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HOW TO SUBSIDIZING THE USED APPAREL RECYCLING SUPPLY CHAINS EFFECTIVE? AN ANALYSIS BASED ON THE GAME FRAMEWORK

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Abstract. Motived to find the optimal subsidy strategies in the used apparel recycling supply chains, this paper establishes a benchmark recycling model including a brand retailer and a remanufacturer, and extends the benchmark model based on different subsidy scenarios: (a) the government subsidizes the remanufacturer, (b) the government subsidizes the retailer's remanufacturing part, (c) the government subsidizes all recycled apparel from the retailer. The constructed models show some interesting results. (1) Both the strategies (a) & (b) drove the same recycling efforts. The remanufacturer maybe mistakenly believe its profits could increase with the lower procurement price in scenario (b). However, the profits were the same in both scenarios. (2) The strong consumer sensitivity to recycling efforts not only increases the retailer's profits but also drops the remanufacturer's profits. Therefore, strong consumer sensitivity is only good for some players. (3) The donation ratio should be within a reasonable range. Otherwise, the remanufacturer's profit decreases, and even the remanufacturer withdraws from the supply chain. (4) The optimal subsidy strategy for the supply chain members is that the government subsidizes all recycled from the retailer. Based on our findings, some management insights and suggestions are presented.

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1. Introduction

Human beings are constantly exploring and developing a circular economy system to achieve sustainable development through recycling limited resources when facing population growth and limited resources [1, 2]. For example, as one of the largest clothing consumers globally, China produces tens of millions of tons of used apparel every year, but the utilization rate of used apparel is meager [3]. As a result, plenty of used apparel is burned or buried as garbage, which wastes resources and causes great harm to the environment. In total, three-quarters of all used materials processed along the fashion value chain are lost in landfills [4, 5], and only less than 1% of all materials in clothes are recycled into new garments.

Many countries encourage recycling used clothes to counter the damage to the environment. Governments promulgate laws or provide financial support for recycling behaviors to promote the development of the apparel recycling industry. For example, over $10 million in cap-and-trade program dollars have been awarded to California companies that recover PET, glass, and textiles. Therefore, more and more companies or research

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institutions are constantly exploring and researching new chemical and physical technologies to reduce the pollution generated in the recycling process [6, 7], and some scholars are also attempting to study the apparel recycling supply chain from a management perspective [8,9]. In recent years, China has promulgated many laws and regulations to promote the development of the recycling industry [3]. Such as *Classification and Code of Textile Waste Standard, Technical Specification for Collection of Waste and Textiles Waste Standard*, and so on. And the legislative and financial instruments play essential roles in developing the recycling industry.

Nowadays, consumers pay more attention to corporate social responsibility and environmental awareness[1], and they are willing to buy fashion brands with environmental protection reputations too. Through empirical research, Friedrich [10] studied the German apparel industry's sustainability and showed that companies should practice take-back and reusing new apparel. As a result, consumers can maintain fast consumption and even accept higher prices. Besides, corporate social responsibility initiatives are significantly and positively associated with corporate reputation, customer satisfaction, and customer trust [11]. It revealed that high corporate abilities with well-executed corporate social responsibility initiatives lead to high loyalty. The research highlighted the significance of mandatory corporate social responsibility actions for organizational success and guided policymakers, managers, and scholars. Consumer perceptions of corporate social responsibility are also driving companies in this direction. For example, Ho [12] designed a questionnaire survey to examine the influence of corporate social responsibility and environmental concerns on consumer-retailer love and attitude toward the retailer. The findings showed that corporate social responsibility and environmental concern positively affect consumer-retailer love and attitude toward the retailer. Furthermore, the research of Servera-Francés and Piqueras-Tomás [13] showed that corporate social responsibility policies increase consumers' perceived value towards the company as well as trust, commitment, satisfaction, and loyalty. Therefore, consumers are motivated to participate in the recycling promotion of apparel brand retailers, and the consumers' participation also drives retail sales and improves profitability.

An effective way of promoting the recycling of used apparel is to offer an end-of-use in-store garment collection scheme. By providing in-store end-of-use collection schemes, it moved collection rates globally to 60% and reduced waste by nearly 54 million tons per annum [14][2]. After sorting and screening the recycled apparel, retailers donate better quality products to charity and sell the remaining part to remanufacturers for remanufacturing [15]. Nowadays, many fashion brand retailers carry out long-term recycling operations, such as H&M, which invests a large number of special funds every year. ZARA and GAP have corresponding recycled fiber products and many fans. In addition, used apparel can be donated at any H&M or &Other Story store in the United States, and consumers can receive a 15% off discount coupon for their next purchase [16,17]. Consumers can take old jeans to Levi's to get a 20% off for a single item [18]. Similar brands include *Madewell* and *North Face*. Brand retailers could get economic benefits from recycling apparel, which helps improve the environment and reuse resources, and it is conducive to brand promotion and has significant hidden benefits.

This study considered the optimal government subsidy strategies in a recycling supply chain composed of a retailer and a remanufacturer, and the main research questions in this paper are as follows:

(1) How are the retailer and remanufacturer affected by different government subsidy strategies?
(2) Which government subsidy strategies are optimal for the supply chain players?
(3) How do recycling efforts and donation ratio affect the players' recycling behaviors and profits?

This study is organized as follows. First, it reviews the relevant literature in Section 2 and describes the benchmark model in Section 3. Next, this study builds three extended models considering different government

[1]Based on the survey of *Markstein* and *Certus Insights*, seventy percent of consumers want to know what the brands they support are doing to address social and environmental issues, and 46% pay close attention to a brand's social responsibility efforts when they buy a product. Moreover, when a company supports a social or environmental issue, 92% of consumers would have a more positive image, and 87% of consumers would be more likely to trust the company.

[2]Based on the report, a significant opportunity for value creation awaits the world economy if the fashion industry converts textile waste into raw materials through advanced recycling techniques. Therefore, the current value is based on pure waste reduction along a linear value chain. Consequently, the opportunity to the world economy is modest at around €4 billion per year in 2030 – although under a circular model of production and consumption, this value would be manifold higher.

subsidy strategies in Section 4. Then, these models are compared and analyzed in Section 5. Finally, Section 6 summarizes the findings and presents management insights.

2. Literature review

This study studies the optimal subsidy strategies in the used apparel recycling supply chain and simultaneously considers the recycling, donation, and remanufacturing behaviors. This study draws on and contributes to several streams of literature. The first stream is about the closed-loop supply chain, and the second stream is on subsidy and remanufacturing behaviors.

2.1. Closed-loop supply chains

The closed-loop supply chain considers the entire life cycle of the product [19], which can reduce pollution emissions and residual waste while providing services to customers at a lower cost and has carried out practical applications in many industries [20–22]. With the maturity of technology, used apparel generates greater value with decomposition and refabrication [10,23]. For example, China consumes tens of billions of clothing each year and produces thousands of tons of used apparel[3]. Part of the old products are broken down into raw materials for reuse, and part of the old products are processed for donation.

In recent years, more and more scholars have paid attention to the closed-loop fashion industry. Motivated by the real-world socially responsible practices in the intimate apparel industry, Choi *et al.* [24] explored the used intimate apparel collection (UIAC) programs in a supply chain system by game-theoretic. It showed that an increased level of competition would lead to a higher consumer surplus if the respective consumer goodwill of donation is sufficiently small. Jain *et al.* [25] proposed a customizable framework of a closed-loop hybrid business model which improved to scale up and accelerate reuse, upcycling, and recycling of used apparel. The study illustrated the potential of the closed-loop hybrid business model to generate higher margins and increase the economic pie for brands while reducing the virgin material pie and increasing the product and material life. Moreover, Rausch *et al.* [26] showed that the consumers are concerned about the garment's durability, fair wages, working conditions, and environmentally friendly production process at the same time.

Many factors are integrated into remanufacturing to deal with complex supply chain scenarios in recent research works, such as Nima *et al.* [27] considered the factors of the sales effort, delivery time, and hybrid remanufacturing. The findings showed that the manufacturer-Stackelberg game is the best game strategy to improve the profits of both the distributor and the manufacturer. Taleizadeh *et al.* [28,29] also discussed many phenomena and problems in the closed-loop supply chain considering pricing, product quality, collection efforts, carbon emission reduction, return policy and recycling channel structures. The study showed that the recycling channel member with a predominant market share exerts greater collections efforts and offers lower buyback prices than others in the collection channel. Furthermore, employing all stimulating factors can effectively increase supply chain performance environmentally and economically. Cai *et al.* [30] and Yan *et al.* [31] explored the closed-loop supply chain combined with donation behavior. Both studies showed that donation behavior positively affects the players and provides scientifically sound managerial guidance and insights to practitioners. Moreover, the study works of Taleizadeh *et al.* [32,33] and Zerang *et al.* [34] are valuable and worth learning.

This study is inspired by these research works when studying the used apparel recycling supply chain. This study not only considers the donation behavior of the collected apparel products for charity or sending them to remanufacturing but also discusses how the retailer's donation ratio affects the players' profits.

2.2. Subsidy and remanufacturing

Though building closed-loop supply chains have practical value and positively impacts the local communities, enterprises and governments also need to provide sufficient investment in research and development, logistics, etc.

[3]According to the data of the *National Bureau of Statistics*, as early as 2018, the purchase of Chinese clothing reached 54.06 billion pieces.

[35]. Usually, governments encourage enterprises to recycle and remanufacture used products through financial subsidies. For example, it is widely used in the biofuel supply chain [36], online-to-offline supply chain [37], social responsibility [38], electric vehicle [39,40], *et al.* Based on these valuable studies, this paper examines the impact of government subsidy strategies on the used apparel recycling supply chains.

After brand retailers collect large amounts of used apparel through recycling operations, some good quality used apparel is donated by disinfection and finishing. The rest is mainly used for remanufacturing products with lower added value and re-entering the market [30]. Since the collection of used and reused products or resources are the front behaviors in all the reverse logistics, Weng *et al.* [41] probed into the influence on third-party costs for collecting and handling used products. The subsidy strategy can bring economic benefits to enterprises or consumers. For example, Ma *et al.* [42] pointed out that rural consumers can receive a consumption subsidy worth 13% of the new appliance price, and all the consumers that purchase the new products are beneficiaries of the government consumption subsidy in varying degrees. Moreover, the consumption subsidy is conducive to expanding the closed-loop supply chain.

Considering the impact of subsidy strategy, He *et al.* [43] studied the remanufacturer's optimal channel structures and pricing decisions, and presented optimal subsidy levels under three-channel structures. It showed that the government encourages manufacturers to adopt desired channel structures by setting appropriate subsidy levels, and a higher subsidy level always benefits consumers and the whole supply chain, but it does not always benefit the environment. Chai *et al.* [44] studied the equilibrium production decisions under the Stackelberg game framework. The results showed shareholding operations could reduce environmental impact under specific relative pollution ratios of remanufactured products from an environmental perspective.

Furthermore, the subsidy can stimulate enterprises' enthusiasm for remanufacturing. Yang and Xu [45] analyzed the impact of subsidy and remanufacturing ratio on the equilibrium results under the low carbon economy background. The results showed that subsidies could motivate plants to invest more in carbon emission abatement technologies to reduce carbon emissions. Wang and Zhang [46] found that the state subsidies and corporate environment spending were positively correlated, which indicated that firms receiving government subsidies were more likely to behave more environmentally responsibly. Moreover, the findings showed that firms subject to financial difficulties tend to build an environmentally responsible image and contribute more to environmental protection. Meanwhile, Majumdar *et al.* [47] also pointed out that aligning economic incentives and revenue sharing was the dominant risk mitigation strategy for an environmentally sustainable apparel supply chain.

This study examines the impacts of donations and subsidies on the used apparel supply chain. Briefly, Table 1 summarizes the papers most related to our research and shows all the important issues this study addresses.

Unlike the previous literature, this study builds game models combining different subsidy scenarios and studies the impact of different government subsidy strategies and donation ratios on the profits of the supply chain players. The main contributions in this paper are listed as follows:

(1) This study finds the optimal subsidy strategy to improve the used apparel supply chain profit and social welfare.
(2) This study analyzes the recycling motivation of the retailer and remanufacturer considering donate behavior.
(3) This study compares some subsidy strategies and provides suggestions for enterprise and government decision-makers.

3. Basic model

3.1. Problem description

Apparel retailers conduct marketing campaigns by recycling used apparel and donating them to enhance the brand's social image and responsibility. At the same time, governments provide financial subsidy policies to support environment-friendly behaviors. Therefore, this study builds a benchmark model and explores three extended models under different government subsidy scenarios. Some interesting phenomena and findings are analyzed and discussed.

Table 1. A brief literature review.

Article	Apparel/Fashion recycling	Remanufacturing	Subsidy	Game	Recycling efforts	Donation
Alizadeh-Basban and Taleizadeh [27], Taleizadeh and Sadeghi [33], Taleizadeh *et al.* [28, 32, 49], Sadeghi *et al.* [48]		√		√	√	
Bubicz *et al.* [15], Cai and Choi [2], Dhir *et al.* [50], Friedrich [7], Roy *et al.* [8], Rausch *et al.* [26], Sadiq *et al.* [51], Sandvik and Stubbs [35]	√					
Choi *et al.* [24], Guo *et al.* [52]	√			√		
He *et al.* [43], Ma *et al.* [42]		√	√	√		
Chen *et al.* [37], Choi *et al.* [20]		√		√		
Cheng *et al.* [40], Fu *et al.* [39], Liu *et al.* [38]			√	√		
Moon *et al.* [53]	√			√		
Cai *et al.* [30]	√	√		√		√
Yan *et al.* [31]		√		√		√
This paper	√	√	√	√	√	√

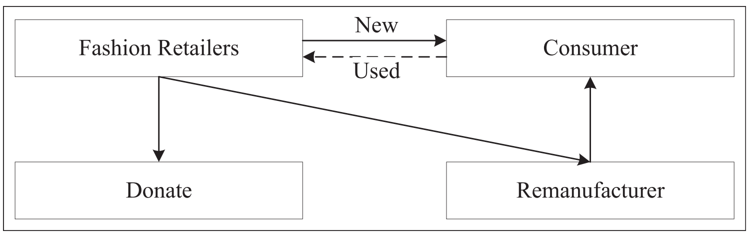


Figure 1. Model description of the benchmark model.

In the benchmark model, the apparel retailer not only sells new products but also recycles used apparel, and some good quality used apparel is donated. The remanufacturer acquires the used apparel from the retailer and sells the remanufactured products to the market. The structure of the benchmark model is shown in Figure 1. The structure of the benchmark model is shown in Figure 1. Considering the positive effects of donates, this study built an apparel recycling supply chain composed of a retailer and a remanufacturer. In the benchmark model, the apparel retailer not only sells new products but also recycles used apparel. The remanufacturer acquires the used apparel from the retailer and simultaneously sells the remanufactured products to the market.

The demand for new apparel is mainly affected by the price and the brand retailer's recycling efforts [30, 54]. Therefore, the demand function can be set as $D = a - bp + rs$, where a is the potential market demand, b is the sensitivity of consumers to price p, s is the degree of effort that the retailer pays to recycle the used apparel, and r is the corresponding sensitivity coefficient. Moreover, the profits of the remanufacturer and retailer are

TABLE 2. Description of parameters and variables.

Symbol	Description
Model parameters	
D	Market demand
a	Potential market size
b	Consumers' sensitivity to the new product price
r	Consumers' sensitivity to the retailer recycling efforts
δ	Return ratio of used apparel
τ	Donation ratio of the collected used apparel
λ	Coefficient of the collection cost
p	The price of the new product
p_u	The price of the remanufactured products
p_d	Social benefits brought by retailer donations
p_s	The subsidy for the unit used apparel
Decision variables	
s	Recycling efforts of the retailer
p_c	The remanufacturer's procurement price for purchasing used apparel
Other variables	
π_m, π_r	Profits of the remanufacturer and retailer, respectively
π_{Total}	Supply chain total profit

π_m and π_r, respectively. Therefore, this study can provide some assumptions and explanations without loss of generality before formally constructing the game models.

Assumption 3.1. *In the benchmark model, since only some consumers pay attention to the recycling behavior of fashion retailer, it is assumed that only part of consumers delivers the used apparel to the retailers. Therefore, the total recycled quantity is δD, where $0 < \delta < 1$. Then the retailer selects a part of ($\tau\delta D$, $0 < \tau < 1$) better quality to donate and delivers the remaining portion to the remanufacturer.*

Assumption 3.2. *The retailer's investment cost of the recycling efforts is diminishing marginal utility so that it is a nonlinear function [55, 56], i.e., $C(s) = \frac{1}{2}\lambda s^2$. The retailer recycling used apparel also incurs additional costs, such as paying workers to collect, sort, transport, etc. It also needs to provide consumers with gifts and discount coupons to attract consumers to participate in recycling activities. All these costs can be regarded as the total cost of the recycling efforts.*

Assumption 3.3. *Generally, to avoid trivial solutions, the potential market demand a is large enough, and the consumers' price sensitivity is more significant than the sensitivity to recycling efforts, i.e., $1 > b > r > 0$.*

Assumption 3.4. *The remanufacturer collects from the retailer to produce new derivative products for sale, and the unit collect cost is p_c. Then the remanufacturer profit from selling those derivative products and obtain subsidies from the government. The value of unit derivative products is set as p_u. Since the equipment and technology used in the remanufacturing process are often very mature, it can be regarded as a constant zero.*

Briefly, the main symbols and parameters are summarized in Table 2.

3.2. Benchmark model

Based on the assumptions, the profit functions of the retailer and remanufacturer in the benchmark model can be presented as follows. The retailer's profit consists of revenue from the sale of new products, the sale of used apparel to remanufacturers, social benefits through donations, and the cost of recycling efforts. The remanufacturer's profit mainly includes selling derivative products and paying for used apparel.

$$\begin{cases} \pi_r = Dp + \tau\delta D p_d + (1-\tau)\delta D p_c - \dfrac{1}{2}\lambda s^2 & (1) \\ \pi_m = (1-\tau)\delta D(p_u - p_c). & (2) \end{cases}$$

Based on equations (1) and (2), the optimal strategies of the supply chain players can be obtained. Because the retailer's profit function is estimated to be a concave function of s, by solving the first-order condition, the recycling efforts $s' = \frac{r(p+\delta(p_c^*(1-\tau)+p_d\tau))}{\lambda}$ and procurement price $p_c^* = \frac{1}{2}\left(p_d + p_u + \frac{r^2(p+p_d\delta)+D\lambda}{r^2\delta(\tau-1)}\right)$ are obtained. Substituting p_c^* into s', then the optimal recycling efforts is $s^* = \frac{r^2(p+\delta\Delta_1)-D\lambda}{2r\lambda}$. Thus, the profits of supply chain players are obtained as follows (proof see Appendix A).

$$\begin{cases} \pi_m^* = \dfrac{\left(r^2(p+\delta\Delta_1)+D\lambda\right)^2}{4r^2\lambda}, & (3) \\ \pi_r^* = \dfrac{\left(r^2(p+\delta\Delta_1)-D\lambda\right)\left(r^2(p+\delta\Delta_1)+3D\lambda\right)}{8r^2\lambda} & (4) \end{cases}$$

where $\Delta_1 = (1-\tau)p_u + p_d\tau$.

In this section, this study constructs a benchmark model and obtains the supply chain players' optimal strategies. In the following, this study will propose three extended models that consider different government subsidy strategies and give some interesting propositions.

4. Extended model with considering government subsidy

The government can provide incentive policies to promote the recycling of used apparel, and the commonly used strategy is to subsidize recycled products directly. Therefore, this study presents three extended models based on different subsidy scenarios to find the optimal subsidizing strategy. The first case is to subsidize the remanufacturer. The second case is to subsidize the remanufacturing part of the retailer. Finally, the third case is to subsidize all the recycled products of the retailer.

4.1. Case 1

Compared with the benchmark model, the profit of the remanufacturer should add to the financial subsidy provided by the government, while the retailer's profit function unchanged. Thus, the profit functions of Case 1 are shown in equations (5) and (6).

$$\begin{cases} \pi_r^{\text{case1}} = Dp + \tau\delta D p_d + (1-\tau)\delta D p_c - \dfrac{1}{2}\lambda s^2 & (5) \\ \pi_m^{\text{case1}} = (1-\tau)\delta D(p_u - p_c + p_s). & (6) \end{cases}$$

4.2. Case 2

When considering the government subsidy for the non-donation part of the retailer, the retailer's profit is increased the subsidy part compared with the benchmark model. Thus, the profit functions in Case 2 are shown in equations (7) and (8).

$$\begin{cases} \pi_r^{\text{case2}} = Dp + \tau\delta D p_d + (1-\tau)\delta D(p_c + p_s) - \dfrac{1}{2}\lambda s^2 & (7) \\ \pi_m^{\text{case2}} = (1-\tau)\delta D(p_u - p_c). & (8) \end{cases}$$

TABLE 3. The optimal strategies of different game models.

Model cases	Recycling efforts (s)	Unit procurement price (p_c)	The profit of the remanufacturer (π_m)	The profit of the retailer (π_r)
Benchmark	$\frac{r^2(p+\delta\Delta_1)-D\lambda}{2r\lambda}$	$\frac{D\lambda+r^2(p+\delta\Gamma)}{2r^2\delta(\tau-1)}$	$\frac{\left(r^2(p+\delta\Delta_1)+D\lambda\right)^2}{4r^2\lambda}$	$\frac{\left(r^2(p+\delta\Delta_1)+3D\lambda\right)\left(r^2(p+\delta\Delta_1)-D\lambda\right)}{8r^2\lambda}$
Case 1	$\frac{r^2(p+\delta\Delta_2)-D\lambda}{2r\lambda}$	$\frac{D\lambda+r^2(p+\delta\Gamma)}{2r^2\delta(\tau-1)}+\frac{p_s}{2}$	$\frac{\left(r^2(p+\delta\Delta_2)+D\lambda\right)^2}{4r^2\lambda}$	$\frac{\left(r^2(p+\delta\Delta_2)+3D\lambda\right)\left(r^2(p+\delta\Delta_2)-D\lambda\right)}{8r^2\lambda}$
Case 2	$\frac{r^2(p+\delta\Delta_2)-D\lambda}{2r\lambda}$	$\frac{D\lambda+r^2(p+\delta\Gamma)}{2r^2\delta(\tau-1)}-\frac{p_s}{2}$	$\frac{\left(r^2(p+\delta\Delta_2)+D\lambda\right)^2}{4r^2\lambda}$	$\frac{\left(r^2(p+\delta\Delta_2)+3D\lambda\right)\left(r^2(p+\delta\Delta_2)-D\lambda\right)}{8r^2\lambda}$
Case 3	$\frac{r^2(p+\delta\Delta_3)-D\lambda}{2r\lambda}$	$\frac{D\lambda+r^2(p+\delta\Gamma)}{2r^2\delta(\tau-1)}+\frac{p_s}{2(\tau-1)}$	$\frac{\left(r^2(p+\delta\Delta_3)+D\lambda\right)^2}{4r^2\lambda}$	$\frac{\left(r^2(p+\delta\Delta_3)+3D\lambda\right)\left(r^2(p+\delta\Delta_3)-D\lambda\right)}{8r^2\lambda}$

Notes. Where $\Delta_1 = (1-\tau)p_u + p_d\tau, \Delta_2 = \Delta_1 + (1-\tau)p_s, \Delta_3 = \Delta_1 + p_s, \Gamma = p_u(\tau-1) + p_d\tau$.

4.3. Case 3

Since recycling and donating used apparel are socially and environmentally friendly, the government could provide corresponding financial subsidies to support the retailer's recycling and donation behaviors. Different from the benchmark model, the retailer's profit function should add the government subsidy for all recycling apparel. Thus, the profit functions in Case 3 are shown in equations (9) and (10).

$$\begin{cases} \pi_r^{\text{case3}} = Dp + \tau\delta Dp_d + (1-\tau)\delta Dp_c + \delta Dp_s - \frac{1}{2}\lambda s^2 & (9)\\ \pi_m^{\text{case3}} = (1-\tau)\delta D(p_u - p_c). & (10)\end{cases}$$

Based on the three extended game models under different subsidy scenarios, the optimal strategies of supply chain players are derived and shown in Table 3.

Proposition 4.1. *The optimal recycling efforts s of the retailer are the same in Cases 1 and 2. Furthermore, although the optimal procurement prices p_c are different, the profits of supply chain players are the same.*

Proposition 4.1 points out that the government subsidies to the remanufacturer or the remanufacturing part of the retailer have the same effect. It does not affect the retailer's optimal recycling efforts, and the supply chain players' profits are the same in Cases 1 and 2. It also means that the government spends the same financial subsidy in both scenarios. Therefore, it is only the form difference but does not change the player's profits.

5. MODELS ANALYSIS AND COMPARISON

This study obtains optimal strategies and profits for the supply chain players under different subsidy scenarios based on the benchmark and extended models. However, some important parameters can significantly impact these optimal strategies. Therefore, this study analyzes the sensitivity of some important parameter.

5.1. Sensitivity analyses

Based on the optimal strategies of the supply chain players, the sensitivity of s and p_c for various variates are presented in Table 4. (For the sake of brevity, the sensitivity analyses of the profits are shown in Tab. B.1, Appendix B.)

Table 4 shows the sensitivities of s and p_c for various variates. It can be found that as the market size a increases, it leads to a reduction in the retailer's recycling efforts s and the remanufacturer's procurement price p_c. It may be due to the retailer producing more new products to capture the market share and spending less on recycling efforts. Moreover, consumers' sensitivity to price can positively affect recycling efforts and procurement prices. Combining with the optimal profits of supply chain players, Table B.1 shows that the remanufacturer's

TABLE 4. Sensitivity analyses of s and p_c with various variates.

Parameters	Benchmark model		Case 1/2		Case 3	
	Effect on s.	Effect on p_c.	Effect on s.	Effect on p_c.	Effect on s.	Effect on p_c.
$a \uparrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$
$b \uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
$r \uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
$\delta \uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
$\tau \uparrow$	$\uparrow p_u < p_d$, $\downarrow p_u > p_d$	$\downarrow$	$\uparrow p_s + p_u < p_d$, $\downarrow p_s + p_u > p_d$	$\downarrow$	$\uparrow p_u < p_d$, $\downarrow p_u > p_d$	$\downarrow$
$p_s \uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
$p \uparrow$	$\uparrow$	$\uparrow \lambda > \frac{r^2}{b}$, $\downarrow \lambda < \frac{r^2}{b}$	$\uparrow$	$\uparrow \lambda > \frac{r^2}{b}$, $\downarrow \lambda < \frac{r^2}{b}$	$\uparrow$	$\uparrow \lambda > \frac{r^2}{b}$, $\downarrow \lambda < \frac{r^2}{b}$
$p_u \uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
$p_d \uparrow$	$\uparrow$	$\downarrow$	$\uparrow$	$\downarrow$	$\uparrow$	$\downarrow$

profit always increases as the market size a increases, while the retailer's profit increases only when $\lambda < \frac{r^2(p+\delta\Delta)}{3(a-bp)}$, and *vice versa*[4]. The remanufacturer's profit decreases as b increases, while the retailer's profit increase only when $\lambda > \frac{r^2(p+\delta\Delta)}{3(a-bp)}$, and *vice versa*.

Proposition 5.1. (a) *Consumers' sensitivity to recycling efforts promotes retailers' recycling efforts and increases remanufacturers' procurement costs.*
(b) *The recycling ratio increases retailers' recycling efforts and remanufacturers' procurement costs.*

From proposition 5.1, it can be found that the increase in consumers' sensitivity to the recycling efforts r and used apparel recycling ratio δ are positively correlated to the retailer recycling efforts. Intuitively, we believe that the retailer's recycling efforts decrease as the recycling ratio increase. However, they are positively correlated. It also means that when consumers pay more attention to the environment, the retailer invests more in recycling efforts, and it benefits the environment and society. Moreover, with the increase of r, the remanufacturer's profit always decreases, while the retailer's profit increase only when $\lambda > \frac{r^2(p+\delta\Delta)}{3(a-bp)}$, and *vice versa*.

Furthermore, with r and δ increase, the remanufacturer's procurement costs also increase. Intuitively, the increase in procurement cost may lead to a decrease in the remanufacturer's profit. However, the remanufacturer's profit always increases with δ. The increase of recycling efforts isn't always beneficial for the remanufacturer's profit, *i.e.*, it is benefit for remanufacturing only when $\lambda > \frac{r^2(p+\delta\Delta)}{3(a-bp)}$, and *vice versa*.

Proposition 5.2. (a) *The relation between recycling efforts in different subsidy scenarios is* $s^{\text{benchmark}} < s^{\text{case1}} = s^{\text{case2}} < s^{\text{case3}}$.
(b) *The relation between procurement prices in different subsidy scenarios is* $p_c^{\text{case3}} < p_c^{\text{case2}} < p_c^{\text{benchmark}} < p_c^{\text{case1}}$.

Proof. Since $s^{\text{case1}} - s^{\text{case2}} = 0$, then we have $s^{\text{case1}} = s^{\text{case2}}$. Moreover, $s^{\text{case1}} - s^{\text{benchmark}} = \frac{psr\delta(1-\tau)}{2\lambda} > 0$, and $s^{\text{case3}} - s^{\text{case1}} = \frac{psr\delta\tau}{2\lambda} > 0$. Thus, we can obtain the relation between recycling efforts in different subsidy scenarios is $s^{\text{benchmark}} < s^{\text{case1}} = s^{\text{case2}} < s^{\text{case3}}$.

Similarly, $p_c^{\text{case2}} - p_c^{\text{case3}} = \frac{ps\tau}{2(1-\tau)} > 0$, then we have $p_c^{\text{case2}} > p_c^{\text{case3}}$. Moreover, $p_c^{\text{benchmark}} - p_c^{\text{case2}} = \frac{ps}{2} > 0$, and $p_c^{\text{case1}} - p_c^{\text{benchmark}} = \frac{ps}{2} > 0$. Thus, we can obtain the relation between procurement prices in different subsidy scenarios is $p_c^{\text{case3}} < p_c^{\text{case2}} < p_c^{\text{benchmark}} < p_c^{\text{case1}}$. □

[4]In the benchmark model, Δ corresponds to Δ_1; in Cases 1 and 2, Δ corresponds to Δ_2; in Case 3, Δ corresponds to Δ_3. It is consistent in the following expressions.

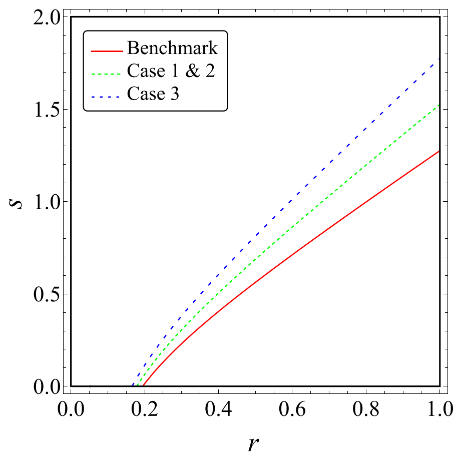


FIGURE 2. The relations between r and s.

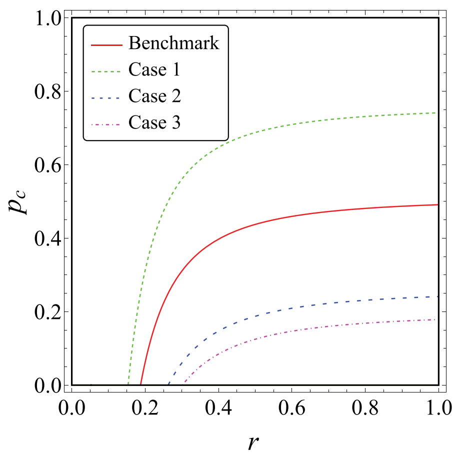


FIGURE 3. The relations between r and p_c.

Based on the known constraints, this study selects a data set to clearly illustrate the relation between decision variables and parameters, *i.e.*, $a = 1.1, b = 1, \tau = 0.5, \delta = 0.5, \lambda = 0.5, p = 1, p_u = 0.8, p_d = 0.5, p_s = 1$. As the sensitivity r increases, Figures 2 and 3 present the evolution of recycling efforts and procurement price, respectively.

As shown in Figure 2, the consumers' sensitivity to recycling efforts positively affect the recycling efforts in all game scenarios. It means that the consumers are more aware of environmental protection, and the retailer pays more attention to the environment. It can be found that the recycling efforts s is the lowest in the benchmark model, and it is always higher in Case 3, *i.e.*, $s^{\text{benchmark}} < s^{\text{case1}} = s^{\text{case2}} < s^{\text{case3}}$. Figure 3 shows that the consumers' sensitivity to recycling efforts positively affects the procurement price in all game models. It can be found that the procurement price is the lowest in Case 3, and it is always higher in Case 1, *i.e.*, $p_c^{\text{case3}} < p_c^{\text{case2}} < p_c^{\text{benchmark}} < p_c^{\text{case1}}$.

This study illustrates the relations between the recycling ratio and procurement price in Figures 4 and 5. It can be found that the increase in the recycling ratio can promote the recycling efforts and the procurement price simultaneously.

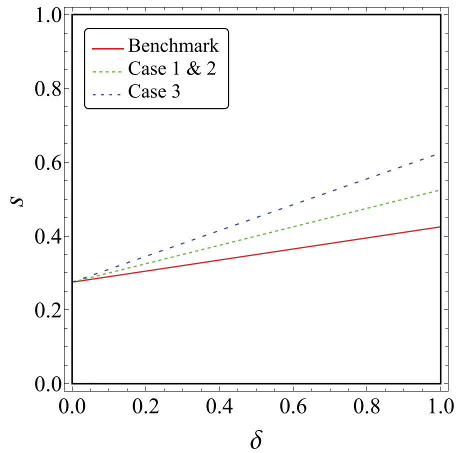


FIGURE 4. The relations between δ and s.

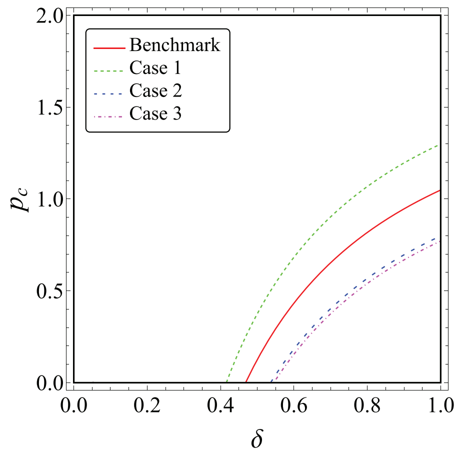


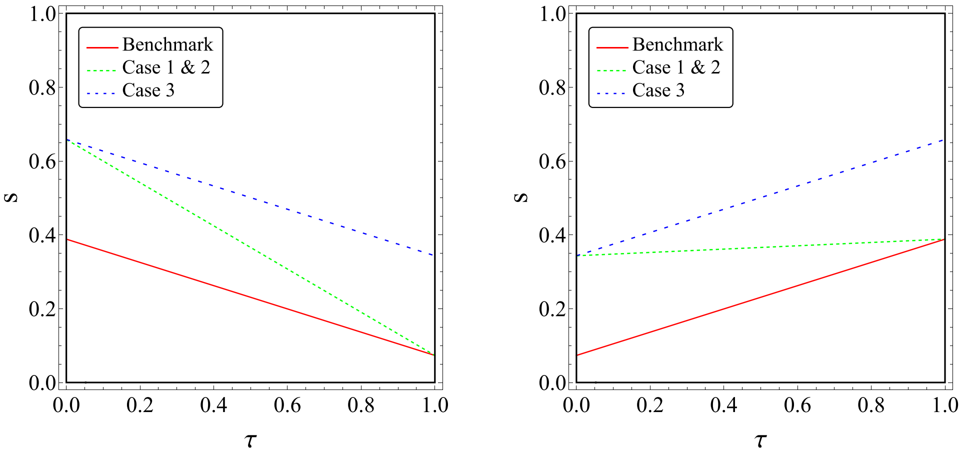
FIGURE 5. The relations between δ and p_c.

Proposition 5.3. (a) *In the benchmark model and Case 3, the recycling efforts increase with the retailer's donation ratio only when $p_u < p_d$, and vice versa.*

(b) *In Cases 1 and 2, the recycling efforts increase with the retailer's donation ratio only when $p_s + p_u < p_d$, and vice versa.*

Interestingly, different donation ratios can show the opposite result. As the donation ratio increases, the recycling efforts decrease with the donation ratio when $p_u > p_d$. The recycling efforts increase with the donation ratio when $p_u < p_d$.

As shown in Figure 6, Cases 1 and 2 form a kind of bridge between the benchmark model and Case 3 as two moderate situations, enabling a smooth transition between them. Therefore, Cases 1 and 2 have a buffering effect on the government's subsidy policy. As shown in Figure 7, the donation ratio is negatively related to the procurement price. It maybe creates an illusion for the remanufacturer that a lower procurement price may increase its profit. However, the remanufacturer's profit increases accordingly only when $p_u < p_d$ (Benchmark model, Cases 1 and 2) or $p_s + p_u < p_d$ (Case 3). Otherwise, the remanufacturer's profit decrease. The increase



(a) (b)

FIGURE 6. The relations between τ and s. (a) When $p_u > p_d$. (a) When $p_u < p_d$.

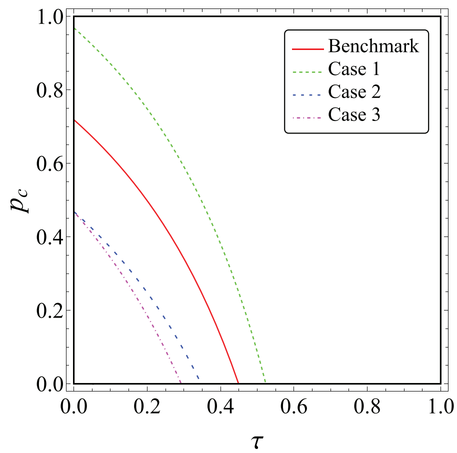


FIGURE 7. The relations between τ and p_c.

in donation ratio may reduce the remanufacturer's profit and even withdraw it from the recycling supply chain. Therefore, the government should subsidize the remanufacturer when τ is larger.

5.2. Pareto improvement

Studying the relation between profits in different game scenarios is practical since firms are driven by profits. Thus, proposition 5.4 shows the Pareto improvement from the profits perspective.

Proposition 5.4. *Compared with the benchmark model, a Pareto improvement occurs when the government subsidizes the remanufacturer (Case 1) or the retailer's remanufacturing part (Case 2). Furthermore, when the government subsidizes all recycled products of the retailer (Case 3), Pareto improvement occurs again.*

Proposition 5.4 shows that the subsidy positively affects the profits of supply chain players, and Case 3 is the optimal strategy, *i.e.*, $\pi_m^{\text{benchmark}} < \pi_m^{\text{case1}} = \pi_m^{\text{case2}} < \pi_m^{\text{case3}}$, $\pi_r^{\text{benchmark}} < \pi_r^{\text{case1}} = \pi_r^{\text{case2}} < \pi_r^{\text{case3}}$,

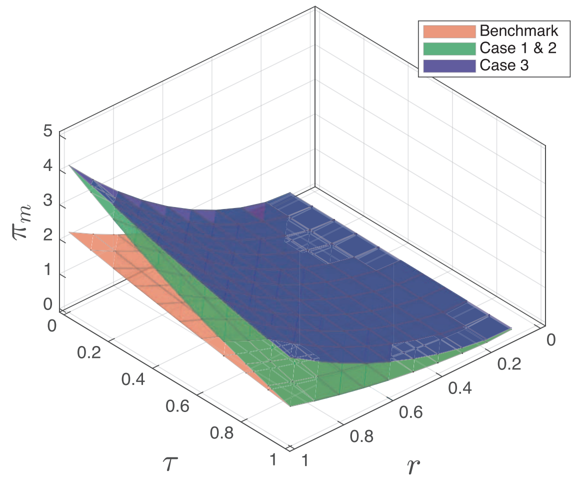


FIGURE 8. The profits of the remanufacturer.

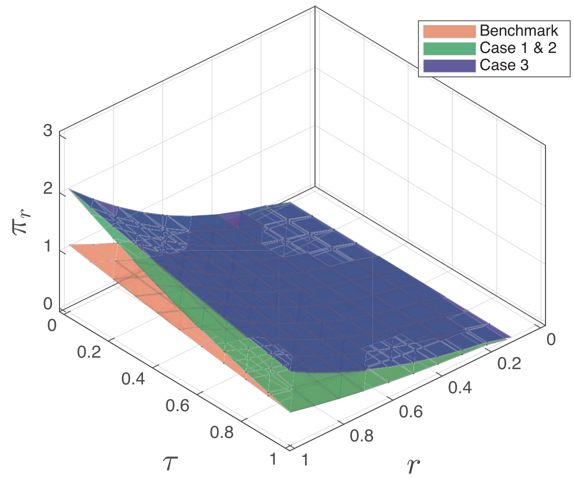


FIGURE 9. The profits of the retailer.

and $\pi_{\text{Total}}^{\text{benchmark}} < \pi_{\text{Total}}^{\text{case1}} = \pi_{\text{Total}}^{\text{case2}} < \pi_{\text{Total}}^{\text{case3}}$. With various recycling efforts' sensitivity and donation ratios, Figures 8 and 9 show the profits of the remanufacturer and retailer, respectively. Figure 10 shows the total profit of the supply chain. It can be seen that the profits of the retailer and remanufacturer changed with the government subsidy strategies change. Case 3 is the best strategy for supply chain players, Cases 1 and 2 have the same effect, and the supply chain gains the lowest profit in the benchmark scenario.

Figures 8–10 indicates that all the government subsidy strategies benefit the profit of the used apparel recycling supply chain, and Pareto improvement can be obtained when considering the government subsidy. In Figures 8–10, the red surfaces represent the profit of the benchmark model. The green surfaces represent the profit of Cases 1 and 2, *i.e.*, the government subsidizes the remanufacturer or the retailer's remanufacturing part. The blue surfaces represent the profit of Case 3, *i.e.*, the government subsidizes all recycled used apparel. It presents a Pareto improvement when the government adopts the subsidy strategies of Case 1 or Case 2. Moreover, when the government adopts the subsidy strategy of Case 3, the Pareto improvement occurs again.

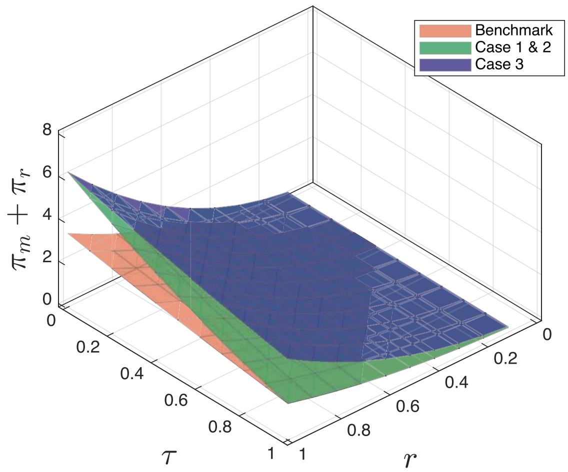


FIGURE 10. The total profits of the supply chain.

Therefore, Case 3 is the optimal subsidy strategy for the recycling system. It also means that the government is motivated to provide financial subsidies for the supply chain players when developing an environmentally friendly society or circular economy.

6. Conclusion

This study constructs a benchmark model without subsidy and proposes three extended models based on different subsidy scenarios. It carries out the optimal subsidy strategies for the used apparel recycling supply chain, and presents some interesting results and managerial insights.

6.1. Main findings

This study finds some interesting results after comparing and analyzing the game models.

Firstly, it obtains a lower procurement price when the government subsidizes the remanufacturer (Case 1) or only subsidizes the retailer's remanufacturing part (Case 2). Therefore, it may lead the decision-makers to believe the remanufacturer gains a higher profit. However, the remanufacturer and retailer have the same profit in Cases 1 and 2, which means the subsidy strategies in Cases 1 and 2 have the same effect.

Secondly, when the consumers' sensitivity to recycling efforts increases, the retailer is willing to invest in recycling efforts. However, it may need to be clarified for the remanufacturer that it does not always benefit its profits. Instead, the profit of the remanufacturer may drop when the collection coefficient is more significant.

Finally, the government subsidizing all the recycled used apparel (Case 3) is the optimal strategy for the supply chain player, and it obtains the Pareto improvement. Nevertheless, the government pays a higher payment of financial subsidies. Therefore, as a moderate choice, the government may choose the subsidy strategy of Case 1 or Case 2.

6.2. Managerial insights

This study drives some managerial insights into the used apparel recycling supply chain. It can provide a reference for government decision-makers when formulating subsidy strategies for the used apparel recycling industry. Although the government applies various subsidy strategies, sometimes the overall effect on the supply chain is the same, and it even may be against the weak enterprise. Therefore, governments should be careful before enacting subsidy policies. It positively affects the retailer's social image and resource utilization only when the retailer's donation is within an acceptable range. Otherwise, it will be detrimental to the remanufacturer's profit and even cause it withdraws from the recycling supply chain when the donation ratio is too high.

6.3. Future research work

There are several research directions to improve and supplement this study work. For example, it could be in conjunction with third-party recycling companies and the government's low-carbon policies for more in-depth discussions on the development of the recycling industry. Moreover, the optimal strategies can be studied combined with social welfare and environmental benefits. Furthermore, the coordination mechanism between enterprises can be studied and discussed.

Appendix A. Proof of the optimal conditions

Proof. Based on the profit function equation (1), we can obtain,

$$\begin{cases} \frac{\partial \pi_r}{\partial s} = -s\lambda + r(p + \delta(p_c(1-\tau) + p_d\tau)), \\ \frac{\partial^2 \pi_r}{\partial s^2} = -\lambda. \end{cases}$$

Obviously, $\frac{\partial^2 \pi_r}{\partial s^2} = -\lambda < 0$. Let $\frac{\partial \pi_r}{\partial s} = 0$, we get

$$s' = \frac{r(p + \delta(p_c^*(1-\tau) + p_d\tau))}{\lambda}.$$

Take s' into equation (2), we get

$$\begin{cases} \frac{\partial \pi_m(s^*)}{\partial p_c} = \frac{\delta(\tau-1)\left(D\lambda + pr^2 + r^2\delta(2p_c - p_u + (p_d + p_u - 2p_c)\tau)\right)}{\lambda}, \\ \frac{\partial^2 \pi_m(s^*)}{\partial p_c^2} = -\frac{2r^2\delta^2(1-\tau)^2}{\lambda}. \end{cases}$$

Obviously, $\frac{\partial^2 \pi_m(s^*)}{\partial p_c^2} = -\frac{2r^2\delta^2(1-\tau)^2}{\lambda} < 0$, thus, we obtain the optimal solution of equation (1), *i.e.*,

$$p_c^* = \frac{1}{2}\left(p_d + p_u + \frac{r^2(p + p_d\delta) + D\lambda}{r^2\delta(\tau - 1)}\right).$$

Finally, take p_c^* into s', we get

$$s^* = s'(p_c^*) = \frac{r^2(p + \delta\Delta_1) - D\lambda}{2r\lambda}.$$

Then we can obtain the optimal profit of the retailer and remanufacturer, which is shown in (A.1) and (A.2), respectively.

$$\begin{cases} \pi_m^* = \frac{\left(r^2(p + \delta\Delta_1) + D\lambda\right)^2}{4r^2\lambda}, & \text{(A.1)} \\ \pi_r^* = \frac{\left(r^2(p + \delta\Delta_1) - D\lambda\right)\left(r^2(p + \delta\Delta_1) + 3D\lambda\right)}{8r^2\lambda} & \text{(A.2)} \end{cases}$$

where $\Delta_1 = (1-\tau)p_u + p_d\tau$.

The proofs for the extended models are similar, so they are omitted. □

TABLE B.1. Sensitivity analyses of π_m and π_r with various parameters.

Parameters	Benchmark model		Case 1/2		Case 3	
	Effect on π_m.	Effect on π_r.	Effect on π_m.	Effect on π_r.	Effect on π_m.	Effect on π_r.
$a\uparrow$	$\uparrow$	$\uparrow \lambda < \frac{r^2(p+\delta\Delta_1)}{3(a-bp)}$, $\downarrow \lambda > \frac{r^2(p+\delta\Delta_1)}{3(a-bp)}$	$\uparrow$	$\uparrow \lambda < \frac{r^2(p+\delta\Delta_2)}{3(a-bp)}$, $\downarrow \lambda > \frac{r^2(p+\delta\Delta_2)}{3(a-bp)}$	$\uparrow$	$\uparrow \lambda < \frac{r^2(p+\delta\Delta_3)}{3(a-bp)}$, $\downarrow \lambda > \frac{r^2(p+\delta\Delta_3)}{3(a-bp)}$
$b\uparrow$	$\downarrow$	$\uparrow \lambda > \frac{r^2(p+\delta\Delta_1)}{3(a-bp)}$, $\downarrow \lambda < \frac{r^2(p+\delta\Delta_1)}{3(a-bp)}$,	$\downarrow$	$\uparrow \lambda > \frac{r^2(p+\delta\Delta_2)}{3(a-bp)}$, $\downarrow \lambda < \frac{r^2(p+\delta\Delta_2)}{3(a-bp)}$,	$\downarrow$	$\uparrow \lambda > \frac{r^2(p+\delta\Delta_3)}{3(a-bp)}$, $\downarrow \lambda < \frac{r^2(p+\delta\Delta_3)}{3(a-bp)}$
$r\uparrow$	$\uparrow \lambda < \frac{r^2(p+\delta\Delta_1)}{a-bp}$, $\downarrow \lambda > \frac{r^2(p+\delta\Delta_1)}{a-bp}$	$\uparrow$	$\uparrow \lambda < \frac{r^2(p+\delta\Delta_2)}{a-bp}$, $\downarrow \lambda > \frac{r^2(p+\delta\Delta_2)}{a-bp}$	$\uparrow$	$\uparrow \lambda < \frac{r^2(p+\delta\Delta_3)}{a-bp}$, $\downarrow \lambda > \frac{r^2(p+\delta\Delta_3)}{a-bp}$	$\uparrow$
$\delta\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
$\tau\uparrow$	$\uparrow p_u < p_d$, $\downarrow p_u > p_d$	$\uparrow p_u < p_d$, $\downarrow p_u > p_d$	$\uparrow p_s + p_u < p_d$, $\downarrow p_s + p_u > p_d$	$\uparrow p_s + p_u < p_d$, $\downarrow p_s + p_u > p_d$	$\uparrow p_u < p_d$, $\downarrow p_u > p_d$	$\uparrow p_u < p_d$, $\downarrow p_u > p_d$
$p_s\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
$p\uparrow$	$\uparrow \lambda < \frac{r^2}{b}$, $\downarrow \lambda > \frac{r^2}{b}$	$\uparrow$	$\uparrow \lambda < \frac{r^2}{b}$, $\downarrow \lambda > \frac{r^2}{b}$	$\uparrow$	$\uparrow$	$\uparrow$
$p_u\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
$p_d\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\downarrow$	$\uparrow$	$\uparrow$

Notes. Where $\Delta_1 = (1-\tau)p_u + p_d\tau, \Delta_2 = \Delta_1 + (1+\tau)p_s, \Delta_3 = \Delta_1 + p_s$.

APPENDIX B. SENSITIVITY ANALYSES OF π_m AND π_r.

Table B.1 shows the sensitivity relations between the players' profits and parameters. As a complement, this study presents several valuable propositions as follows.

Proposition B.1. *Increasing market size a is beneficial to the remanufacturer. However, it increases the retailer's profit only when $\lambda < \frac{r^2(p+\delta\Delta)}{3(a-bp)}$, and vice versa. (In the Benchmark model, $\Delta = \Delta_1$; in Cases 1 and 2, $\Delta = \Delta_2$; and in Case 3, $\Delta = \Delta_3$.)*

Proposition B.2. *Increasing consumers' sensitivity to recycling efforts r is beneficial to the retailer. However, it increases the remanufacturer's profit only when $\lambda < \frac{r^2(p+\delta\Delta)}{a-bp}$, and vice versa. (In the Benchmark model, $\Delta = \Delta_1$; in Cases 1 and 2, $\Delta = \Delta_2$; and in Case 3, $\Delta = \Delta_3$.)*

Proposition B.3. *Increasing the price of new products is beneficial to the retailer in all cases, and beneficial to the remanufacturer only in Case 3. In other cases, it is beneficial to the remanufacturer only when $\lambda < \frac{r^2}{b}$, and vice versa.*

Propositions B.1–B.3 present some significant and valuable conclusions. Proposition B.1 shows the remanufacturer always benefits from the increase of market size a, and the retailer's profit increases only when $\lambda < \frac{r^2(p+\delta\Delta)}{3(a-bp)}$, and *vice versa*. Proposition B.2 shows the retailer always benefits from the increase in consumers' sensitivity to recycling efforts r, and it improves the remanufacturer's profit only when $\lambda < \frac{r^2(p+\delta\Delta)}{a-bp}$, and *vice versa*. Proposition B.3 shows the increase in new products price is beneficial to the retailer in all cases, and it is advantageous to the remanufacturer in Case 3. However, it is beneficial to the remanufacturer's profit only when $\lambda < \frac{r^2}{b}$ in the benchmark model and Cases 1 and 2.

More conclusions can be found based on the sensitivity analysis in Table B.1. For example, the decrease in consumers' price sensitivity b is beneficial to the profit of the remanufacturer, and the increase in return ratio is beneficial to the profits of the supply chain players. Moreover, the increase in remanufacturing products is positively related to the players' profits. The increase in the benefit from donations is not beneficial to the retailer in cases 1 & 2, but it is beneficial to both players in the other subsidy scenarios. All these findings can provide theoretical support for decision-makers. In addition, government decision-makers can select subsidy strategies that are more beneficial to society and the environment through the above results, promoting the development of an environment-friendly society.

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References

[1] F. Jia, S. Yin, L. Chen and X. Chen, The circular economy in the textile and apparel industry: a systematic literature review. *J. Cleaner Prod.* **259** (2020) 120728.

[2] Y.-J. Cai and T.-M. Choi, A United Nations' sustainable development goals perspective for sustainable textile and apparel supply chain management. *Transp. Res. Part E: Logistics Transp. Rev.* **141** (2020) 102010.

[3] X. Li, L. Wang and X. Ding, Textile supply chain waste management in China. *J. Cleaner Prod.* **289** (2021) 125147.

[4] J.M. Hawley, Understanding and improving textile recycling: a systems perspective, in Sustainable Textiles. *Woodhead Publishing Series in Textiles*, edited by R.S. Blackburn. Woodhead Publishing (2009) 179–199.

[5] Ellen MacArthur Foundation, A new textiles economy: redesigning fashion's future. Technical report (2017).

[6] P.D. Venkatraman, K. Scott and C. Liauw, Environmentally friendly and sustainable bark cloth for garment applications: evaluation of fabric properties and apparel development. *Sustainable Mater. Technol.* **23** (2020) e00136.

[7] D. Friedrich, What makes bioplastics innovative for fashion retailers? An in-depth analysis according to the triple bottom line principle. *J. Cleaner Prod.* **316** (2021) 128257.

[8] V. Roy, B.S. Silvestre and S. Singh, Reactive and proactive pathways to sustainable apparel supply chains: manufacturer's perspective on stakeholder salience and organizational learning toward responsible management. *Int. J. Prod. Econ.* **227** (2020) 107672.

[9] L. Repp, M. Hekkert and J. Kirchherr, Circular economy-induced global employment shifts in apparel value chains: job reduction in apparel production activities, job growth in reuse and recycling activities. *Res. Conserv. Recycling* **171** (2021) 105621.

[10] D. Friedrich, Comparative analysis of sustainability measures in the apparel industry: an empirical consumer and market study in Germany. *J. Environ. Manage.* **289** (2021) 112536.

[11] T. Islam, R. Islam, A.H. Pitafi, L. Xiaobei, M. Rehmani, M. Irfan and M.S. Mubarak, The impact of corporate social responsibility on customer loyalty: the mediating role of corporate reputation, customer satisfaction, and trust. *Sustainable Prod. Consumption* **25** (2021) 123–135.

[12] C.-W. Ho, Does practicing CSR makes consumers like your shop more? Consumer–retailer love mediates CSR and behavioral intentions. *Int. J. Environ. Res. Publ. Health* **14** (2017) 1558.

[13] D. Servera-Francés and L. Piqueras-Tomás, The effects of corporate social responsibility on consumer loyalty through consumer perceived value. *Econ. Res.-Ekonomska Istraživanja* **32** (2019) 66–84.

[14] Global Fashion Agenda and The Boston Consulting Group, Pulse of the fashion industry. Technical report, Global Fashion Agenda & The Boston Consulting Group (2017).

[15] M.E. Bubicz, A.P.F.D. Barbosa-Póvoa and A. Carvalho, Social sustainability management in the apparel supply chains. *J. Cleaner Prod.* **280** (2021) 124214.

[16] H&M Group, Sustainability performance report 2019. Technical report (2019).

[17] H&M Group, Sustainability performance report 2020. Technical report (2020).

[18] Levi Strauss & Co, 2020 sustainability report. Technical report (2020).

[19] K. Govindan and H. Soleimani, A review of reverse logistics and closed-loop supply chains: a journal of cleaner production focus. *J. Cleaner Prod.* **142** (2017) 371–384.

[20] T.-M. Choi, Y. Li and L. Xu, Channel leadership, performance and coordination in closed loop supply chains. *Int. J. Prod. Econ.* **146** (2013) 371–380.

[21] T.-M. Choi, Optimal return service charging policy for a fashion mass customization program. *Serv. Sci.* **5** (2013) 56–68.

[22] H. Chen, Z. Dong, G. Li and K. He, Remanufacturing process innovation in closed-loop supply chain under cost-sharing mechanism and different power structures. *Comput. Ind. Eng.* **162** (2021) 107743.

[23] L. Norris, The limits of ethicality in international markets: imported second-hand clothing in India. *Geoforum* **67** (2015) 183–193.

[24] T.-M. Choi, P.-S. Chow, C.H. Lee and B. Shen, Used intimate apparel collection programs: a game-theoretic analytical study. *Transp. Res. Part E: Logistics Transp. Rev.* **109** (2018) 44–62.

[25] V. Jain, W. O'Brien and T.P. Gloria, Improved solutions for shared value creation and maximization from used clothes: streamlined structure of clothing consumption system and a framework of closed loop hybrid business model. *Cleaner Responsible Consumption* **3** (2021) 100039.

[26] T.M. Rausch, D. Baier and S. Wening, Does sustainability really matter to consumers? Assessing the importance of online shop and apparel product attributes. *J. Retailing Consum. Serv.* **63** (2021) 102681.

[27] N. Alizadeh-Basban and A.A. Taleizadeh, A hybrid circular economy – game theoretical approach in a dual-channel green supply chain considering sale's effort, delivery time, and hybrid remanufacturing. *J. Cleaner Prod.* **250** (2020) 119521.

[28] A.A. Taleizadeh, M.S. Moshtagh and I. Moon, Pricing, product quality, and collection optimization in a decentralized closed-loop supply chain with different channel structures: game theoretical approach. *J. Cleaner Prod.* **189** (2018) 406–431.

[29] A.A. Taleizadeh, N. Alizadeh-Basban and S.T. Akhavan Niaki, A closed-loop supply chain considering carbon reduction, quality improvement effort, and return policy under two remanufacturing scenarios. *J. Cleaner Prod.* **232** (2019) 1230–1250.

[30] Y.-J. Cai, T.-M. Choi and T. Zhang, Commercial used apparel collection operations in retail supply chains. *Eur. J. Oper. Res.* **298** (2022) 169–181.

[31] Y. Yan, F. Yao and J. Sun, Manufacturer's cooperation strategy of closed-loop supply chain considering corporate social responsibility. *RAIRO: Oper. Res.* **55** (2021) 3639–3659.

[32] A.A. Taleizadeh, E. Sane-Zerang and T.-M. Choi, The effect of marketing effort on dual-channel closed-loop supply chain systems. *IEEE Trans. Syst. Man Cybern. Syst.* **48** (2018) 265–276.

[33] A.A. Taleizadeh and R. Sadeghi, Pricing strategies in the competitive reverse supply chains with traditional and e-channels: a game theoretic approach. *Int. J. Prod. Econ.* **215** (2019) 48–60.

[34] E. Sane Zerang, A.A. Taleizadeh and J. Razmi, Analytical comparisons in a three-echelon closed-loop supply chain with price and marketing effort-dependent demand: game theory approaches. *Environ. Dev. Sustainability* **20** (2018) 451–478.

[35] I.M. Sandvik and W. Stubbs, Circular fashion supply chain through textile-to-textile recycling. *J. Fashion Marketing Manage. Int. J.* **23** (2019) 366–381.

[36] A.H. Bajgiran, J. Jang, X. Fang and J.H. Peoples, A biofuel supply chain equilibrium analysis with subsidy consideration. *Int. J. Energy Res.* **43** (2019) 1848–1867.

[37] Z. Chen, L. Fang and S.-I. Ivan Su, The value of offline channel subsidy in bricks and clicks: an O_2O supply chain coordination perspective. *Electron. Commerce Res.* **21** (2021) 599–643.

[38] Y. Liu, B. Ting Quan, Q. Xu and J.Y.-L. Forrest, Corporate social responsibility and decision analysis in a supply chain through government subsidy. *J. Cleaner Prod.* **208** (2019) 436–447.

[39] J. Fu, X. Chen and Q. Hu, Subsidizing strategies in a sustainable supply chain. *J. Oper. Res. Soc.* **69** (2018) 283–295.

[40] J. Cheng, J. Wang and B. Gong, Game-theoretic analysis of price and quantity decisions for electric vehicle supply chain under subsidy reduction. *Comput. Econ.* **55** (2020) 1185–1208.

[41] T.-C. Weng and C.-K. Chen, Competitive analysis of collection behavior between retailer and third-party in the reverse channel. *RAIRO: Oper. Res.* **50** (2016) 175–188.

[42] W. Ma, Z. Zhao and H. Ke, Dual-channel closed-loop supply chain with government consumption-subsidy. *Eur. J. Oper. Res.* **226** (2013) 221–227.

[43] P. He, Y. He and H. Xu, Channel structure and pricing in a dual-channel closed-loop supply chain with government subsidy. *Int. J. Prod. Econ.* **213** (2019) 108–123.

[44] J. Chai, H. Li, C.-H. Lee S.-B. Tsai and H. Chen, Shareholding operation of product remanufacturing – from a sustainable production perspective. *RAIRO: Oper. Res.* **55** (2021) S1529–S1549.

[45] Y. Yang and X. Xu, A differential game model for closed-loop supply chain participants under carbon emission permits. *Comput. Ind. Eng.* **135** (2019) 1077–1090.

[46] Y. Wang and Y. Zhang, Do state subsidies increase corporate environmental spending? *Int. Rev. Financial Anal.* **72** (2020) 101592.

[47] A. Majumdar, S.K. Sinha and K. Govindan, Prioritising risk mitigation strategies for environmentally sustainable clothing supply chains: insights from selected organisational theories. *Sustainable Prod. Consumption* **28** (2021) 543–555.

[48] R. Sadeghi, A.A. Taleizadeh, F.T.S. Chan and J. Heydari, Coordinating and pricing decisions in two competitive reverse supply chains with different channel structures. *Int. J. Prod. Res.* **57** (2019) 2601–2625.

[49] A.A. Taleizadeh, S.T.A. Niaki and N. Alizadeh-Basban, Cost-sharing contract in a closed-loop supply chain considering carbon abatement, quality improvement effort, and pricing strategy. *RAIRO: Oper. Res.* **55** (2021) S2181–S2219.

[50] A. Dhir, M. Sadiq, S. Talwar, M. Sakashita and P. Kaur, Why do retail consumers buy green apparel? A knowledge-attitude-behaviour-context perspective. *J. Retailing Consum. Serv.* **59** (2021) 102398.

[51] M. Sadiq, K. Bharti, M. Adil and R. Singh, Why do consumers buy green apparel? The role of dispositional traits, environmental orientation, environmental knowledge, and monetary incentive. *J. Retailing Consum. Serv.* **62** (2021) 102643.

[52] S. Guo, T.-M. Choi and B. Shen, Green product development under competition: a study of the fashion apparel industry. *Eur. J. Oper. Res.* **280** (2020) 523–538.

[53] K.K.-L. Moon, C. Youn, J.M.T. Chang and A.W.H. Yeung, Product design scenarios for energy saving: a case study of fashion apparel. *Int. J. Prod. Econ.* **146** (2013) 392–401.

[54] Y. Wang, Z. Wang, B. Li, Z. Liu, X. Zhu and Q. Wang, Closed-loop supply chain models with product recovery and donation. *J. Cleaner Prod.* **227** (2019) 861–876.

[55] X. Chen, X. Wang and H.K. Chan, Manufacturer and retailer coordination for environmental and economic competitiveness: a power perspective. *Transp. Res. Part E: Logistics Transp. Rev.* **97** (2017) 268–281.

[56] J.-Y. Chen, S. Dimitrov and H. Pun, The impact of government subsidy on supply chains' sustainability innovation. *Omega* **86** (2019) 42–58.