Article

CSR Remanufacturing Supply Chains under WTP Differentiation

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Abstract: With the shortage of global resources and the call for sustainable development, the remanufacturing supply chain and the corporate social responsibility of enterprises have attracted extensive attention from scholars. This paper studies a manufacturer-retailer corporate social responsibility (CSR) remanufacturing supply chain in which the manufacturer collects the used products grounded in the willingness to pay (WTP) differentiation. Different from previous literature, this paper first adds WTP differences to the CSR remanufacturing supply chain. Next, we analyze the manufacturer exhibiting CSR activity by Stackelberg game theory in both centralized and decentralized models with a consideration of prices, recycling, consumer surplus, and profits for the chain players in the two models with different CSR ratios. Through calculation and analyses of the models, we note that the chain members have the best status when the consumers’ WTP for new and remanufactured products is within a threshold. Subsequently, we compare the optimal price decisions and the expected profits in the decentralized and centralized systems, and we find that the retail price, wholesale price, and recycling rate decrease with a rising CSR under WTP differentiation. The centralized retail price is lower than the decentralized one. Conversely, the profit is higher when the increment of demand is higher. On top of that, in common cases, the pure and total profits of manufacturing are ascending while the retailer’s profit is descending. We also find that the consumer surplus is increasing in two cases. Finally, to motivate the players in the supply chain to engage in CSR activity, we consider the revenue sharing contract. From the perspective of WTP differences, this paper studies CSR remanufacturing, which has certain influences on the sustainable development of the economy.

Keywords: willingness to pay; corporate social responsibility; remanufacturing supply chain; game theory

1. Introduction

With the rapid development of science and technology, human quality of life has been drastically improved. At the same time, environmental degradation and poverty are still critical problems that we must prioritize. While some of us order takeaway with our smartphones, others suffer from starvation due to poverty. While astronomers search for the secrets of space with their telescopes, the ecological environment in which we reside is deteriorating. Though we cannot see it with our own eyes, this does not necessarily mean that it does not exist. Thus, the research on the remanufacturing chain plays an immeasurable role in saving natural resources and protecting the environment. Over the years, many researchers have made great contributions to this field. Thus, it is of great significance to study...
these issues. Nunen Jaee et al. (2004) showed that the remanufacturing supply chain is the realization of enterprise remanufacturing, which refers to the organic combination of the traditional forward and reverse supply chain to form a complete circular supply chain [1]. Remanufacturing not only relieves resource shortages but also mitigates environmental pollution. Therefore, it is highly valued in business and academic circles. There are many research results of remanufacturing supply chains. They mainly focus on the product price, product quality, channel preference, risk attitude, and the social environment [2–12]. More recently, in terms of the sustainability of the economy and the profits of consumers, some research has focused on corporate social responsibility (CSR) in remanufacturing supply chains. For instance, according to Merrick (2004), the world’s largest clothing retailers, GAP, admitted that working conditions in up to 3000 factories are substandard around the world. Meanwhile, the development of enterprises brings more or less negative impacts to society and the environment, thus damaging the interests of consumers [13]. Whether or not enterprises undertake corporate social responsibility is also subject to enormous external pressure and public opinion. Auger et al. (2003) studied consumers who are willing to pay higher price for goods with CSR attributes, and CSR affects 70% of consumers’ purchasing decisions [14]. KPMG (2008) stated that 80% of the world’s 250 largest companies published CSR reports in 2008, globally. Eighty percent of the largest companies, such as Apple and Nike, participate in CSR activities. In consideration of corporate profits, many enterprises have to bear the corporate social responsibility [15]. Amaeshi et al. (2008) examined many leading global brands such as Nike, GAP, Adidas, and McDonalds, which have been faced with intense pressure for socially responsible supply chain management as firms enjoy the benefits. Amaeshi et al. (2008) investigated numerous forward-looking consumers support products with CSR [16]. In prior studies, some researchers were interested in the members engaged in CSR activities in the supply chain [17–24].

In light of the past literature, many scholars believe that there is no discrepancy between the manufacturing process of remanufactured and new products when consumers’ willingness to pay for new and remanufactured products is consistent. From the perspective of product differential pricing, there is little literature about the impact of recycling and remanufacturing on pricing strategies, recovery rates, and profits of new products and remanufactured products in the remanufacturing supply chain. In practice, due to the limitation of reengineering technology and consumers’ prejudice on the understanding of remanufactured products, there are still differences in recognition and demand for new and remanufactured products in the market. Actually, with the advance of the Internet and information technology, the cognition degree of products, shopping environment, social economic factors, and consumers’ characteristics are increasingly prominent. Individuals have distinct willingness to pay (WTP) due to varying salaries, poverty levels, and personal preferences. There are significant differences in the willingness of consumers to pay for new and remanufactured products, exerting a significant impact on the decision-making of manufacturers. Guide et al. (2010) used a novel approach and field auctions, exploring their study with in-depth conversations with practicing managers. They proposed that consumers’ WTP for remanufactured consumer product was 15.3% lower than for new product, whereas other action results showed that consumers’ WTP for remanufactured products was 9.7% lower than for new ones. When we approach the commodity market; empirically we can feel a significant gap between new products and remanufactured products. It is unquestionable that researchers are concerned about the differences in new and remanufactured products [25]. As a matter of fact, there are earlier studies on consumer’s cognition of the product in the related issues. To illustrate, Aaker and Keller (1990) investigated consumer evaluations of brand extensions and noted that consumers were willing to pay more for branded products [26]. Vorasayan and Ryan (2006) studied the optimal demand and price of remanufactured products in the market [27]. In particular, Gerado Ferrer et al. (2006) considered the differences between new and remanufactured products in greater detail [28]. The research of Guide et al. (2010) illustrated that the WTP differentiation had a significant impact on manufacturer’s decision making and on the decision makers in the remanufacturing supply chain [25]. Consequently, the WTP differentiation is
quite critical in the study of the CSR remanufacturing supply chain, and this paper will also consider this difference.

This study is concerned with manufacturers who collect used products and engage in CSR activities in the remanufacturing supply chain under WTP differentiation. In particular, Panda Shibaji et al., (2017) considered retailers collecting and manufacturing with CSR, enriching the related literature, but none consider WTP differentiation [22]. In this paper, consumers pay differently for new and remanufactured products, and the demand function is similar to Ferrer Geraldo et al. (2006, 2010) [28,29]. In consideration of the existing literature and in response to the psychological warfare of consumers paying inconsistently for new and remanufactured products, we develop models for the manufacturer who collects used products in the decentralized and centralized models in light of the Stackelberg game. Also, we propose a simple revenue sharing contract to improve the marginal effect based on research on prices, recycling rates, and profit change with the proportion of CSR. Actually, it is commonplace in real life for manufacturers to collect used products, and it is worth mentioning that the calculation of the model is very complicated in this paper. The majority of our research concerns the coordination problem by adopting relevant contracts in the supply chain. Understandably, the coordination of the supply chain has been extensively studied, and many coordination strategies are theoretically optimal and feasible in practice, such as the wholesale price coordination contract, the revenue sharing contracts, buyback, and the discount contract [19,21,30–34].

As discussed above, in light of observation and analyses, we attempt to answer these questions:

(1) What are the effects of recycling and profits under WTP differences in two models?
(2) How does investment change in the CSR affect decisions and profits in the remanufacturing supply chain?
(3) Can the revenue sharing contract improve the revenue of each player and enable him to actively participate in CSR activities?

To solve the above problems, this paper adopts the classic game theory decision, which plays a critical role in supply chain decision-making. Many prior studies also applied this method to solving related [19,22,34,35]. The manufacturer serves as a Stackelberg leader while the retailer serves as a follower, i.e., the decision process follows this principle. In this game, when two players do not act simultaneously, the latter can know exactly the action of the former and then take his/her individual action.

The rest of the paper is organized as follows. In Section 2, we discuss the related literature, and Section 3 introduces the model description and analyses. In Section 4, numerical analysis is described. Some results and future research orientations are presented in Section 5.

2. Literature Review

Remanufacturing supply chain management has been much researched, and has mainly included the product price, product quality, channel preference, risk attitude, and the social environment, among many other issues [2–12]. This section aims to present a brief review of the literature related to our paper, which considers the remanufacturing supply chain with recycling approaches, corporate social responsibility, and the consumers’ willing to pay.

2.1. Remanufacturing Supply Chain with Recycling Approaches

Guide et al. (2003) proposed to solve the problem of recycling through economic rebate [36]. Savaskan et al. (2004) researched the recycling channel to coordinate the remanufacturing supply chain, discussing four options for collecting used products: centralized collecting, manufacturer collecting, retailer collecting, and third party collecting [8]. It is considered as a classic paper in the reverse channel. Our paper studies manufacturer led collection.

Some researchers are interested in studying the relevant problems. Huang Min and Song Min et al., (2013) explored the optimal strategies of a remanufacturing supply chain with the dual recycling channel in which the manufacturer sells products via the retailer in the forward supply chain, while the
retailer and the third party competitively collect used products in the reverse supply chain. Through a comparative analysis, the results can serve as a reference for choosing the recycling model to collect used products [37]. Yi Pengxing et al. (2016) confirmed that the remanufacturer can gain more used product returns and profits with the dual recycling channel, and that the optimal allocation of the collection efforts to the retailer and the third party are determined by the relationship of the reverse logistics cost coefficients [38]. Georgiadis (2013) proposed a system dynamics model for strategic capacity planning in the recycling industry. This model captures physical stocks and flows apparent in real-world recycling networks, including the feedback mechanisms that regulate these flows [39]. Modak et al. (2018) analyzed the effects of recycling and product quality level on pricing decision in a two-echelon remanufacturing supply chain, where demand is sensitive to price and the quality level of the product, with consideration of three possible collection activities of used products for recycling, viz, retailer led collection, manufacturer led collection, and third party led collection. They found that the third party’s involvement in the used product collection activity is always disadvantageous [40]. Su Jiafu et al. (2019) established a two-stage closed-loop supply chain game model. In terms of the influence of the environmental protection input on the whole supply chain, the different choices will have impacts on the benefits of the whole supply chain when manufacturers select a closed-loop supply chain model of third-party recycling [41]. Xu Lang et al. (2018) compared the decisions and profits in the centralized and decentralized scenarios, where a contract through revenue and cost sharing was provided to achieve the supply chain coordination in the framework of Nash negotiation, and the coefficient of sharing was obtained to improve the performance [42].

2.2. Corporate Social Responsibility in Supply Chains

With growing globalization, CSR has attracted tremendous attention and become the mainstream in academic and business circles. Among a multitude of ways to measure corporate social responsibilities, most researchers measure CSR activities by consumer surplus, and they mostly focus on the coordination of the remanufacturing supply chain with corporate social responsibility. Previously, Carter Jennings (2002) found a positive relationship between CSR and supplier performance [17]. Murphy et al. (2002) studied a CSR report, explaining the importance of CSR in enterprise production [43]. In the following year, Auger et al. (2003) proposed that consumers tend to pay for products with social responsibility features [14]. Maloni et al. (2006) drew upon previous research and the emerging industry to develop a comprehensive framework of supply chain CSR in the industry [44]. The framework details unique CSR applications in the food supply chain including animal welfare, biotechnology, environment, fair trade, health and safety, and human rights. Panda (2014) argued that corporate social responsibility is roughly defined as a kind of behavior in which an enterprise shows social responsibility and ethical responsibility to many stakeholders. When the enterprise pursues profit maximization, its working conditions, among other things, are unsatisfactory. With closer attention to the profits of consumers, several scholars have studied the CSR supply chain in recent years. Several recent studies of remanufacturing have centered on corporate social responsibility [45]. Stekelorum (2019) provided a systematic literature review of the implementation of CSR practices in the supply chains of (small-and medium-sized enterprises) SMEs [46]. Shi Yuan et al. (2015) considered a remanufacturing supply chain consisting of retailers, manufacturers, and third-party logistics service providers, who bear the product recycling responsibilities [24]. Hsueh (2014) displayed a new revenue sharing contract involving corporate social responsibility (RS-CSR) for coordinating a two-tier supply chain. The experiment results not only corresponded to some facts revealed in the literature but also provided some insights into the integration of CSR into the supply chain. The RS-CSR contract requires that the manufacturer invests in CSR and charges the retailer a wholesale price. After the retailers sell products, they will return a ratio of its revenue to the manufacturer [19]. Panda et al. (2017) analyzed the effects of corporate social responsibility (CSR) and explored channel coordination in a socially responsible manufacturer-retailer remanufacturing supply chain by considering two areas of profit maximization and social responsibility through product recycling. The study depicted the manufacturer who used
CSR in the form of recycling as a profit-making tool. Our article is similar to Panda et al. (2017), which means that CSR concerns the closed-loop supply chain. The difference is that we consider manufacturers recycling used products, whereas they studied retailers recycling used products. Most importantly, they believe that consumers are just as willing to pay for remanufactured products as they are for new ones. Recycling cannot be done arbitrarily, because there is an upper limit of recycling for profit maximization. When the manufacturers increase CSR, they also reduce the wholesale price. In response, the retailer makes more efforts to collect used product and decreases the selling price to encourage the customers to buy more [22]. Shu et al. (2018) investigated the optimal decisions of remanufacturing supply chains in the context of social responsibility, explored the impacts of the constraints of carbon emissions and corporate social responsibility on recycling and remanufacturing decisions, and introduced the model of maximizing social welfare for further comparison and analysis [23]. Additionally, Hsueh (2014) developed a CSR index (CSRI) to quantitatively evaluate CSR, consisting of four dimensions measuring a firm’s contribution to the economy, society, environment, and corporate governance [19]. Recently, Modak and Kazemi (2019) considered the effects of selling prices and social work on demand, developing optimal closed-form solutions for a structure with three decentralized channels and a centralized channel [40]. Hosseini-Motlagh et al. (2019) developed an (reverse supply chain) RSC model and derived the optimal pricing, sustainability level, and corporate social responsibility (CSR) decisions under demand disruptions for both the decentralized and centralized RSCs, proposing a combinational scheme by using the combined two-part-tariff (CTPT) contract [18]. Stekelorum et al. (2019) investigated to what extent the CSR requirements of customers influence the CSR activities of SMEs and their CSR requirements toward their own suppliers [47]. Of course, there is a lot of literature on supply chain coordination contracts, all of which are classic (Cachon and Lariviere, 2005; Govindan and Popiuc, 2014; Shi et al., 2016; Panda et al., 2016; Raza, 2018) [30,32–34,48]. These contracts can address the supply chain problem with CSR. Based on the existing literature, our paper finally proposes a simple revenue sharing contract to solve the benefit problem of the remanufacturing supply chain members.

2.3. WTP Differentiation

With the development of economy and the change of consumers’ preference for products, there are significant differences in consumers’ willingness to pay for new and remanufactured products in the remanufacturing supply chain. This paper takes this difference into account in the CSR remanufacturing supply chain and studies how the price, recovery rate, and profit of the supply chain members will be affected by the presence of this difference. In fact, the WTP differences for new and remanufactured products have drawn scholars’ attention. Since Devavrat (1992) pointed out that prices of older versions in the secondary market adjusted in response to changes incorporated in new versions of the product [49]. Harrison et al. (2005) studied the rationale for these tests, arising from debates over the validity of the contingent valuation method (CVM) for valuing environmental damages. The CVM is a survey instrument commonly used in environmental resource valuations, which is hypothetical in both the payment for and the provision of the goods being valued [35]. Daniel and Guide (2010) addressed the cannibalization issue by using auctions to determine consumers’ willingness to pay (WTP) for both new and remanufactured products. The auctions also allow us to understand the potential impact of offering new and remanufactured products at the same time, which provides us insights into the potential for new product cannibalization [25]. The research of Guide et al. (2010) shows that the WTP differentiation has an enormous impact on the manufacturer’s decision making and has a paramount impact on decision makers in the closed-loop supply chain [25]. Geraldo et al. (2006, 2010) showed that, if remanufacturing was very profitable, the original-equipment manufacturer may forgo some of the first-period margin by lowering the price and selling additional units to increase the number of cores available for remanufacturing in future. They found that the remanufactured product was differentiated from the new product and, therefore, the firm needs to choose differentiated prices and characterize the optimal pricing and production strategy under finite (two, three, four, and five
periods) and infinite planning horizons of a remanufacturing monopolist in order to identify patterns in the optimal policy [28,29]. Our article concerns the WTP differentiation using demand functions similar to Guide et al. (2010) and Ferrer Geraldo et al. (2006, 2010) [28,29]. Previously, some scholars considered similar problems in the closed-loop supply chain and studied relevant decision-making problems. Gao et al. (2014) established decision-making models in the two-period remanufacturing closed-loop supply chain in two contexts: The decentralized decision and centralized decision under WTP differentiation, having a profound influence on the decisions of the members in the supply chain and on profits [50]. Long, X. et al. (2019) considered the WTP heterogeneity or various remanufactured products in one-period and two-period remanufacturing supply chain scenarios [51].

Based on the literature above, the gaps that the paper can fill in are summarized as follows. Firstly, few studies or little literature considers WTP differentiation in the CSR remanufacturing supply chain. On top of that, previous research assumes that there is no difference in consumers’ willingness to pay for new and remanufactured products, and therefore the results of our study are significant from this perspective. Most importantly, our article takes this difference into account, and the results may not be consistent with the past. As a result, this paper can shed light on the influence on the decisions of the remanufacturing supply chain’s members and the profits of the CSR remanufacturing supply chain.

3. Model Description and Analysis

3.1. Notation and Assumption

**Notation.** The model parameters and the major notions in the model

- $p_i$: Unit retail price of the product
- $w_i$: Unit wholesale price of the product
- $c_i$: Unit cost of a product
- $k$: Recovery scale parameter
- $\epsilon$: Consumers’ willingness to pay for both new and remanufactured products, $0 < \epsilon < 1$
- $Q$: Capacity of the market
- $c$: Unit of the manufacturer paid to customers for a returned unit
- $\alpha$: The fraction of CSR, $0 \leq \alpha \leq 1$
- $C_j$: The consumer surplus
- $\tau$: Return rate of used products from the consumers, $0 < \tau < 1$
- $v_{jn}$: Total profit function of $n$ in model $j$
- $i, n, ji = m, r$, denotes new and remanufacturing product; $n = r, m, c$, denotes retailer, manufacturer, the supply; $j = C, D$, denotes centralized and decentralized model

**Assumption 1.** The unit production cost of the new product is more than producing a new product by using a used product, which means that $c_m > c_r$. $\tau$ is the certain range $[0, 1]$, denoting the fraction of current generation product remanufacturing units. The manufacturer recycles (End-of-Life) EOL products, and the total recovery cost can be expressed as $k\tau^2 + c\tau(q_m + q_r)$, where $c$ is the fixed payment to the customer who returns a used product and $c$ is exogenous to the model. All recycled products can be remanufactured and fully meet the raw material requirements of remanufactured products. This assumption is similar to Savaskan et al. (2004) [8].

**Assumption 2.** $q_r = \frac{p_m - p_r}{\epsilon - \epsilon^2}$ denotes the demand function of the new product; $q_m = Q - \frac{p_m - p_r}{1 - \epsilon}$ denotes the demand function of the remanufactured product, $0 < \epsilon < 1$ and $p_m > p_r$, which means that there is less willingness to pay for remanufactured products than for new ones (Ferrer and Swaminathan (2006, 2010)) [28,29].

**Assumption 3.** A firm’s CSR is denoted through consumer surplus of its stakeholders. Consumer surplus is the gap between the maximum price that consumers are willing to pay for a product and the market price that they actually pay for the product. In combination with assumption 3, the consumer surplus is provided by (Panda et al. (2017)) [22], $\int_{p_{min}}^{p_{max}} \left( Q - \frac{p_r}{\tau} \right) dp_r = \frac{(\epsilon Q - p_r)^2}{2\epsilon}$. 
Assumption 4. In this game, the manufacturer serves as a Stackelberg leader, and the retailer serves as a follower, i.e., the decision process follows this principle. Also, when two players do not act simultaneously, the latter can know exactly the action of the former and then take his/her individual action. Much literature follows this rule. It is assumed that there is information symmetry and the risk is neutral (Savaskan et al., 2004; Panda et al., 2017; Ghosh and Shah, 2015; Xie et al., 2017; Shu et al., 2018) [8,22,31,52,53].

3.1.1. Decentralized Remanufacturing Supply Chain with CSR

According to the manufacturer’s strategy, the retailer makes the move to maximize profits. Below is the profit function of the retailer.

\[
\pi_r^D = (p_m - w_m)\left(Q - \frac{p_m - p_r}{1 - \epsilon}\right) + (p_r - w_r)\epsilon\frac{p_m - p_r}{(1 - \epsilon)} \tag{1}
\]

The pure profit function of the manufacturer is

\[
\pi_m^D = (w_m - c_m)\left(Q - \frac{p_m - p_r}{1 - \epsilon}\right) + (w_r - c_r)\epsilon\frac{p_m - p_r}{(1 - \epsilon)} - k\tau^2 - c\tau\left(Q - \frac{p_r}{\epsilon}\right) \tag{2}
\]

The total profit of the manufacturer is

\[
\nu_m^D = (w_m - c_m)\left(Q - \frac{p_m - p_r}{1 - \epsilon}\right) + (w_r - c_r)\epsilon\frac{p_m - p_r}{(1 - \epsilon)} - k\tau^2 - c\tau\left(Q - \frac{p_r}{\epsilon}\right) + \frac{\alpha(\epsilon Q - p_r)^2}{2\epsilon} \tag{3}
\]

Firstly, the retailer makes decisions on the retail price, and the manufacturer utilizes the results to make decisions about the wholesale price and recycling rate. All results are shown in Table 1.

| /Profits       | Model C | Model D |
|----------------|---------|---------|
| \(w_m^*\)     | Nil     | \(\frac{M+2}\alpha Q L}{2(N+2\alpha Q L)} + \frac{2H \epsilon + 2\alpha Q L}{4(N+2\alpha Q L)}\) |
| \(w_r^*\)     | Nil     | \(\frac{M+2\alpha Q L}{2(N+2\alpha Q L)} + \frac{2H \epsilon + 2\alpha Q L}{4(N+2\alpha Q L)}\) |
| \(p_m^*\)     | \(\frac{2(N+4\alpha Q L + 2\alpha Q L)}{H+2\alpha Q L + 2\alpha Q L + 2\alpha Q L^2 + 2\alpha Q L^2}\) | \(\frac{Q}{2} + \frac{2}{4(N+2\alpha Q L)}\) |
| \(p_r^*\)     | \(\frac{N+4\epsilon + 2\epsilon}{2(\epsilon + 2\epsilon)}\) | \(\frac{\epsilon(Q(2N+4\epsilon) + 2(H + 2\alpha Q L + 2\alpha Q L^2))}{2(\epsilon + 2\epsilon)}\) |
| \(\tau^*\)    | \(\frac{(\epsilon(Q + 4\epsilon + 2\epsilon)(2(N+4\epsilon + 2\epsilon)) + 2H \epsilon + 2\alpha Q L}{2(N+4\epsilon + 2\epsilon)}\) | \(\frac{32Q(N\epsilon^2 + 2\alpha Q L + 2H \epsilon + 2\alpha Q L + 2\alpha Q L^2)}{2(N+4\epsilon + 2\epsilon)}\) |
| \(C^*\)       | \(\frac{X + Y}{X + Y + 2N(1-\epsilon)^2(2(N+2\alpha Q L)}{4(1-\epsilon)(N+4\epsilon + 2\epsilon)}\) | \(\frac{X + Y}{X + Y + 2N(1-\epsilon)^2(2(N+2\alpha Q L)}{4(1-\epsilon)(N+4\epsilon + 2\epsilon)}\) |
| \(\pi_r^*\)   | \(\frac{\epsilon Q^2 - 2\epsilon Q}{2(\epsilon + 2\epsilon)}\) | \(\frac{\epsilon Q^2 - 2\epsilon Q}{2(\epsilon + 2\epsilon)}\) |
| \(\pi_m^*\)   | \(\nu^* - \alpha C^*\) | \(\nu^* - \alpha C^*\) |

\(M = c^2L - 8\epsilon(Q + c_m), N = c^2 - 8\epsilon, L = \epsilon Q + Q + c_m - c_r, H = c^2\epsilon Q - 4\epsilon c_m - 4\epsilon k^2 Q.\)

It is worth noting that the following analysis is easy, whereas the results are too large and complex. We note \(X, Y, X_1, Y_1, X_2, Y_2, X_3,\) and \(Y_3\) as follows.

\[
\begin{align*}
X &= 16\alpha^2 \epsilon^2 Q^2 - 32\alpha^2 \epsilon^2 Q L + 16\alpha \epsilon^3 Q M + 4\alpha^2 \epsilon^2 L^2 + 4\alpha \epsilon^2 L M - 8\alpha \epsilon^2 LH + 16\alpha \epsilon^2 QH + \epsilon M^2 - 4\epsilon HM + 4 H^2, \\
Y &= 2\epsilon(N + 2\alpha)Q^2 + 2Q^2 - 2MQ - 2MQ, \\
X_1 &= 2\epsilon(-M^2 - 4\epsilon \alpha Q L + 4HM + 8\epsilon^2 Q - 4\alpha^2 \epsilon^2 L^2 + 4\epsilon^2 L M - 8\epsilon^2 LH + 16\epsilon^2 QH - 16\alpha^2 \epsilon^2 \epsilon^2 Q^2, \\
\end{align*}
\]
\[ X_2 = 16\epsilon(1 - \epsilon)k\varepsilon^2(\varepsilon Q - c_r)^2 - 8H^2 - 8(1 - \epsilon)c_rH + 8\epsilon(1 - \epsilon)(c^2HQ + k^2\alpha^2\varepsilon^2Q^2 + ka^2\varepsilon^2H) + 2(1 - \epsilon)aH^2, \]

\[ Y_1 = \varepsilon(1 - \epsilon)QM + 2\varepsilon^2(1 - \epsilon)\alpha LQ + (1 - \epsilon)c_mM + 2\kappa k\alpha c_m e^2L - 2\epsilon c_r H - 4\kappa a c_m e^2Q - \varepsilon c_r M - 2\kappa a\alpha c_r e^2L, \]

\[ Y_2 = 2\epsilon c_r H + 4\kappa a c_r e^2Q + 2\epsilon(1 - \epsilon)c_r c_r Q^2 - 4(1 - \epsilon)\kappa a c_r e^2Q - 2(1 - \epsilon)^2e^2Q^2 + 4(1 - \epsilon)k\varepsilon c_r e^2Q^2 - \epsilon(1 - \epsilon)\alpha Q - 2(1 - \epsilon)a\varepsilon^2Q. \]

\[ X_3 = (2\alpha(1 - \epsilon) - 4)(H + 2k\varepsilon c_r + 2\kappa a\varepsilon c_r) \]

\[ Y_3 = -\varepsilon(M + 4\kappa\varepsilon Q + 4\kappa \varepsilon c_m + 2\kappa a\varepsilon L), \]

\[ (H + 2k\varepsilon c_r + 2\kappa a\varepsilon c_r) - 4\varepsilon(1 - \epsilon)k\varepsilon e^2(\varepsilon Q - c_r)^2. \]

In the decentralized model, we solve the supply chain’s profit function. Taking the first order conditions into (1) and joining them,

\[ \frac{\partial\pi_D^r}{\partial p_m} = \frac{Q - p_m - p_r}{1 - \epsilon} - \frac{p_m - w_m}{1 - \epsilon} + \frac{p_r - w_r}{1 - \epsilon} \]

\[ \frac{\partial\pi_D^r}{\partial p_r} = \frac{p_m - w_m + \varepsilon p_m - p_r}{1 - \epsilon} - \frac{p_r - w_r}{\varepsilon(1 - \epsilon)} \]

Taking (4) and (5) as equal to zero, we can solve the \( p_m^{D*,} \), \( p_r^{D*} \)

\[ p_m^{D*} = \frac{Q + w_m}{2}, \quad p_r^{D*} = \frac{\varepsilon Q + w_r}{2} \]

The Hessian matrix of the retailer’s profit function is negative and the profit of the retailer is concave, thus (1) has the optimal solution. We substitute (6) into (3) and derive

\[ \frac{\partial v_D}{\partial w_m} = \frac{Q - \varepsilon Q - 2w_m + 2w_r + \varepsilon c_m - c_t}{2(1 - \epsilon)} \]

\[ \frac{\partial v_D}{\partial w_r} = \frac{4\varepsilon w_m - 4w_r - 2\varepsilon c_m + 2c_r - \alpha(1 - \epsilon)(\varepsilon Q - w_r)}{4\epsilon(1 - \epsilon)} \]

\[ \frac{\partial v_D}{\partial \tau} = -2kt - \frac{\varepsilon Q + w_r}{2\epsilon} \]

Joining (7), (8), and (9), we can solve \( w_m^{D*}, w_r^{D*}, \tau^{D*} \).

The Hessian matrix of the manufacturer’s total profit function in the decentralized model is negative.

Taking \( w_m^{D*}, w_r^{D*}, \) and \( \tau^{D*} \) into (6), we get \( p_m^{D*}, p_r^{D*} \).

Similarly, in the centralized case, we have

\[ \frac{\partial v_C}{\partial p_m} = \frac{(1 - \epsilon)Q - 2p_m + 2p_r + \varepsilon c_m - c_t}{1 - \epsilon} \]

\[ \frac{\partial v_C}{\partial p_r} = \frac{2\varepsilon p_m - \varepsilon c_m + c_r + c_r(1 - \epsilon) - \alpha c(1 - \epsilon)Q + (\alpha(1 - \epsilon) - 2)p_r}{\varepsilon(1 - \epsilon)} \]

\[ \frac{\partial v_C}{\partial \tau} = \frac{-2k\varepsilon c_r - \varepsilon Q + cp_r}{\varepsilon} \]

Due to the fact that the Sequential Principal Minor is negative in the odd order and positive in the even order, the Hessian matrix of the manufacturer’s total profit function in the centralized model is negative.
Proposition 1. In the decentralized model, \( \frac{\partial \tilde{w}_m^{D*}}{\partial \alpha} < 0, \frac{\partial \tilde{w}_r^{D*}}{\partial \alpha} < 0, \frac{\partial \tilde{\tau}_m^{D*}}{\partial \alpha} < 0, \frac{\partial \tilde{\tau}_r^{D*}}{\partial \alpha} < 0, \frac{\partial (q_m + q_r)}{\partial \alpha} > 0, \frac{\partial r_c^{D*}}{\partial \alpha} < 0, \frac{\partial c^{D*}}{\partial \alpha} > 0, \) where \( q_m + q_r = Q - \frac{1}{\epsilon_1}, \epsilon Q - c_r > 0. \)

Proof. Taking the first order of the wholesale and recycling rate with respect to \( \alpha, \) we have

\[
\frac{\partial \tilde{w}_m^{D*}}{\partial \alpha} = \frac{\partial \tilde{w}_r^{D*}}{\partial \alpha} = \frac{\partial \tilde{\tau}_m^{D*}}{\partial \alpha} = \frac{\partial \tilde{\tau}_r^{D*}}{\partial \alpha} = \frac{\partial (q_m + q_r)}{\partial \alpha} > 0, \frac{\partial r_c^{D*}}{\partial \alpha} < 0, \frac{\partial c^{D*}}{\partial \alpha} > 0. \]  

Taking (13) into (6), we have \( \frac{\partial \tilde{w}_m^{D*}}{\partial \alpha} < 0, \frac{\partial \tilde{w}_r^{D*}}{\partial \alpha} < 0, \) then \( \frac{\partial (q_m + q_r)}{\partial \alpha} > 0. \)  

When the manufacturer places more weight on corporate social responsibility, the wholesale prices of new and remanufactured products, and the recycling rates, decrease. On the contrary, both the total demand and the consumer surplus increase. Actually, consumer surplus is only related to inventory capacity, and consumers are willing to pay for the price of remanufactured products. In response to the manufacturer’s activity, the retailer also reduces the retail price to encourage customers to buy more. Thus, the increment of demand is greater than the decrement of price. What is more, CSR brings manufacturers extra profits.

Proposition 2. The recycling rate increases with a rising WTP, i.e., \( \frac{\partial \tilde{\tau}_r^{D*}}{\partial \epsilon} > 0. \)

Proof. Taking the first order of recycling rate with respect to \( \epsilon, \) we have

\[
\frac{\partial \tilde{\tau}_r^{D*}}{\partial \epsilon} = \frac{c^3 Q + 2kca - 8kcc_r}{(c^2 - 8k\epsilon + 2k\epsilon c)^2} > 0. \]  

As we see, (14) depends on \( c^3 Q + 2kca - 8kcc_r. \) Obviously, \( c^3 Q + 2kca - 8kcc_r > 0 \) because \( c_r \ll Q. \)
mean that the profits of channel members also increase. It can be seen from Tables 2 and 3 that the profits of channel members are higher when the recycling rate is lower.

Table 2. $\varepsilon = 0.2$, the results of recycling rate and profits with corporate social responsibility (CSR).

| Decision or Profits | $\alpha$ | Trend |
|---------------------|----------|-------|
| $\pi_{C}^{C}$       | 0.2762   |       |
| $\pi_{D}^{C}$       | 0.3106   |       |
| $\pi_{D}^{D}$       | 2.8318   |       |
| $\pi_{m}^{C}$       | 5.4688   |       |
| $\pi_{m}^{D}$       | 5.4697   |       |
| $\pi_{C}^{C}$       | 11.1111  |       |
| $\pi_{C}^{D}$       | 11.1119  |       |
| $\pi_{m}^{C}$       | 8.3015   |       |
| $\pi_{m}^{D}$       | 0.7471   |       |
| $\pi_{C}^{C}$       | 0.0008   |       |
| $\pi_{C}^{D}$       | 0.0009   |       |

Table 3. $\varepsilon = 0.3$, the results of recycling rate and profits with CSR.

| Decision or Profits | $\alpha$ | Trend |
|---------------------|----------|-------|
| $\pi_{C}^{C}$       | 0.5831   |       |
| $\pi_{D}^{C}$       | 0.7067   |       |
| $\pi_{D}^{D}$       | 2.382    |       |
| $\pi_{m}^{C}$       | 3.7501   |       |
| $\pi_{m}^{D}$       | 3.7576   |       |
| $\pi_{C}^{C}$       | 8.3404   |       |
| $\pi_{C}^{D}$       | 8.3455   |       |
| $\pi_{C}^{C}$       | 6.1396   |       |
| $\pi_{C}^{D}$       | 0.7357   |       |
| $\pi_{C}^{C}$       | 0.0051   |       |
| $\pi_{C}^{D}$       | 0.0075   |       |

Proposition 3. The monotonicity of the retailer’s and manufacturer’s profit depends on the roots of the first order of the profit function with a rising CSR.

Proof. The retailer’s profit function is a quadratic function after the first-order of $\alpha$, and the quadratic function is opening downwards, i.e., $\frac{\partial \pi_{m}^{D}}{\partial \alpha} = \frac{4}{(1 + b + 2a\alpha)^2} \left( \frac{x + b}{b} \right)^2 + \frac{c}{\alpha}$. Taking it equal to zero, its monotonicity is determined by its two roots. When two roots are not in intersection with the Lateral Axis, its monotonicity depends on the range of $\bar{a}$, where $\bar{a} = \frac{-b}{2a}$, and $\alpha^{*}$ is the quadratic coefficient of $\alpha$ and $b^{*}$ is the first-order coefficient of $\alpha$. When two roots are in intersection on the Lateral Axis, its monotonicity hinges on the two roots range. Through analysis, we have $\alpha_{1} = \frac{-b - \sqrt{b^{2} - 4ac}}{2a}$ and $\alpha_{2} = \frac{-b + \sqrt{b^{2} - 4ac}}{2a}$, where $c^{*}$ is a constant term of the quadratic function. Then we get the following cases. The profits of the retailer decrease with a rising CSR when $\alpha_{1} > 1$ or $\alpha_{2} < 0$. The profits of the retailer increase with a rising CSR when $\alpha_{1} < 0$ or $\alpha_{2} > 1$. Under the condition $\alpha_{1} (0, \alpha_{2})$, the profits of retailers increase with a rising CSR when $0 < \alpha < \alpha_{2}$, and the profits of retailers decrease with a...
We find that the retailer’s profit is the cubic function of the CSR investment ratio in the real number $R$, where \( \varepsilon < \alpha < 1 \) with a rising CSR when \( 0 < \alpha < \alpha_1 \) or \( \alpha_2 < \alpha < 1 \), and the profits of retailers increase with a rising CSR when \( \alpha_1 < \alpha < \alpha_2 \). In the final case, under the condition \( \alpha_1 > 0, \alpha_2 > 1 \), the profits of retailers decrease with a rising CSR when \( 0 < \alpha < \alpha_1 \), and the profits of retailers increase with a rising CSR when \( \alpha_1 < \alpha < 1 \). \( \Box \)

In the following numerical analysis, they are the complex roots, indicating that it is not in intersection with the Lateral Axis. The quadratic function is opening downwards, and then we have the max value \( \frac{\partial \pi^C_m}{\partial \alpha}(\varepsilon) < 0 \), and therefore the profits of retailer decrease with a rising CSR when \( 0 < \alpha < 1 \). We find that the retailer’s profit is the cubic function of the CSR investment ratio in the real number $R$, while the profits decrease with a rising CSR when \( \alpha \in (0, 1) \). Relative to the retailer, the manufacturer’s profit is the fourth order function of the CSR investment ratio in the real number $R$, while the profits increase with a rising CSR when \( 0 < \alpha < 1 \). The monotonicity analysis of CSR by manufacturers is similar to that of retailers. In the following numerical analysis, the profits of the manufacturer increase with a rising CSR when \( 0 < \alpha < 1 \).

Proposition 3 illustrates that the manufacturer’s total profits increase whereas the retailer’s profits decline with a rising CSR. The reduction in the recycling rate directly affects the profits of retailers.

### 3.1.2. The Centralized Case

In the centralized model, the manufacturer and the retailer are willing to collaborate as a whole system. The result is a benchmark for decentralized. Then pure and the total profit functions are as follows:

\[
\pi^C_m = (p_m - c_m)(Q - \frac{p_m - p_r}{1 - \varepsilon}) + (p_r - c_r)\frac{\varepsilon p_m - p_r}{\varepsilon(1 - \varepsilon)} - k\tau^2 - cr\left(Q - \frac{p_r}{\varepsilon}\right)
\]

\[
\pi^C_r = (p_m - c_m)(Q - \frac{p_m - p_r}{1 - \varepsilon}) + (p_r - c_r)\frac{\varepsilon p_m - p_r}{\varepsilon(1 - \varepsilon)} - k\tau^2 - cr\left(Q - \frac{p_r}{\varepsilon}\right) + \frac{\alpha(\varepsilon Q - p_r)^2}{2\varepsilon}
\]

The result is shown in Table 1.

**Proposition 4.** In the centralized model, \( \frac{\partial \pi^C_m}{\partial \alpha}, \frac{\partial \pi^C_r}{\partial \alpha} < 0 \), \( \frac{\partial (\pi^C_m + \pi^C_r)}{\partial \alpha} > 0 \), \( \frac{\partial \pi^C_m}{\partial \alpha} < 0 \), and \( \frac{\partial \pi^C_r}{\partial \alpha} > 0 \), where \( q_m + q_r = Q - \frac{p_r}{\varepsilon} \), \( \varepsilon Q - c_r > 0 \).

Taking the first order of \( p^C_m, p^C_r, \) and \( \tau^C \) with respect to $\alpha$, we have

\[
\frac{\partial p^C_m}{\partial \alpha} = \frac{\partial p^C_r}{\partial \alpha} = \frac{4k^2\varepsilon^2(c_r - \varepsilon Q)}{(\varepsilon^2 - 4k\varepsilon + 2kae)^2} < 0, \quad \frac{\partial \tau^C_m}{\partial \alpha} = \frac{-2ke(\varepsilon Q - c_r)}{(\varepsilon^2 - 4k\varepsilon + 2kae)^2}
\]

where \( \varepsilon Q - c_r > 0 \). Similar to Proposition 1, we do not repeat the analysis. The recycling rate also increases with a rising WTP in the centralized model. It is hardly surprising that these results are consistent with those in the decentralized model. In the following section, we analyze the relationship between the retail price and the wholesale price of new products and remanufactured products, the recovery rate, and profits through a comparison of these two models.

### 3.1.3. Comparison and Analysis

In these two cases, we compare prices, recoveries, and profits.

**Proposition 5.** Comparing these two models, we have \( \tau^C < \tau^D \), \( p^C_m < p^D_m \), and \( p^C_r < p^D_r \).

From Table 1, we note that \( \tau^C < \tau^D \) because \( N + 2k\varepsilon Q < N + 4k\varepsilon + 2k\varepsilon \).

\[
p^D_m - p^C_m = \frac{(N + 4k\varepsilon + 2kae)(N + 2k\varepsilon)(Q + 4k\varepsilon Q + 4k\varepsilon c_m + 2kae)}{(N + 2k\varepsilon)(N + 4k\varepsilon + 2kae)} > 0 \text{ because } QN + 2k\varepsilon Q > 4k\varepsilon Q + 4k\varepsilon c_m. \]

Similarly, \( p^C_r < p^D_r \). In the case of the manufacturer collecting used products, the retailer does not engage in CSR activity. The retail prices of new and remanufactured
products of the centralized channel are lower than those of the decentralized one. Apparently, the manufacturer invests the proportion of the CSR for more profits to acquire some consumer surplus. It is noteworthy that consumers’ willingness to pay for new and remanufactured products is limited to a smaller range, due to the necessary constraints. It is amazing that the retailer loses some profit with an increasing CSR, just because the increment in total demand is not enough to exceed the reduction in price. The recycling rate decreases as the manufacturer’s involvement in CSR increases. As opposed to the decentralized decision, the increment of the recycling is lower in the centralized one. However, the total profit in the centralized case is higher than that in the decentralized model. Obviously, the increment in total demand and consumer surplus in the centralized scenario exceeds that in the decentralized one. The total function contains too many variables in these two cases, and the direct comparison is too complicated. We can integrate the analysis of Proposition 3 to compare the profits of centralized and decentralized systems. In the following section, we assign values to the important parameters and make numerical calculations in Tables 2 and 3.

4. Numerical Analysis

4.1. Numerical Simulation and Discussion

As we can see, the model parameters are numerous and the calculated results are complex, which can be quite tedious if the profit function is directly compared. Consequently, we combine the constraints, assuming $c = 4, k = 2, c_m = 3, c_r = 1,$ and $Q = 10$, and the numerical value of each parameter is very large in real life. For convenience, we narrow the numerical value, whereas the result is not affected. From the constraint conditions, the specific range of consumers’ willingness to pay is $[0.15, 0.35]$. Thus, we analyze these two cases; $\epsilon = 0.2$ and $\epsilon = 0.3$.

In the CSR model, consumer surplus is closely related to market capacity, remanufactured retail price, and WTP. With the two WTP values, the recycling rate and the retailer’s profit decrease with a rising CSR. Manufacturers’ profits and channel efficiency increase with a rising CSR. Comparing the two tables, we note that the higher the WTP value is, the higher the recycling rate and consumer surplus are, while the results of retailers, manufacturers’ profits, and channel efficiency were not satisfactory.

The increase in CSR investment is beneficial to consumers. Conversely, the consumer surplus is not only affected by the CSR investment. Moreover, an increase in recycling rates does not improve profits for retailers and manufacturers, presumably because, in the presence of consumer surplus, it is closely related, not only to WTP, but also to CSR. As consumers consider their own profits, the resulting increase in demand throughout the supply chain is much less than the reduction in price, leading to lower profits.

Based on the above analyses, we get the relationship between retail price and CSR in Figure 1, wholesale price and CSR in Figure 2, recovery rate and CSR in Figure 3. We depict the relationship between the retailer’s profit and CSR in Figure 4. Figure 5 shows the relationship between manufacturers’ profits and CSR. Figure 6 illustrates the relationship between the recovery rates and WTP differentiation in two models. In order to facilitate analyses and observation, we compare the real data. The data in this paper is insufficient, but do not affect the actual result analysis.
Figure 1 shows that, in the centralized and decentralized models, the retail price of new remanufacturing products decreases with a rising CSR input ratio, although the decrease is not significant. As we can see in Figure 3, the recovery rate decreases with a rising CSR. As the recycling rate decreases, the manufacturer has to lower the wholesale price. As depicted in Figure 2, the wholesale price drops with a rising CSR.

Figure 1. $\alpha$ vs. price.

Figure 2. $\alpha$ vs. wholesale price.

Figure 3. $\alpha$ vs. recycling rates.
In the centralized model, the retail price is lower than that in the decentralized model. In these two models, the retail price of new products is much lower than that of remanufactured products. As shown in Table 2, the total demand increases accordingly, and the increase in demand is at least greater than the decrease in price. Consequently, both the net profits and the total profits of the manufacturer increase, as shown in Figures 4 and 5. In other words, manufacturers make visible profits from their involvement in CSR activities. Retailers’ margins fell because they did not participate in corporate social activities, and the increase in demand was not sufficient to offset the difference caused by falling prices. By comparing Tables 2 and 3, we can see that the recovery rate increases with an increase in the consumers’ willingness to pay, as shown in Figure 6. As opposed to the centralized model, the profit
of manufacturers decreases due to the dual marginal effect in the decentralized model. The higher the willingness of consumers to pay is, the lower the proportion of channel coordination is and the more consumer surplus is, which is unfavorable to manufacturers. Through an analysis of Table 2, it can be seen that retailers are at a disadvantage in this model. As their profits decrease with a rising CSR, they are unlikely to get involved in corporate social responsibility, for which the manufacturer is responsible. Subsequently, we adopt the revenue sharing contract.

4.2. Revenue-Sharing Contract

In the above analysis, with a rising CSR and a falling retailers’ profit, and a rising manufacturers’ profit coupled with the influence of double margin, the total profits of the centralized model are higher than those of the decentralized one. In order to enable the retailer to actively participate in the activities of CSR undertaken by the manufacturer, it is necessary to provide retailers with necessary profits that are larger than those in the decentralized model. Now, we present a simple revenue sharing contract. Many researchers apply revenue sharing contracts to coordinating members’ profits in the remanufacturing chain. Although the contract forms are varied, the purpose of all is to coordinate the interests of channel members (Cachon and Lariviere, 2005; Govindan and Popiuc, 2014) [30,32].

Here, in the centralized model, the retailer chooses part of the profit to make its profits more than those in the decentralized mode. Meanwhile, whether the manufacturer chooses to accept or reject this contract depends on whether the profits of the remaining proportion are greater than the total profits of the decentralized one. The contact is as follows.

\[ \emptyset \pi^{C^*} \geq \pi^{D^*} \emptyset \geq \pi^{m^*} \]

From (18), we note

\[ \emptyset \geq \frac{\pi^{D^*}}{\pi^{C^*}} = \emptyset_{\text{min}}, \emptyset \leq 1 - \frac{\pi^{D^*}}{\pi^{C^*}} = \emptyset_{\text{max}} \]

Proposition 6. The profits of the chain members will be greater than those in the decentralized system when \( \emptyset \in (\emptyset_{\text{min}}, \emptyset_{\text{max}}) \).

The retailer gets involved in the activity when \( \emptyset \in (\emptyset_{\text{min}}, \emptyset_{\text{max}}) \). Through the analysis, we note that the ratio of revenue sharing has a threshold. Furthermore, the ratio is associated with the ratio of retailers’ or manufacturers’ profits in the decentralized model and total profits in the centralized model. Although the calculation is complicated, it can be operated. Thus, for any \( \emptyset \in (\emptyset_{\text{min}}, \emptyset_{\text{max}}) \), the channel is coordinated and the chain members can be win-win. From (19), (20), and (21), we have

\[ \emptyset_{\text{min}} = \frac{X + Y}{16(1 - \epsilon)(N + 2k\alpha)^2} + \frac{Q^2}{4} \]

\[ \emptyset_{\text{max}} = 1 - \frac{X_1 + Y_2 + 4(N + 2k\alpha)(Y_1 + Y_2)}{16(1 - \epsilon)(N + 2k\alpha)^2} + \frac{\pi^{D^*} - 4\alpha\epsilon Q}{8} \]
Now, taking the numerical value into Table 1, we get

\[ v^C = \frac{6.4\alpha^3 + 208.8\alpha^2 + 1213.6\alpha - 8524.8}{(14.4 + 0.8\alpha)^2} + \frac{-16\alpha^2 - 229.8\alpha + 1095.2}{14.4 + 0.8\alpha} + 10\alpha - 27 \]  (24)

\[ \pi^r = \frac{-7.8\alpha^2 - 243.2\alpha - 1891.2}{(12.8 + 0.8\alpha)^2} + \frac{184 + 12\alpha}{12.8 + 0.8\alpha} \]  (25)

\[ \pi^m = \frac{6.4\alpha^3 + 172.4\alpha^2 + 609\alpha - 8166.4}{(12.8 + 0.8\alpha)^2} + \frac{-16\alpha^2 - 187\alpha + 1092}{12.8 + 0.8\alpha} + 10\alpha - 30 \]  (26)

Taking (24), (25), and (26) into (22) and (23), we have \( \emptyset \in (0.25, 0.51) \) when \( \alpha = 0.5, \epsilon = 0.2 \).

5. Conclusions and Future Research

In consideration of the WTP differentiation for new and remanufactured products, this paper focuses on a single manufacturer-retailer where the manufacturer collects used products and bears corporate social responsibility in the remanufacturing supply chain. Specifically, this study adopts classic Stackelberg game theory. In particular, this paper has made two contributions. Firstly, we consider the WTP differentiation for new and remanufactured products. In the light of the gap, this article approximates the real market, although the calculation of the models becomes complicated. Secondly, in this paper, the manufacturer collects used products and gets involved in CSR activity. Additionally, despite the fact that the retailer recycling model dominates the three types of recycling, manufacturer recycling is often seen in real life. Thus, our contribution is that this paper enriches the relevant literature and also is the first to consider the WTP differentiation in a CSR remanufacturing supply chain.

In this article, we appropriately analyze the decision variables of the centralized and decentralized models, exploring the changes of prices and recycling rates with the corporate social responsibility under WTP differentiation. We note that the chain members have the best status when the consumers’ WTP for new and remanufactured products is within a threshold. Manifestly, we note that the retail price and wholesale price in new and remanufactured products decline with a rising CSR. Even the recycling rate in the two cases also decreases with a rising CSR. Additionally, the recycling rate is also influenced by the WTP value. On top of that, the manufacturer’ pure and total profits are more than the profits of the retailer. Comparing these two models, we observe that the price and recycling rate in the centralized system are lower than those in the decentralized one. Conversely, the total profits in the centralized case are higher than those in the decentralized case because the increment of demand is higher in the centralized model. As a matter of fact, the marginalization doubles in the decentralized system. In addition, we find that consumer surplus is ascending when the CSR is descending in these two models, whereas, in the decentralized case, it is higher. Due to the differences in consumers’ willingness to pay, the consumers are concerned about their profits. Apparently, there exists a threshold value in the WTP differentiation in a CSR remanufacturing supply chain. From Tables 1 and 2, the lower WTP value is better for the chain members. Finally, we devise a simple revenue sharing contract to improve the chain members’ profits in the decentralized model. The results demonstrate that the ratio is associated with that of retailers’ or manufacturers’ profits in the decentralized model and the total profits in the centralized model. Thus, the chain members will be win-win through the contract, indicating some practical significance.

The results of this paper give us some enlightenment. The manufacturer’s efforts to collect used products are inversely proportional to the manufacturer’s corporate social responsibility intensity. That is to say, in the case of consumers’ different willingness to pay for new and remanufactured products, some industries, such as electronic enterprises (smartphones) and manufacturers who collect used products, may need to consider whether they desire to participate in corporate social responsibility. It is essential to recycle the used products within a certain threshold value of WTP differences and
consider the profit impact of the retailer. The results of this study suggest that, within the threshold value of WTP differences, manufacturers can collect properly. With the increase in CSR investment, the profits of the manufacturer and the retailer are profoundly affected. Generally speaking, in the decentralized model, the profits of manufacturers are lower than those in the centralized one, and the profits of the retailer decline with the rise in CSR investment in the decentralized model. Admittedly, this is just the case. According to Proposition 3, the profits of manufacturers and retailers increase with a rise in the manufacturer’s investment in CSR, which is not a simple increase or decrease. It depends on the profit function to analyze the solution of CSR parameters, and the situation is very complex. This paper gives a simple model analysis in remanufacturing supply chain management by considering WTP differentiation, though it has a lot of inspirations. There are still many breakthroughs required to solve this kind of problem. Next, we will study whether retailers and manufacturers undertake CSR activities together, and whether this situation can improve the recovery of the used products, because many previous studies show that the retailer recycling used products remanufacturing supply chain performance is the most impressive. Furthermore, we will study how the retailer recycles used products, and how manufacturers and retailers can bear corporate social responsibility together in the future.

However, there are some limitations in this paper. In this article, it is assumed that consumers share a $\epsilon$ value for all remanufactured products, and the variation rule is the same. In fact, consumers have different preferences for different remanufactured products, and the $\epsilon$ value also differs. Initially, under the assumption that the demand is determined, this paper takes into account the differences in consumers’ willingness to pay. Although some results can be obtained, in real life, the demand is often uncertain. On top of that, in the process of comparing profit functions in this paper, there are numerous parameters, and, thus, the process, including the use of appropriate values for analysis, is tedious. This is an area where this article needs to improve. In future studies, the above mentioned all need to be taken into account.

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