \alpha^2 \eta (2B - \gamma^2)(X - A))} \]
\[ > 0, \text{ if } B > \frac{X + A}{2}. \]
\[ p_{MN} - p_{RN} = \frac{\alpha \eta \lambda \mu (D_0 - c_m \alpha)}{\mu (2\lambda (4\alpha \theta - \gamma^2) - \eta \beta^2)} \frac{2(2B - A)^2}{2(2B - B)^2} \]
\[ > 0, \text{ if } B > \frac{X + A}{2}. \]
\[ p_{RN} - p_{C} = \frac{\lambda \mu (D_0 - c_m \alpha)}{\mu (2\lambda (4\alpha \theta - \gamma^2) - \alpha^2 \eta (2B - \gamma^2)(X - A))} \]
\[ > 0. \]

Appendix B4.

Proof of Proposition 4

(i) For the manufacturer's profit
\[ \Pi_{RN}^m - \Pi_{MN}^m = \frac{\alpha^2 \eta \lambda \mu (D_0 - c_m \alpha)^2}{\mu (2(2B + (X - B))^2)} \frac{B - A)(X - A)}{(X - A)^2} \]
\[ > 0, \text{ if } B > \frac{X + A}{2}. \]
\[ \Pi_{MN}^m - \Pi_{TN}^m = \frac{\alpha^2 \eta \lambda \mu (D_0 - c_m \alpha)^2}{\mu (2(2B + (X - B))^2)} \frac{B - A)(X - A)}{(X - A)^2} \]
\[ > 0. \]

(ii) For the retailer's profit
\[ \Pi_{RN}^r - \Pi_{MN}^r = \frac{\alpha^2 \eta \lambda \mu (D_0 - c_m \alpha)^2}{\mu (2(2B + (X - B))^2)} \frac{B - A)(X - A)}{(X - A)^2} \]
\[ > 0, \text{ if } B > \lambda + \sqrt{\lambda \mu (4\alpha \theta - \gamma^2)Y_2}. \]
where
\[ Y_1 = \frac{\beta}{\lambda} \frac{(2(2B + (X - B))^2 - \eta \beta^2)}{\lambda (2B + (X - B))^2} - \alpha^2 \eta \lambda (2\beta^2 \mu + \alpha^2 \lambda (X - A)^2), \]
\[ Y_2 = \frac{\beta}{\lambda} \frac{(2(2B + (X - B))^2 - \alpha^2 \eta \lambda (X - A)^2)}{\lambda (2B + (X - B))^2} - \alpha^2 \eta \lambda (X - A)^2. \]
\[ \Pi_{MN}^r - \Pi_{TN}^r = \frac{\alpha^2 \eta \lambda \mu (D_0 - c_m \alpha)^2}{\mu (2(2B + (X - B))^2)} \frac{B - A)(X - A)}{(X - A)^2} \]
\[ > 0. \]
Appendix B5.

Proof of Proposition 5

\[ w_{MN} - μ_MF = \]
\[ 2\lambda^2 δ^2 \left[ \frac{2(\lambda X - A)}{2(\lambda X - A)^2} \right] > 0. \]

\[ \frac{\mu}{\lambda} \left[ 2(\lambda X - A) \right] > 0. \]

\[ p_{MN} - \frac{p}{MF} = \]
\[ \eta(\lambda X - A)^2 \left[ \frac{2(\lambda X - A)}{2(\lambda X - A)^2} \right] > 0. \]

\[ \theta_{MN} - \frac{θ}{MF} = \]
\[ \frac{α}{λ} \left[ 2(\lambda X - A) \right] > 0. \]

\[ e_{MN} - e_{MF} = \]
\[ \gamma(\lambda X - A)^2 \left[ \frac{2(\lambda X - A)}{2(\lambda X - A)^2} \right] > 0. \]

\[ Π_{MN} - Π_{MF} = \]
\[ 2\lambda^2 δ^2 \left[ \frac{2(\lambda X - A)}{2(\lambda X - A)^2} \right] > 0. \]

\[ Π_{RF} - Π_{RF} = \]
\[ \eta(\lambda X - A)^2 \left[ \frac{2(\lambda X - A)}{2(\lambda X - A)^2} \right] > 0. \]

\[ \frac{μ}{λ} \left[ 2(\lambda X - A) \right] > 0. \]

Let \[ F(Z) = Z^2 ξ(4+ξ) - 4\lambda Z(4\lambda X - A)^2 Z - 4\lambda^2 δ^2 (4\lambda X - A)^2 \]. The discriminant of \( F(Z) \) is \( 16\lambda^2 ξ^2 (4\lambda X - A)^2 [1 + ξ(4 X + A)] > 0 \). Hence, roots of \( F(Z) \) are real and given by \[ Z_+ = \frac{2\lambda(4\lambda X - A)^2 [1 + ξ(4 X + A)]}{4 + ξ} \]. Now, \[ Z > Z_+ \]. Therefore, \[ Π_{RF} > Π_{MN} \] is proved.

Proofs for the retailer-led collection and third-party-led collection being similar, for brevity, we omitted those proofs.

Appendix B6.

Proof of Proposition 6

On simplification, the numerator of \( p_{RF} - p_{TF} \) becomes \( 2\lambda(\lambda X - A) [\xi(X - B)^2 - (B - A)^2] \) which is greater than 0 if \( B < \frac{\sqrt{ξ(4 + ξ)}}{1 + ξ} \). Hence, \( p_{RF} > p_{TF} \) if \( B < \frac{\sqrt{ξ(4 + ξ)}}{1 + ξ} \).

The other results of Proposition 6 can be proved similarly.

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