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Contracts Selection Under Quality Uncertainty in Refurbish Decisions

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ABSTRACT With the rapid development of the information technology industry, refurbished products play significant roles in this challenge of environmental, economic, and social performance revolution. Meanwhile, when the refurbished product is launched in the market compete with new products, how and whom to repair the used products effectively and what kind of effective coordinate incentive mechanisms utilized to alleviate conflict and achieve the challenge become one of the most significant issues. Therefore, this study compares two refurbishing structures (manufacturer refurbishing and retailer refurbishing) under three different contract incentive mechanisms (wholesale price, revenue sharing, and reward points contracts) in two periods closed-loop supply chain (CLSC) model with demand uncertainty. Our results show that the manufacturer should allow his retailer to refurbish used products under the condition of using reward points contract strategies. It will help improve the whole channel performance and create much higher profits. Meanwhile, all channel members benefit from the reward point contract in the manufacturer refurbishing scenarios. However, manufacturers prefer revenue-sharing contracts while retailers prefer wholesale price contracts in the retailer refurbishing scenarios.

INDEX TERMS Refurbished products, channel coordination, closed-loop supply chain.

I. INTRODUCTION

Rapid advancements in the information technology industry, increasing the replacement frequency of the electronic productions generations. For example, as the new smartphone generation is introduced, customers are willing to change new one even if the phone is still working well [1]. According to various researchers, the waste of electrical and electronic equipment (WEEE) will increase to 27.22 million tons by 2030, up from 6.03 million tons in 2014. It grows in the average increase rate of 3-4% every year [2]. The wasted of WEEEs contain amass of lead, cadmium, arsenic, and selenium, the toxic chemicals that would cause severe pollution to the environment.

Meanwhile, many precious metals contained in the WEEEs can be easily reused after refurbished. Consequently, for environmental and economic purposes, WEEEs refurbished developed rapidly. The U.S. government began to implement Waste Electronic Products Recycling Law in 2002 and the European Union in 2003 [3]. Therefore, effectively recycling and repairing the used products and achieving the challenge of environmental, economic, and social performance become one of the most significant issues for the manufacturers [4].

Meanwhile, with the rapid growth of the refurbishing market, many retailers such as Game Stop, Best Buy, and Newegg are also involved in refurbishing used products [5]. Although the retailer takes some market share from the manufacturer, the manufacturer faces competition from refurbished products, and the retailer's benefits in the refurbishing market lead to conflict. However, prior research [6] highlighted that appropriate contract and incentive mechanisms might be achieved a win-win situation and increase all channel members' profits. Therefore, it is unwise to restrict access to spare parts and not share repair manuals to prevent other players' refurbishing their products [7]. Meanwhile, how and whom to effectively refurbish the used products and how to achieve environmental, economic, and social performance become one of the most significant issues for the manufacturer and retailer.

Therefore, this study compares three contract incentive mechanisms: wholesale price contract, revenue sharing,

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TABLE 1. Summarize relevant literature.

Authors	Supply chain structure			Contract type			Demand uncertain
	MR	RR	TR	MW	MR	MP	
Debo et al. [8]	✓		✓	✓			
Atasu et al. [9]	✓		✓	✓			
Chen and Chang [10]	✓		✓	✓			✓
Agrawal al. [11]	✓		✓				
Yan et al. [12]				✓	✓		
Niu et al.[1]			✓	✓			✓
Timoumi et al. [7]	✓	✓	✓	✓			
This study	✓	✓		✓	✓	✓	✓

MR, RR, and TR represent manufacturers refurbishing used products, retailers refurbishing used products, and third-party firms refurbishing used products, respectively. MW, MR, and MP represent wholesale price contracts, revenue sharing contracts, and reward points.

reward points contract in manufacturer (such as Apple and Samsung), and retailer refurbishing (such as Best Buy) models in the refurbishing CLSC. Our research presents important issues, and our observations provide valuable academic and business managerial implications in the two periods refurbishing CLSC. Therefore, the following questions are investigated in this research: (1) when refurbished products are competitive with the new product, which contract incentive can be utilized to alleviate conflict and achieve win-win. (2) whether and when the manufacturer should allow his retailer to refurbish products, such as iPhone, to Best Buy. (3) when the production cost increases, how would the cost increase affect the channel members' demand and performance?

The rest of this paper is organized as follows. Section 2 briefly reviews the relevant literature. Section 3 describes the methodology and model setting. Section 4 analyzes the different scenarios and illustrates key outcomes. Finally, the Conclusion and managerial implications are discussed in Section 5.

II. LITERATURE REVIEW

Our work contributes to the refurbishing (remanufacturing) closed-loop supply chain (CLSC). The previous literature closely related to our study can be classified into three streams: the first stream studies the secondary market for refurbishing CLSC. The second stream investigates the three different widely explored contract and incentive mechanisms in the refurbishing (remanufacturing) CLSC, and the third stream considers the demand uncertain in the refurbishing (remanufacturing) CLSC. We summarize some of the relevant literature in Table 1.

A. SECONDARY MARKET FOR REFURBISHING CLSC

Heese *et al.* [13] investigate that the manufacturer produces new products as well as refurbishing used products. Ferrer and Swaminathan [14] consider the competition between manufacturers and refurbishing firms. Oraiopoulos *et al.* [15] investigate relicensing of software in the IT sector as a consumer should buy the refurbished hardware from a remanufacturer and must purchase a license for a bundled software from the manufacturer. They present that achieving the refurbishing used products secondary markets increase not only all the channel members' profits but also enhances their impact on these firms' competitive advantage. Huang *et al.* [16] formulate how firms sell used products through secondary markets. Liu *et al.* [17] commend that the manufacturer can benefit from the secondary markets by refurbishing of sale used products. Gürel and Gullu [18] study how the secondary markets for remanufactured products affect the inventory control policy. The key difference between this study and the above research is that we compare the refurbishing strategy between manufacture and retailer. Moreover, they did not reach the refurbishing strategies under different contracts either.

B. CONTRACT AND INCENTIVE MECHANISMS IN THE REMANUFACTURING CLSC

Savaskan *et al.* [6] highlight that an appropriate contract could coordinate the CLSC. Song *et al.* [19] study the efficiencies of wholesale pricing contracts, buyback contracts, return contracts, and consignment contracts. Su [20] examines the different performances of the buyback, returns contract, and rebate contract. Atasu *et al.* [11] study the wholesale pricing contract provided by the manufacturer for the new products as well as the refurbishing products. Gu and Tagaras [21] investigate the buyback and return contract in the CLSC. De Giovanni [22] considers a revenue-sharing contract in the CLSC, and he finds that the contract incentive mechanism could help all the channel members to achieve a win-win. Mafakheri and Nasiri [23] consider the manufacturer sharing refurbishing products selling revenue to the retailer to recoup the collection cost spent by the retailer. He [24] uses the supply risk-sharing contracts to resolve the closed-loop supply chain risk. Taleizadeh *et al.* [25] investigate the two-part tariff contract in a dual-channel closed-loop supply chain. They find that the two-part tariff contract can coordinate the CLSC when the manufacturer is the investor. Niu and Xie [1] set a quality certification incentive mechanism for refurbished products. The above researches study on contracts and incentive mechanisms just focuses on the manufacturer or third-party refurbishing, they didn't consider about retailer refurbishing. Consequently, in this research, we examine the efficiencies and performance on different contract incentive mechanisms under manufacturer and retailer refurbishing.

C. DEMAND UNCERTAIN IN THE REMANUFACTURING CLSC

Mukhopadhyay and Ma [26] developed a mathematical model taking into account a single product for a single period to solve the issue of a hybrid system was used, and new parts are taken as inputs in the remanufacturing process to satisfy the uncertain market demands. Giri and Sharma [27] study an optimization benefits model under demand uncertainty in the refurbishing market. Jena and Sarmah [28] investigate the optimal price and service coopetition strategies in

TABLE 2. Contract incentive mechanisms in the REFURBISHING CLSC.

Model	Contract incentive mechanisms		
Manufacture refurbishing	Wholesale price	Revenue sharing	Reward points
Retailer refurbishing	Wholesale price	Revenue sharing	Reward points

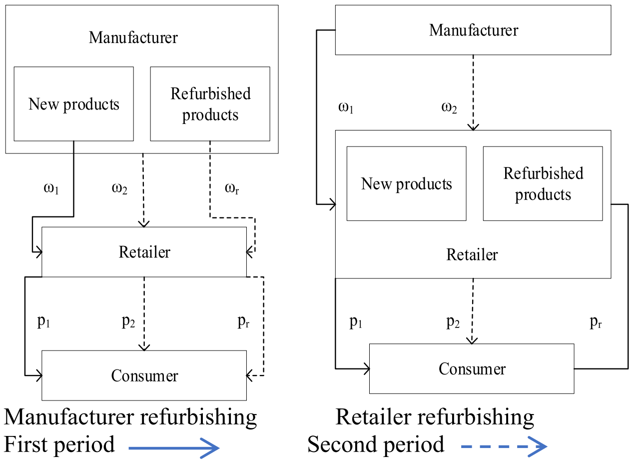


FIGURE 1. Channel structure of the refurbishing CLSC.

uncertain demand and quality to maximize the total profits of the remanufacturing system. Liao and Deng [29] consider an EOQ model under uncertain demand for refurbishing products. They suggest that it is reasonably necessary to study the additional uncertainty factors in the CLSC systematically. Zeng and Hou [30] investigate the reverse mobile phone supply chain under three different situations of quantity incentive mechanisms. They show that the quality improvement scheme could benefit the entire reverse mobile phone supply chain under demand uncertainty. Niu and Xie [1] use quality certification as an incentive alignment strategy to coordinate the refurbishing supply chain under demand uncertainty. However, different from the above studies, we consider the quality uncertainty of the refurbished products under different contract incentive mechanisms in manufacture refurbishing progress and retailer.

III. THE MODEL

In this paper, we consider three different contract incentive mechanisms: wholesale price contract, revenue sharing, reward points contract under manufacturer (such as Apple and Samsung), and retailer refurbishing (such as Best Buy) models in the remanufacturing CLSC (See table 2).

Following Timoumi *et al.* [7], we propose a two-period CLSC model that the manufacturer (player M) is the leader and the retailer (player R) is the follower. The manufacturer sells new products through the retailer. The retailer subsequently sets the retail price as p_1 in the first period. Only new products provided in the first period and used WEEEs are collected for remanufacturing in the second period at the refurbishing cost c_r. The retailer sells both of the new products and refurbished products together in the second period and sets the retail prices as p_2 and p_r, respectively. which the refurbished products would hurt the demand of the new products (see Figure.1). The manufacturer produces the new products at a production cost c_m, and wholesales them to the retailer at the wholesale price ω_1. As Atasu *et al.* (2008) assumed, refurbishing cost is lower than producing a new product, which means, $0 < c_r < c_m$. The inverse demand function for manufacturer and retailer are given by

$$p_1 = 1 - q_1 \tag{1}$$

$$p_2 = 1 - q_2 - \beta q_r \tag{2}$$

$$p_r = 1 - \beta q_2 - q_r + \varepsilon \tag{3}$$

Because the refurbished products are derived from the used WEEEs, and the customers' quality images are uncertain for the refurbished products. Therefore, we set ε presents the customers' demand uncertainty with a mean zero and variance of σ^2. If consumers have high environmental consciousness, they will think the refurbishing products have a price premium of the environment and are thus interpreted as the value of the environment. In contrast, if the consumers have low environmental consciousness, the price premium would be negative. The parameter $\beta \in (0, 1)$ measures the competition intensity of the new products and refurbished products. The notations in the rest of our paper are summarized in table 3.

TABLE 3. Summarized notations.

Notations	Interpretation
M, R	Manufacturer, Retailer
ε	Demand uncertain of the refurbished product
β	Competition intensity of the new and refurbished products
c_m	The production cost of the new product
c_r	The production cost of the refurbished product
θ	Sharing parameter of the retailer's profit agrees to share
	Decision variables
p_1	Unit new product price in the first period
p_2	Unit new product price in the second period
p_r	Unit refurbished product price
q_1	New product demand in the first period
q_2	New product demand in the second period
q_r	Refurbished product demand
s	The reward points incentive level
ω_1	The wholesale price of the new product in the first period
ω_2	The wholesale price of the new product in the second period
ω_r	The wholesale price of the refurbished product

IV. SCENARIOS OF THE CLSC

As shown in Figure 1, we study manufacturer and retailer refurbishing models in the CLSC and derive relevant equilibrium solutions.

A. THE MANUFACTURER REFURBISHED CLSC

1) WHOLESALE PRICE CONTRACT SCENARIO

In this scenario, the manufacturer refurbishes used products at the refurbishing cost c_r and wholesales both of the new products and refurbished products together to the retailer at the wholesale price ω_2 and ω_r, respectively. By backward induction, we first focus on the second period. Given the demand functions of the retailer, the expected profit function of the retailer can be expressed as follows

$$\pi_{R,2}^{MW} = E\left[q_2^{MW}\left(p_2^{MW} - \omega_2^{MW}\right) + q_r^{MW}\left(p_r^{MW} - \omega_r^{MW}\right)\right] \tag{4}$$

Given the retailer's response function, the expected profit function of the manufacturer can be shown as

$$\pi_{M,2}^{MW} = E\left[q_2^{MW}\left(\omega_2^{MW} - c_m\right) + q_r^{MW}\left(\omega_r^{MW} - c_r\right)\right] \tag{5}$$

In the first period, the expected profit function of the retailer can be expressed as

$$\pi_{R,1}^{MW} = E\left[q_1^{MW}\left(p_1^{MW} - \omega_1^{MW}\right)\right] \tag{6}$$

Given the retailer's response function, the expected profit function of the manufacturer in the first period can be shown as

$$\pi_{M,1}^{MW} = E\left[q_1^{MW}\left(\omega_1^{MW} - c_m\right)\right] \tag{7}$$

The expected profit function of the retailer in two periods can be expressed as follows

$$\pi_R^{MW} = E\begin{bmatrix} q_1^{MW}\left(p_1^{MW} - \omega_1^{MW}\right) + q_2^{MW}\left(p_2^{MW} - \omega_2^{MW}\right) \\ +q_r^{MW}\left(p_r^{MW} - \omega_r^{MW}\right) \end{bmatrix} \tag{8}$$

Given the retailer's response function, the expected profit function of the manufacturer in two periods can be shown as

$$\pi_M^{MW} = E\begin{bmatrix} q_1^{MW}\left(\omega_1^{MW} - c_m\right) + q_2^{MW}\left(\omega_2^{MW} - c_m\right) \\ +q_r^{MW}\left(\omega_r^{MW} - c_r\right) \end{bmatrix} \tag{9}$$

2) REVENUE SHARING CONTRACT SCENARIO

In this scenario, the manufacturer utilizes profit sharing as an incentive mechanism to coordinate the remanufacture refurbishing CLSC and ultimately achieve the Pareto-improving. When implementing the revenue sharing contract in the model, the retailer pays wholesales of the new and refurbished products to the manufacture as well as a percentage of the retailer's profit. We set parameter $\theta(0 < \theta < 1)$ presents the proportion of the retailer's profit agrees to share. By backward induction, we first focus on the second period. Given the demand functions of the retailer, the expected profit function of the retailer can be expressed as follows

$$\pi_{R,2}^{MR} = E\begin{bmatrix} q_2^{MR}\left[(1-\theta)\,p_2^{MR} - \omega_2^{MR}\right] \\ +q_r^{MR}\left[(1-\theta)\,p_r^{MR} - \omega_r^{MR}\right] \end{bmatrix} \tag{10}$$

Given the retailer's response function, the expected profit function of the manufacturer can be shown as

$$\pi_{M,2}^{MR} = E\begin{bmatrix} q_2^{MR}\left(\omega_2^{MR} - c_m + \theta p_2^{MR}\right) \\ +q_r^{MR}\left(\omega_r^{MR} - c_r + \theta p_r^{MR}\right) \end{bmatrix} \tag{11}$$

In the first period, the expected profit function of the retailer can be expressed as

$$\pi_{R,1}^{MR} = E\left[q_1^{MR}\left\{(1-\theta)\,p_1^{MR} - \omega_1^{MR}\right\}\right] \tag{12}$$

Given the retailer's response function, the expected profit function of the manufacturer in the first period can be shown as

$$\pi_{M,1}^{MR} = E\left[q_1^{MR}\left(\omega_1^{MR} - c_m + \theta p_1^{MR}\right)\right] \tag{13}$$

The expected profit function of the retailer in two periods can be expressed as follows

$$\pi_R^{MR} = E\begin{bmatrix} q_1^{MR}\left\{(1-\theta)\,p_1^{MR} - \omega_1^{MR}\right\} \\ +q_2^{MR}\left\{(1-\theta)\,p_2^{MR} - \omega_2^{MR}\right\} \\ +q_r^{MR}\left\{(1-\theta)\,p_r^{MR} - \omega_r^{MR}\right\} \end{bmatrix} \tag{14}$$

Given the retailer's response function, the expected profit function of the manufacturer in two periods can be shown as

$$\pi_M^{MR} = E\begin{bmatrix} q_1^{MR}\left(\omega_1^{MR} - c_m + \theta p_1^{MR}\right) \\ +q_2^{MR}\left(\omega_2^{MR} - c_m + \theta p_2^{MR}\right) \\ +q_r^{MR}\left(\omega_r^{MR} - c_r + \theta p_r^{MR}\right) \end{bmatrix} \tag{15}$$

3) REWARD POINTS CONTRACT SCENARIO

In this scenario, we consider the reward points contract. The manufacturer provides financial support to the retailer to improve his retailer's demand, which ultimately increases his demand. We set $0 < s < 1$ presents the reward points incentive level for demand. By backward induction, we first focus on the second period. Given the demand functions of the retailer, the expected profit function of the retailer can be expressed as follow

$$\pi_{R,2}^{MP} = E\begin{bmatrix} \left(q_2^{MP} + \sqrt{s}^M\right)\left(p_2^{MP} - \omega_2^{MP}\right) \\ + \left(q_r^{MP} + \sqrt{s}^M\right)\left(p_r^{MP} - \omega_r^{MP}\right) \end{bmatrix} \tag{16}$$

Given the retailer's response function, the expected profit function of the manufacturer can be shown

$$\pi_{M,2}^{MP} = E\begin{bmatrix} \left(q_2^{MP} + \sqrt{s}^M\right)\left(\omega_2^{MP} - c_m\right) \\ + \left(q_r^{MP} + \sqrt{s}^M\right)\left(\omega_r^{MP} - c_r\right) - s^M \end{bmatrix} \tag{17}$$

In the first period, the expected profit function of the retailer can be expressed as

$$\pi_{R,1}^{MP} = E\left[\left(q_1^{MP} + \sqrt{s}^M\right)\left(p_1^{MP} - \omega_1^{MP}\right)\right] \tag{18}$$

Given the retailer's response function, the expected profit function of the manufacturer in the first period can be shown as

$$\pi_{M,1}^{MP} = E\left[\left(q_1^{MP} + \sqrt{s}^M\right)\left(\omega_1^{MP} - c_m\right)\right] \tag{19}$$

The expected profit function of the retailer in two periods can be expressed as follows

$$\pi_R^{MP} = E\begin{bmatrix} \left(q_1^{MP} + \sqrt{s}^M\right)\left(p_1^{MP} - \omega_1^{MP}\right) \\ +\left(q_2^{MP} + \sqrt{s}^M\right)\left(p_2^{MP} - \omega_2^{MP}\right) \\ +\left(q_r^{MP} + \sqrt{s}^M\right)\left(p_r^{MP} - \omega_r^{MP}\right) \end{bmatrix} \tag{20}$$

Given the retailer's response function, the expected profit function of the manufacturer in two periods can be shown as

$$\pi_M^{MP} = E\begin{bmatrix} \left(q_1^{MP} + \sqrt{s}^M\right)\left(\omega_1^{MP} - c_m\right) \\ +\left(q_2^{MP} + \sqrt{s}^M\right)\left(\omega_2^{MP} - c_m\right) \\ +\left(q_r^{MP} + \sqrt{s}^M\right)\left(\omega_r^{MP} - c_r\right) - s^M \end{bmatrix} \tag{21}$$

B. THE RETAILER REFURBISHING CLSC

1) WHOLESALE PRICE CONTRACT SCENARIO

In the retailer refurbishing model, the retailer refurbishes used products at the refurbishing cost c_r in the second period, sells both of the new and refurbished products together to the consumers at the prices p_2 and p_r, respectively. By backward induction, we first focus on the second period. Given the demand functions of the retailer, the expected profit function of the retailer can be expressed as follows

$$\pi_{R,2}^{RW} = E\left[q_2^{RW}\left(p_2^{RW} - \omega_2^{RW}\right) + q_r^{RW}\left(p_r^{RW} - c_r\right)\right] \tag{22}$$

Given the retailer's response function, the expected profit function of the manufacturer can be shown as

$$\pi_{M,2}^{RW} = E\left[q_2^{RW}\left(\omega_2^{RW} - c_m\right)\right] \tag{23}$$

In the first period, the expected profit function of the retailer can be expressed as

$$\pi_{R,1}^{RW} = E\left[q_1^{RW}\left(p_1^{RW} - \omega_1^{RW}\right)\right] \tag{24}$$

Given the retailer's response function, the expected profit function of the manufacturer in the first period can be shown as

$$\pi_{M,1}^{RW} = E\left[q_1^{RW}\left(\omega_1^{RW} - c_m\right)\right] \tag{25}$$

The expected profit function of the retailer in two periods can be expressed as follows

$$\pi_R^{RW} = E\left[\begin{matrix} q_1^{RW}\left(p_1^{RW} - \omega_1^{RW}\right) + q_2^{RW}\left(p_2^{RW} - \omega_2^{RW}\right) \\ +q_r^{RW}\left(p_r^{RW} - c_r\right) \end{matrix}\right] \tag{26}$$

Given the retailer's response function, the expected profit function of the manufacturer in two periods can be shown as

$$\pi_M^{RW} = E\left[q_1^{RW}\left(\omega_1^{RW} - c_m\right) + q_2^{RW}\left(\omega_2^{RW} - c_m\right)\right] \tag{27}$$

2) REVENUE SHARING CONTRACT SCENARIO

In this scenario, the manufacturer utilizes profit-sharing as an incentive mechanism to coordinate the remanufacture refurbishing CLSC and ultimately achieve the Pareto-improving. When implementing the Revenue sharing contract in the model, the retailer pays wholesales of the new products as well as a percentage of the retailer's profit. We set parameter $\theta (0 < \theta < 1)$ presents the proportion of the retailer's profit agrees to share. By backward induction, we first focus on the second period. Given the demand functions of the retailer, the expected profit function of the retailer can be expressed as follows

$$\pi_{R,2}^{RR} = E\begin{bmatrix} q_2^{RR}\left\{(1-\theta)\,p_2^{RR} - \omega_2^{RR}\right\} \\ +q_r^{RR}\left\{(1-\theta)\,p_r^{RR} - c_r\right\} \end{bmatrix} \tag{28}$$

Given the retailer's response function, the expected profit function of the manufacturer can be shown as

$$\pi_{M,2}^{RR} = E\left[q_2^{RR}\left(\omega_2^{RR} - c_m + \theta p_2^{RR}\right) + \theta p_r^{RR} q_r^{RR}\right] \tag{29}$$

In the first period, the expected profit function of the retailer can be expressed as

$$\pi_{R,1}^{RR} = E\left[q_1^{RR}\left\{(1-\theta)\,p_1^{RR} - \omega_1^{RR}\right\}\right] \tag{30}$$

Given the retailer's response function, the expected profit function of the manufacturer in the first period can be shown as

$$\pi_{M,1}^{RR} = E\left[q_1^{RR}\left(\omega_1^{RR} - c_m + \theta p_1^{RR}\right)\right] \tag{31}$$

The expected profit function of the retailer in two periods can be expressed as follows

$$\pi_R^{RR} = E\begin{bmatrix} q_1^{RR}\left\{(1-\theta)\,p_1^{RR} - \omega_1^{RR}\right\} \\ +q_2^{RR}\left\{(1-\theta)\,p_2^{RR} - \omega_2^{RR}\right\} \\ +q_r^{RR}\left\{(1-\theta)\,p_r^{RR} - c_r\right\} \end{bmatrix} \tag{32}$$

Given the retailer's response function, the expected profit function of the manufacturer in two periods can be shown as

$$\pi_M^{RR} = E\begin{bmatrix} q_1^{RR}\left(\omega_1^{RR} - c_m + \theta p_1^{RR}\right) \\ +q_2^{RR}\left(\omega_2^{RR} - c_m + \theta p_2^{RR}\right) + \theta p_r^{RR} q_r^{RR} \end{bmatrix} \tag{33}$$

3) REWARD POINTS CONTRACT SCENARIO

In this scenario, we consider the reward points contract. The manufacturer also provides financial support to the retailer to improve the retailer's demand. By backward induction, we first focus on the second period. Given the demand functions of the retailer, the expected profit function of the retailer can be expressed as follows

$$\pi_{R,2}^{RP} = E\begin{bmatrix} \left(q_2^{RP} + \sqrt{s}^R\right)\left(p_2^{RP} - \omega_2^{RP}\right) \\ +\left(q_r^{RP} + \sqrt{s}^R\right)\left(p_r^{RP} - c_r\right) \end{bmatrix} \tag{34}$$

TABLE 4. The equilibrium outcomes of three contract scenarios in the manufacturer refurbishing.

	Manufacturer Refurbishing		
	MW	MR	MP
ω_1	$\frac{1+c_m}{2}$	$c_m+\frac{1-c_m}{2-\theta}-\theta$	$\frac{\theta}{2}$
ω_2	$\frac{1+c_m}{2}$	$c_m+\frac{1-c_m}{2-\theta}-\theta$	$\frac{\theta}{2}$
ω_r	$\frac{1+c_r}{2}$	$\frac{(1-\theta)(1+c_r-\theta)}{2-\theta}$	$\frac{\theta}{2}$
q_1	$\frac{1-c_m}{4}$	$\frac{1-c_m}{2(2-\theta)}$	$\frac{1}{2}$
q_2	$\frac{1-c_m-\beta(1-c_r)}{4(1-\beta^2)}$	$\frac{1-c_m-\beta(1-c_r)}{2(1-\beta^2)(2-\theta)}$	$\frac{1}{2(1+\beta)}$
q_r	$\frac{1-c_r-\beta(1-c_m)}{4-4\beta^2}$	$\frac{1-c_r-\beta(1-c_m)}{2(1-\beta^2)(2-\theta)}$	$\frac{1}{2(1+\beta)}$

TABLE 5. The equilibrium outcomes of three contract scenarios in the retailer refurbishing.

	Retailer Refurbished		
	MW	MR	MP
ω_1	$\frac{1+c_m}{2}$	$c_m+\frac{1-c_m}{2-\theta}-\theta$	$\frac{\theta}{2}$
ω_2	$\frac{1+c_m-\beta(1-c_r)}{2}$	$\frac{c_m+B-c_m\theta}{2-\theta}$	$\frac{2c_m+[2-\beta(1-c_r)]\theta}{4}$
q_1	$\frac{1-c_m}{4}$	$\frac{1-c_m}{2(2-\theta)}$	$\frac{1}{2}$
q_2	$\frac{1-c_m-\beta(1-c_r)}{4(1-\beta^2)}$	$\frac{1-c_m-\beta(1-c_r)}{\mathrm{E}}$	$\frac{\beta(1-c_r)(2-\varphi)-2(1-\theta)}{4(1-\theta)-\beta^2(2-\theta)^2}$
q_r	$\frac{\mathrm{A}}{4(1-\beta^2)}$	$\frac{(1-\theta)[C-D]}{\mathrm{E}(1-\theta)}$	$\frac{F(1-\theta)}{4(1-\theta)-\beta^2(2-\theta)^2}$

Here, $\mathrm{A}=2-c_r(2-\beta^2)-\beta(1-c_m+\beta), B=\beta[c_r-(1-\theta)^2]+(1-\theta)^2, C=(2-\theta)-(1-c_m)\beta,\ D=\beta^2(1-\theta)-c_r(2-\beta^2-\theta),$ $\mathrm{E}=(1-\beta^2)(2-\theta),\ F=2+\beta(2-\varphi)-2c_r.$

Given the retailer's response function, the expected profit function of the manufacturer can be shown as

$$\pi_{M,2}^{RP}=E\left[\left(q_2^{RP}+\sqrt{s}^R\right)\left(\omega_2^{RP}-c_m\right)-s^R\right] \tag{35}$$

In the first period, the expected profit function of the retailer can be expressed as

$$\pi_{R,1}^{RP}=E\left[\left(q_1^{RP}+\sqrt{s}^R\right)\left(p_1^{RP}-\omega_1^{RP}\right)\right] \tag{36}$$

Given the retailer's response function, the expected profit function of the manufacturer in the first period can be shown as

$$\pi_{M,1}^{RP}=E\left[\left(q_1^{RP}+\sqrt{s}^R\right)\left(\omega_1^{RP}-c_m\right)\right] \tag{37}$$

The expected profit function of the retailer in two periods can be expressed as follows

$$\pi_R^{RP}=E\begin{bmatrix}\left(q_1^{RP}+\sqrt{s}^R\right)\left(p_1^{RP}-\omega_1^{RP}\right)\\+\left(q_2^{RP}+\sqrt{s}^R\right)\left(p_2^{RP}-\omega_2^{RP}\right)\\+\left(q_r^{RP}+\sqrt{s}^R\right)\left(p_r^{RP}-c_r\right)\end{bmatrix} \tag{38}$$

Given the retailer's response function, the expected profit function of the manufacturer in two periods can be shown as

$$\pi_M^{RP}=E\begin{bmatrix}\left(q_1^{RP}+\sqrt{s}^R\right)\left(\omega_1^{RP}-c_m\right)\\+\left(q_2^{RP}+\sqrt{s}^R\right)\left(\omega_2^{RP}-c_m\right)-s^R\end{bmatrix} \tag{39}$$

The equilibrium outcomes of the three contract scenarios in manufacturer and retailer refurbishing are summarized in Tables 4 and 5, respectively.

Lemma 1: Comparison of different ω and q in manufacturer refurbishing

(1) $\omega_1^{MP}>\omega_1^{MW}>\omega_1^{MR}$;
(2) $\omega_2^{MP}>\omega_2^{MW}>\omega_2^{MR}$;
(3) $\omega_r^{MP}>\omega_r^{MW}>\omega_r^{MR}$;
(4) $q_1^{MR}>q_1^{MW}>q_1^{MP}$;
(5) $q_r^{MR}>q_r^{MW}>q_r^{MP}$
(6) When $0<\theta<\theta',q_2^{MW}>q_2^{MR}>q_2^{MP}$ given $\beta\in\left(\frac{1-c_m}{1-c_r},1\right)$. Otherwise, $q_2^{MW}>q_2^{MP}>q_2^{MR}$ given $\beta\in\left(\frac{1-c_m}{1-c_r},1\right)$.

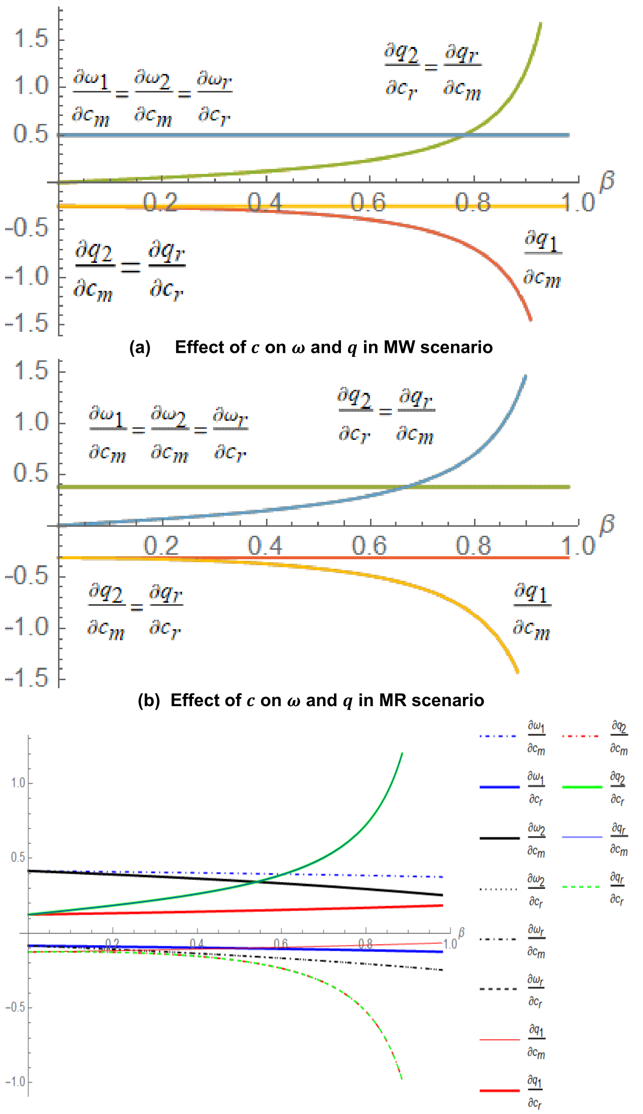
Here $\theta'=\frac{6(-2+c_m+c_r)(-1+\beta^2)}{3(c_m-c_r)-2(-4+c_m+3c_r)\beta+(-8+3c_m+5c_r)\beta^2}$.

Lemma 2: Comparison of different ω and q in the retailer refurbishing

(1) When $0<\theta<\theta_1,\omega_1^{RW}>\omega_1^{RR}>\omega_1^{RP}$, given $\beta\in\left(\frac{1-c_m}{1-c_r},1\right)$. When $\theta_2<\theta<1,\omega_1^{RW}>\omega_1^{RP}>\omega_1^{RR}$, given $\beta\in\left(\frac{1-c_m}{1-c_r},1\right)$.
(2) When $0<\theta<\theta_1,\omega_2^{RW}>\omega_2^{RR}>\omega_2^{RP}$, given $\beta\in\left(\frac{1-c_m}{1-c_r},1\right)$. When $\theta_2<\theta<1,\omega_2^{RW}>\omega_2^{RP}>\omega_2^{RR}$, given $\beta\in\left(\frac{1-c_m}{1-c_r},1\right)$.
(3) When $0<\theta<\theta_1,q_1^{RP}>q_1^{RR}>q_1^{RW}$, given $\beta\in\left(\frac{1-c_m}{1-c_r},1\right)$. When $\theta_2<\theta<1,q_1^{RR}>q_1^{RP}>q_1^{RW}$, given $\beta\in\left(\frac{1-c_m}{1-c_r},1\right)$.
(4) $q_2^{RW}>q_2^{RR}>q_2^{RP}$, given $\beta\in\left(\frac{1-c_m}{1-c_r},1\right)$.
(5) $q_r^{RP}>q_r^{RR}>q_r^{RW}$, given $\beta\in\left(\frac{1-c_m}{1-c_r},1\right)$.

Here $\theta_1=\frac{6-6c_m-6\beta+6c_r\beta}{-4+4c_m-3\beta+3c_r\beta-\beta^2+c_m\beta^2}$, and $\theta_2=\frac{\beta}{14+2\beta^2}$.

Lemma 1 and 2 compare the wholesale prices and quantities of the manufacturer and retailer refurbishing in two stages under three different scenarios. (1) Under manufacturer refurbishing scenarios, in the case of reward points contract, the manufacturer aggressively sets high wholesale prices (ω_1^{MP}, ω_2^{MP}, and ω_r^{MP}) of the new and refurbished products, followed by wholesale price and revenue sharing contracts. The manufacturer sets high wholesale prices in the reward points case because the manufacturer offered financial support for reward points for unit products. He wants to recoup part of his cost through increased wholesale prices. On the other side, high wholesale price increases retailers' high purchasing cost and



(a) Effect of c on ω and q in MW scenario

(b) Effect of c on ω and q in MR scenario

(c) Effect of c on ω and q in MP scenario

FIGURE 2. Effect of new and refurbished production cost changes on outcomes in the manufacturer refurbishing, where $\theta = 0.4$.

ultimately leads the retailer to decrease purchases. In the second period, high revenue sharing is erosion part of the retailer's market demand, which leads $q_2^{MR} < q_2^{MP}$. (2) Under retailer refurbishing scenarios, in the case of wholesale price contracts, the manufacturer aggressively sets the high wholesale price in the two-period CLSC model. High revenue sharing encourages the manufacturer to mark down the wholesale price, which increases the retailer's purchasing cost and decreases the retailer's purchase. In the second period, financial support for reward points could stimulate consumers' enthusiasm to buy the products, which increases the retailer's market share.

Proposition 1: The effect of costs c_m and c_r on ω and q in manufacturer refurbishing are summarized in table 6. Figure. 2 presents how the equilibrium wholesale price and demand are affected by new and refurbishing production cost c_m and c_r.

TABLE 6. Effect of costs on wholesale prices and demands in manufacturer refurbishing scenario.

	Manufacturer Refurbishing			
	MW	MR	MP	
$\frac{\partial\omega_1}{\partial c_m}$	$\frac{1}{2}>0$	$\frac{1-\theta}{2-\theta}>0$	$\frac{\partial\omega_1}{\partial c_m}$, $\frac{\partial\omega_1}{\partial c_r}$	$\frac{5-2\beta}{12-4\beta}>0$, $-\frac{1}{12-4\beta}<0$
$\frac{\partial\omega_2}{\partial c_m}$	$\frac{1}{2}>0$	$\frac{1-\theta}{2-\theta}>0$	$\frac{\partial\omega_2}{\partial c_m}$, $\frac{\partial\omega_2}{\partial c_r}$	$\frac{5-3\beta}{4(3-\beta)}>0$, $\frac{-(1+\beta)}{4(3-\beta)}<0$
$\frac{\partial\omega_r}{\partial c_r}$	$\frac{1}{2}>0$	$\frac{1-\theta}{2-\theta}>0$	$\frac{\partial\omega_r}{\partial c_m}$, $\frac{\partial\omega_r}{\partial c_r}$	$\frac{1+\beta}{4(-3+\beta)}<0$, $\frac{5-3\beta}{4(3-\beta)}>0$
$\frac{\partial q_1}{\partial c_m}$	$-\frac{1}{4}<0$	$-\frac{1}{2(2-\theta)}<0$	$\frac{\partial q_1}{\partial c_m}$, $\frac{\partial q_1}{\partial c_r}$	$\frac{3-2\beta}{8(-3+\beta)}<0$, $\frac{3}{8(3-\beta)}>0$
$\frac{\partial q_2}{\partial c_m}$	$\frac{1}{\mathrm{F}}<0$	$-\frac{1}{\mathrm{E}}<0$	$\frac{-3+(2-3\beta)\beta}{8(-3+\beta)(-1+\beta^2)}<0$	
$\frac{\partial q_2}{\partial c_r}$	$-\frac{\beta}{\mathrm{F}}>0$	$\frac{\beta}{\mathrm{E}}>0$	$\frac{3+(6-5\beta)\beta}{8(-3+\beta)(-1+\beta^2)}>0$	
$\frac{\partial q_r}{\partial c_m}$	$\frac{\beta}{-\mathrm{F}}>0$	$\frac{\beta}{\mathrm{E}}>0$	$\frac{3+(6-5\beta)\beta}{8(-3+\beta)(-1+\beta^2)}>0$	
$\frac{\partial q_r}{\partial c_r}$	$\frac{1}{\mathrm{F}}<0$	$-\frac{1}{\mathrm{E}}<0$	$\frac{-3+(2-3\beta)\beta}{8(-3+\beta)(-1+\beta^2)}<0$	

Here $F = 4(-1+\beta^2)$.

Proposition 1 indicates that, in the wholesale price and revenue sharing contracts cases, the wholesale prices of the new products in the two-period CLSC model always increase in its own production cost c_m. In the reward points case, the wholesale prices and demands in the two-period CLSC model depend not only on their own production cost but also on their competitor's cost. High wholesale price is intuitive that will lead to lower demand. In the second period, the wholesale price of the refurbished products is always increasing in refurbishing cost c_r, which lead to a lower demand q_r. Additional, in the second period, the new and refurbished products are competitive with each other, as the new production (refurbishing) cost increase, leading to a high new (refurbished) product wholesale price which ultimate incentive customers transfer to buy the refurbished (new) products and increase the refurbished (new) product demand. Additional, as Figure 2 (a) and (b) present, in the case of the wholesale price and revenue sharing contracts, when the product competition parameter β increases, the positive impact of an increase in c_r on q_2, as well as c_m on q_r, and there is no impact in c_m on ω_1, ω_2 and q_1, as well as c_r on ω_r. Figure 2 (c) shows that as β increases, the negative effect of an increase in both c_m and c_r on ω_1, ω_2 and ω_r as well as c_m on q_2 and c_r on q_r. And there is a positive impact of an increase in c_r on q_1 and q_2 as well as c_m on q_1 and q_r.

Proposition 2: The effect of costs c_m and c_r on ω and q in the retailer refurbishing are summarized in table 7.

Proposition 2 shows that, in the retailer refurbishing, under three different contracts, both of the new and

TABLE 7. Effect of costs on wholesale prices and quantities in the retailer refurbishing scenario.

	Retailer Refurbishing		
	RW	RR	RP
$\frac{\partial \omega_1}{\partial c_m}$	$\frac{1}{2}>0$	$\frac{1-\theta}{2-\theta}>0$	$\frac{\partial \omega_1}{\partial c_m}$: $\frac{6+\beta^2}{2(7+\beta^2)}>0$; $\frac{\partial \omega_1}{\partial c_r}$: $\frac{\beta}{2(7+\beta^2)}>0$
$\frac{\partial \omega_2}{\partial c_m}$	$\frac{1}{2}>0$	$\frac{1-\theta}{2-\theta}>0$	$\frac{3+\beta^2}{7+\beta^2}>0$
$\frac{\partial \omega_2}{\partial c_r}$	$\frac{\beta}{2}>0$	$\frac{\beta}{2-\theta}>0$	$\frac{4\beta}{7+\beta^2}>0$
$\frac{\partial q_1}{\partial c_m}$	$-\frac{1}{4}<0$	$\frac{-1}{2(2-\theta)}<0$	$\frac{\partial q_1}{\partial c_m}$: $\frac{-(4+\beta^2)}{4(7+\beta^2)}<0$; $\frac{\partial q_1}{\partial c_r}$: $\frac{-3\beta}{4(7+\beta^2)}<0$
$\frac{\partial q_2}{\partial c_m}$	$\frac{1}{F}<0$	$\frac{-1}{2E}<0$	$\frac{1+\beta^2}{-7+6\beta^2+\beta^4}<0$
$\frac{\partial q_2}{\partial c_r}$	$-\frac{\beta}{F}>0$	$\frac{\beta}{2E}>0$	$-\frac{\beta(1+\beta^2)}{-7+6\beta^2+\beta^4}>0$
$\frac{\partial q_r}{\partial c_m}$	$-\frac{\beta}{F}>0$	$\frac{\beta}{2E}>0$	$\frac{-1-\beta[3-(1-\beta)\beta]}{2(-7+6\beta^2+\beta^4)}>0$
$\frac{\partial q_r}{\partial c_r}$	$\frac{(2-\beta^2)}{F}<0$	$\frac{-\beta^2(1-\theta)-E}{2E(1-\theta)}<0$	$\frac{7+\beta-\beta^2(3+\beta)}{2(-7+6\beta^2+\beta^4)}<0$

refurbished products' wholesale prices are always increasing in their production costs. In contrast with proposition 1, because the refurbishing system transfers to the retailer, as the refurbishing production cost increase, it leads to a low refurbishing product, which incentivizes retailers to buy more new products. It ultimately promotes the manufacturer's increase wholesale price of the two-period CLSC model. Additionally, the high wholesale price also leads to a lower demand similar to the manufacturer's refurbishing model. Meanwhile, in the second period, the new production (refurbishing) cost increase also leads to a high increase in the refurbished (new) product demand. In addition, as Figure 3 (a) and (b) present, in the case of wholesale price and revenue sharing contracts, when the product competition parameter β increases, the positive impact of an increase in c_r on ω_2 and q_2, as well as c_m on q_r, and there is no impact in c_m on ω_1, ω_2. As β increases, the negative effect of an increase in c_m on q_2, as well as c_r on q_r. Figure 3 (c) shows that as β increases, the negative effect of an increase in c_m on q_1 and q_2 as well as c_r on q_1 and q_r. And there is a positive impact of an increase in c_r on ω_1, ω_2 and q_2 as well as c_m on ω_1, ω_2 and q_r. Meanwhile, as the competition is stiff (β is high), the impact between production and wholesale price or demand is strong.

Proposition 3: In manufacturer refurbishing scenarios, there exists a threshold σ^M, that could lead both the manufacturer and retailer to obtain the highest profit under reward points contract in the two-period CLSC model so that

(1) $\pi_{M1}^{MW} < \pi_{M1}^{MR} < \pi_{M1}^{MP}$
(2) $\pi_{R1}^{MR} < \pi_{R1}^{MW} < \pi_{R1}^{MP}$
(3) $\pi_{R2}^{MR} < \pi_{R2}^{MW} < \pi_{R2}^{MP}$

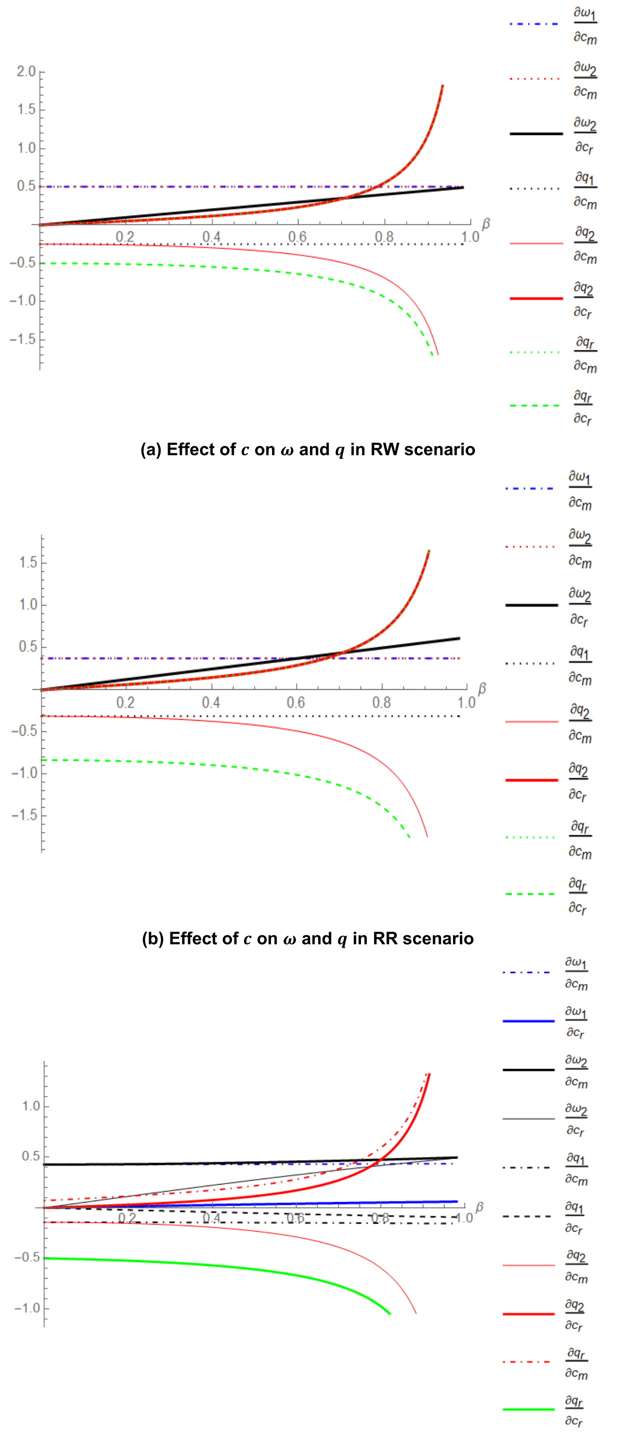

(a) Effect of c on ω and q in RW scenario
(b) Effect of c on ω and q in RR scenario
(c) Effect of c on ω and q in RP scenario

FIGURE 3. Effect of new and refurbished production cost changes on outcomes in the retailer refurbishing, where $\theta = 0.4$.

(4) When $0 < \sigma^2 < \sigma^M$, $\pi_{M2}^{MW} < \pi_{M2}^{MR} < \pi_{M2}^{MP}$. Otherwise, $\pi_{R2}^{MW} < \pi_{R2}^{MP} < \pi_{R2}^{MR}$.

Here $\sigma^M = \frac{2(-2+cm+c_r)^2(-1+\beta^2)-(e1+e2)\theta}{2+\beta^2(-2+\theta)-7\theta+2\beta\theta}$, $e_1 = 16(-1+c_r+\beta) - 2c_m\left[cr+8(-1+\beta)+c_r(-6+\beta)\beta\right]$, $e_2 = c_m^2\left[-7+\beta(2+\beta)\right]+c_r\left[-16\beta+c_r\{-7+\beta(2+\beta)\}\right]$.

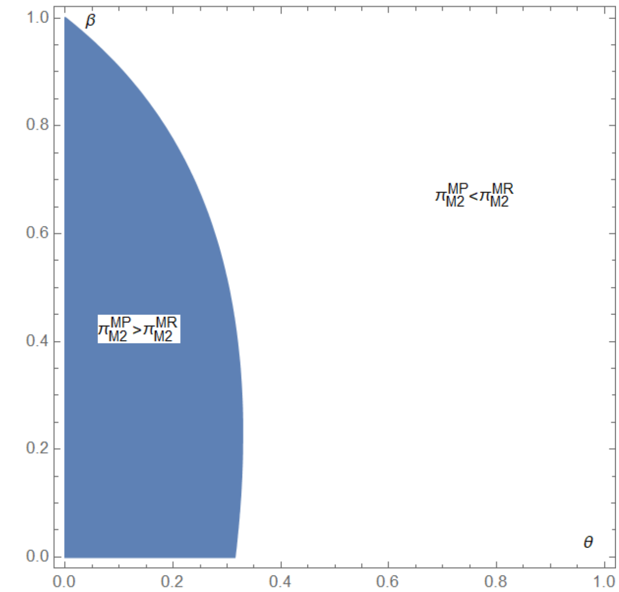


FIGURE 4. The manufacturer's preferences reward point scenario and revenue sharing scenario, where $c_m = 0.6, c_r = 0.5, \sigma^2 = 3$.

Proposition 3 shows that the manufacturer prefers to choose the reward points contract strategy in the first period, which means the manufacturer could get more profits than other contracts under the reward points contract. Followed by a revenue-sharing contract. Profit under wholesale contract is always the lowest. On the other side, the retailer prefers to choose the reward points contract strategy in the first period. Through this strategy, he gets more demand, which ultimately leads to a high profit. In contrast with the manufacturer, no one wants to share his profits. Therefore, the retailer prefers wholesale price contract to revenue-sharing contract and the retailer in the second period. In addition, when the sharing parameter is low in the second period, it is better for the manufacturer if the channel chooses a reward points contract. However, the manufacturer needs to offer financial support for reward points for the unit product, followed by the revenue sharing and wholesale price contract. when σ^2 is sufficiently large, the manufacturer prefers to choose a revenue-sharing contract strategy because through retailer pays percentage of his profit to the manufacturer, and it will benefit the manufacturer more than other contracts (Figure 4). As a result, when the manufacturer refurbishes in the two-period CLSC, it can implement a reward points contract to achieve Pareto-improving for all channel members. This is also supported in the real world in which Apple and its retailer very glade Apple refurbishes Macbook Pro 13 inch by itself and get all channel members win-win.

Proposition 4: In retailer refurbishing scenarios, both the manufacturer and retailer obtain the highest profit under reward points contract in the two-period CLSC model, so that

(1) $\pi_{M1}^{RW} < \pi_{M1}^{RP} < \pi_{M1}^{RR}$
(2) $\pi_{R1}^{RR} < \pi_{R1}^{RP} < \pi_{R1}^{RW}$
(3) $\pi_{M2}^{RW} < \pi_{M2}^{RP} < \pi_{M2}^{RR}$
(4) $\pi_{R2}^{RR} < \pi_{R2}^{RP} < \pi_{R2}^{RW}$

Proposition 4 presents that the manufacturer prefers to choose a revenue-sharing contract strategy in the first period because the manufacturer has to compete with retailers in the refurbished product's market. He needs the incentive mechanism to get more profit. He can get profit directly from the retailer revenue-sharing contract. Under the reward points contract, the manufacturer needs to offer financial support for reward points for the unit product. Although this strategy could increase demand, it is not as well as revenue sharing contract. Profit under wholesale contract is always the lowest. On the other side, the retailer prefers to choose a wholesale price contract in the first period. This means, the revenue sharing and reward points contract is not attractive for the retailer. That's because the retailer can profit from selling new products and selling refurbished products. However, revenue sharing and reward points contract could increase his refurbished products demand in the new product market, but it could not recoup his loss from the refurbished product market. As a result, when retailers refurbishing in the two-period CLSC, it is not in the retailer's interest to employ the contract incentive mechanism. The manufacturer under contract incentive mechanism is better off in the retailer refurbishing model, while all channel members under contract incentive mechanism are better off in the manufacturer refurbishing model.

Proof of Proposition 4. It can easily demonstrate that $\pi_{M1}^{RW} - \pi_{M1}^{RR} = \frac{(1-c_m)^2\theta}{8(-2+\theta)} < 0$, Then, since the sign of first-period manufacturer profit outcomes $\pi_{M1}^{RW} - \pi_{M1}^{RP}$, and $\pi_{M1}^{RR} - \pi_{M1}^{RP}$, the first-period retailer profit outcomes $\pi_{R1}^{RW} - \pi_{R1}^{RR}, \pi_{R1}^{RW} - \pi_{R1}^{RP}$, and $\pi_{R1}^{RR} - \pi_{R1}^{RP}$, second-period manufacturer profit outcomes $\pi_{M2}^{RW} - \pi_{M2}^{RR}, \pi_{M2}^{RW} - \pi_{M2}^{RP}$, and $\pi_{M2}^{RR} - \pi_{M2}^{RP}$, the second-period retailer profit outcomes $\pi_{R2}^{RW} - \pi_{R2}^{RR}, \pi_{R2}^{RW} - \pi_{R2}^{RP}$, and $\pi_{R2}^{RR} - \pi_{R2}^{RP}$ heavily depends on all parameter values, one can numerically verify that $\pi_{M1}^{RW} - \pi_{M1}^{RP} < 0$, $\pi_{M1}^{RR} - \pi_{M1}^{RP} > 0, \pi_{R1}^{RW} - \pi_{R1}^{RR} > 0$, $\pi_{R1}^{RW} - \pi_{R1}^{RP} > 0, \pi_{R1}^{RR} - \pi_{R1}^{RP} < 0, \pi_{M2}^{RW} - \pi_{M2}^{RR} < 0, \pi_{M2}^{RW} - \pi_{M2}^{RP} < 0, \pi_{M2}^{RR} - \pi_{M2}^{RP} > 0, \pi_{R2}^{RW} - \pi_{R2}^{RR}, \pi_{R2}^{RW} - \pi_{R2}^{RP}$, and $\pi_{R2}^{RR} - \pi_{R2}^{RP}$ always holds.[1] □

Proposition 5: Effect of costs on remanufacturer's preferences in the manufacturer refurbishing.

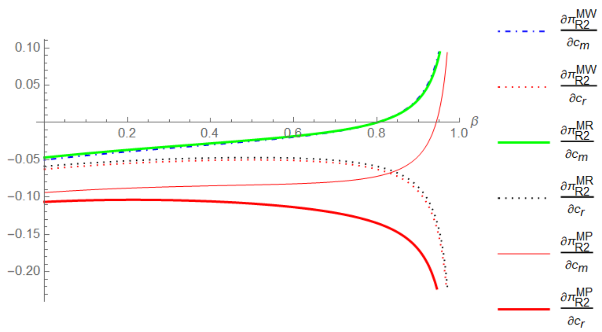
(1) In the first period, for the manufacturer, we have:

$$\frac{\partial \pi_{M1}^{MW}}{\partial c_m} = \frac{-(1-c_m)}{4} < 0, \frac{\partial \pi_{M1}^{MR}}{\partial c_m} = \frac{-(1-c_m)}{2(2-\theta)} < 0,$$

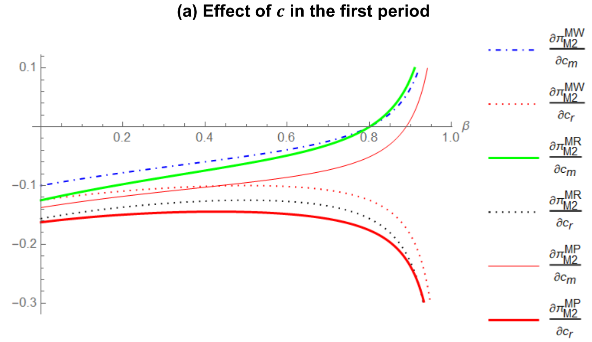
$$\frac{\partial \pi_{M1}^{MP}}{\partial c_m} = \frac{(7-2\beta)\left[-8+c_r+c_m(7-2\beta)+2\beta\right]}{16(3-\beta)^2} < 0,$$

$$\frac{\partial \pi_{M1}^{MP}}{\partial c_r} = \frac{-8+c_r+c_m(7-2\beta)+2\beta}{16(3-\beta)^2} < 0.$$

[1]We set $\sigma^2 = 3, c_m = 0.6, c_r = 0.5, \beta = 0.5, \theta = 0.4$. By using the benchmark parameter values, $\pi_{M1}^{RW} - \pi_{M1}^{RP} = -0.0039, \pi_{M1}^{RR} - \pi_{M1}^{RP} = 0.0011. \pi_{R1}^{RW} - \pi_{R1}^{RR} = 0.362, \pi_{R1}^{RW} - \pi_{R1}^{RP} = 0.045, \pi_{R1}^{RR} - \pi_{R1}^{RP} = -0.317, \pi_{M2}^{RW} - \pi_{M2}^{RR} = -0.3627, \pi_{M2}^{RW} - \pi_{M2}^{RP} = -0.0133, \pi_{M2}^{RR} - \pi_{M2}^{RP} = 0.3494, \pi_{R2}^{RW} - \pi_{R2}^{RR} = 0.362, \pi_{R2}^{RW} - \pi_{R2}^{RP} = 0.045$, and $\pi_{R2}^{RR} - \pi_{R2}^{RP} = -0.317$.

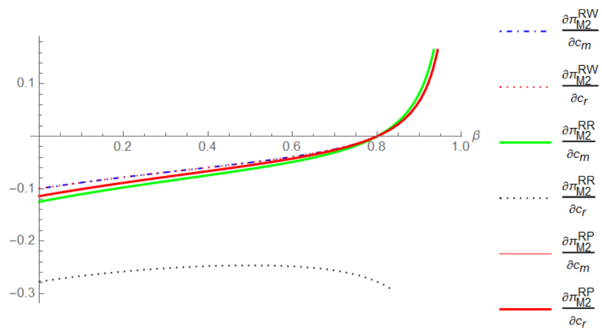


(a) Effect of c in the first period

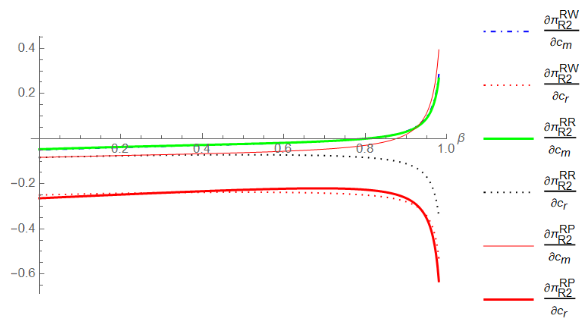


(b) Effect of c in the second period

FIGURE 5. Effect of cost on channel members' preferences in the manufacturer refurbishing, where $c_m = 0.6, c_r = 0.5, \theta = 0.4$.



(a) Effect of c in the second period for the manufacturer



(b) Effect of c in the second period for the retailer

FIGURE 6. Effect of cost on channel members' preferences in the retailer refurbishing, where $c_m = 0.6, c_r = 0.5, \theta = 0.4$.

(2) In the first period, for the retailer, we have:

$$\frac{\partial \pi_{R1}^{MW}}{\partial c_m} = \frac{-(1-c_m)}{8} < 0, \frac{\partial \pi_{R1}^{MR}}{\partial c_m} = \frac{-(1-c_m)(1-\theta)}{2(2-\theta)^2} < 0, \frac{\partial \pi_{R1}^{MP}}{\partial c_m} = \frac{(7-2\beta)\left[-8+c_r+c_m(7-2\beta)+2\beta\right]}{32(3-\beta)^2} < 0,$$

$$\frac{\partial \pi_{R1}^{MP}}{\partial c_r} = \frac{-8+c_r+c_m(7-2\beta)+2\beta}{32(-3+\beta)^2} < 0.$$

(3) In the second period, for the remanufacturer, we have: $\frac{\partial \pi_{M2}^{MW}}{\partial c_r} < 0, \frac{\partial \pi_{M2}^{MR}}{\partial c_r} < 0, \frac{\partial \pi_{M2}^{MP}}{\partial c_r} < 0.$ the effect of costs on $\frac{\partial \pi_{M2}^{MW}}{\partial c_m}, \frac{\partial \pi_{M2}^{MR}}{\partial c_m}, and \frac{\partial \pi_{M2}^{MP}}{\partial c_m}$ as β increases, the relation between the positive and the negative effects will gradually change.

(4) In the second period, for the retailer, we have: $\frac{\partial \pi_{R2}^{MW}}{\partial c_r} < 0, \frac{\partial \pi_{R2}^{MR}}{\partial c_r} < 0, \frac{\partial \pi_{R2}^{MP}}{\partial c_r} < 0.$ the effect of costs on $\frac{\partial \pi_{R2}^{MW}}{\partial c_m}, \frac{\partial \pi_{R2}^{MR}}{\partial c_m}, and \frac{\partial \pi_{R2}^{MP}}{\partial c_m}$ as β increases, the relation between the positive and the negative effects will gradually change.

Proposition 5 indicates that, in the first period, as the product competition parameter β increases, the new and refurbished product become more substitutable, the cost increase of new and refurbished production c_m and c_r have a negative impact on all of the channel member's profits under three different contracts. It is intuitive to note that the cost increase will decrease the profit. In the second period (Figure 5), the cost increase of refurbished production c_r has a negative impact on both the manufacturer's and retailer's profits. However, as the β is sufficiently high, an increase in c_m, the relation between the positive and the negative effects will gradually change. Which means, both of the channel members will benefit from the new production cost increase. As the refurbishing cost increases, it will increase the unit price of the refurbished product, and the demand will transfer to the new product market, which will increase the demand for the new product. Therefore, the negative effect of an increase in c_m underperforms its positive impact, which leads all of the channel members to benefit from such an increase. In addition, as production costs increase, all of the channel members' profits become more and more sensitive under wholesale price and revenue sharing contracts as the competition parameter β increases.

Proposition 6: Effect of costs on remanufacturer's preferences in the retailer refurbishing.

(1) In the first period, for the manufacturer, we have:

$$\frac{\partial \pi_{M1}^{RW}}{\partial c_m} = \frac{-(1-c_m)}{4} < 0, \frac{\partial \pi_{M1}^{RR}}{\partial c_m} = \frac{-(1-c_m)}{2(2-\theta)} < 0,$$

$$\frac{\partial \pi_{M1}^{RP}}{\partial c_m} = \frac{-\left(8+\beta^2\right)\left[8+\beta(-1+c_r+\beta)-c_m(8+\beta^2)\right]}{4(7+\beta^2)^2} < 0, \frac{\partial \pi_{M1}^{RP}}{\partial c_r} = \frac{\beta\left[8+\beta(-1+c_r+\beta)-c_m(8+\beta^2)\right]}{4(7+\beta^2)^2} < 0.$$

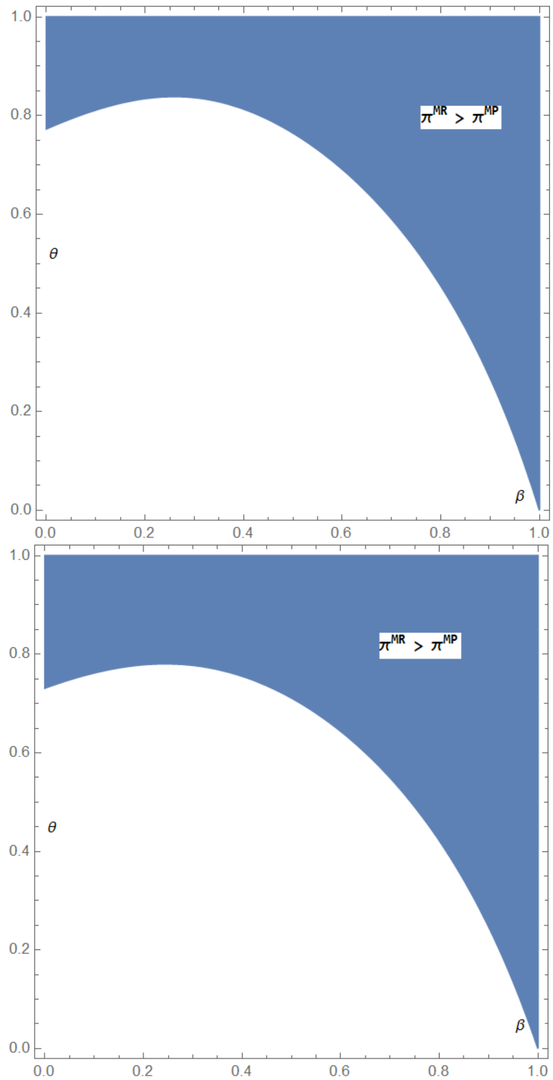


FIGURE 7. Comparisons the performance of MR and MP in the manufacturer refurbishing scenarios, where $c_m = 0.6, c_r = 0.5, \sigma = 3$ (up) and $c_m = 0.6, c_r = 0.5, \sigma = 6$ (down).

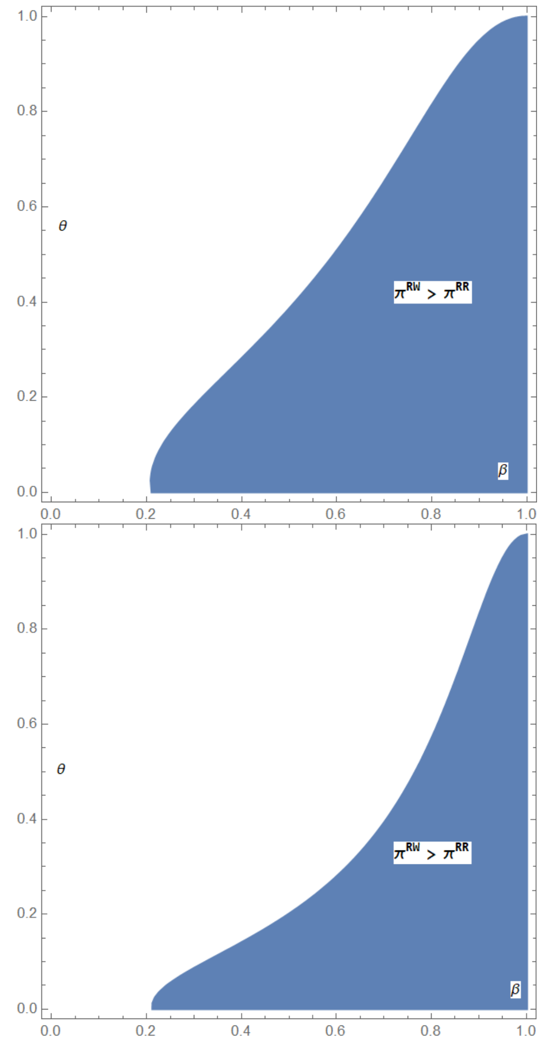


FIGURE 8. Comparisons the performance of RW and RR in the retailer refurbishing scenarios where $c_m = 0.6, c_r = 0.5, \sigma = 3$ (up) and $c_m = 0.6, c_r = 0.5, \sigma = 6$ (down).

(2) In the first period, for the retailer, we have:

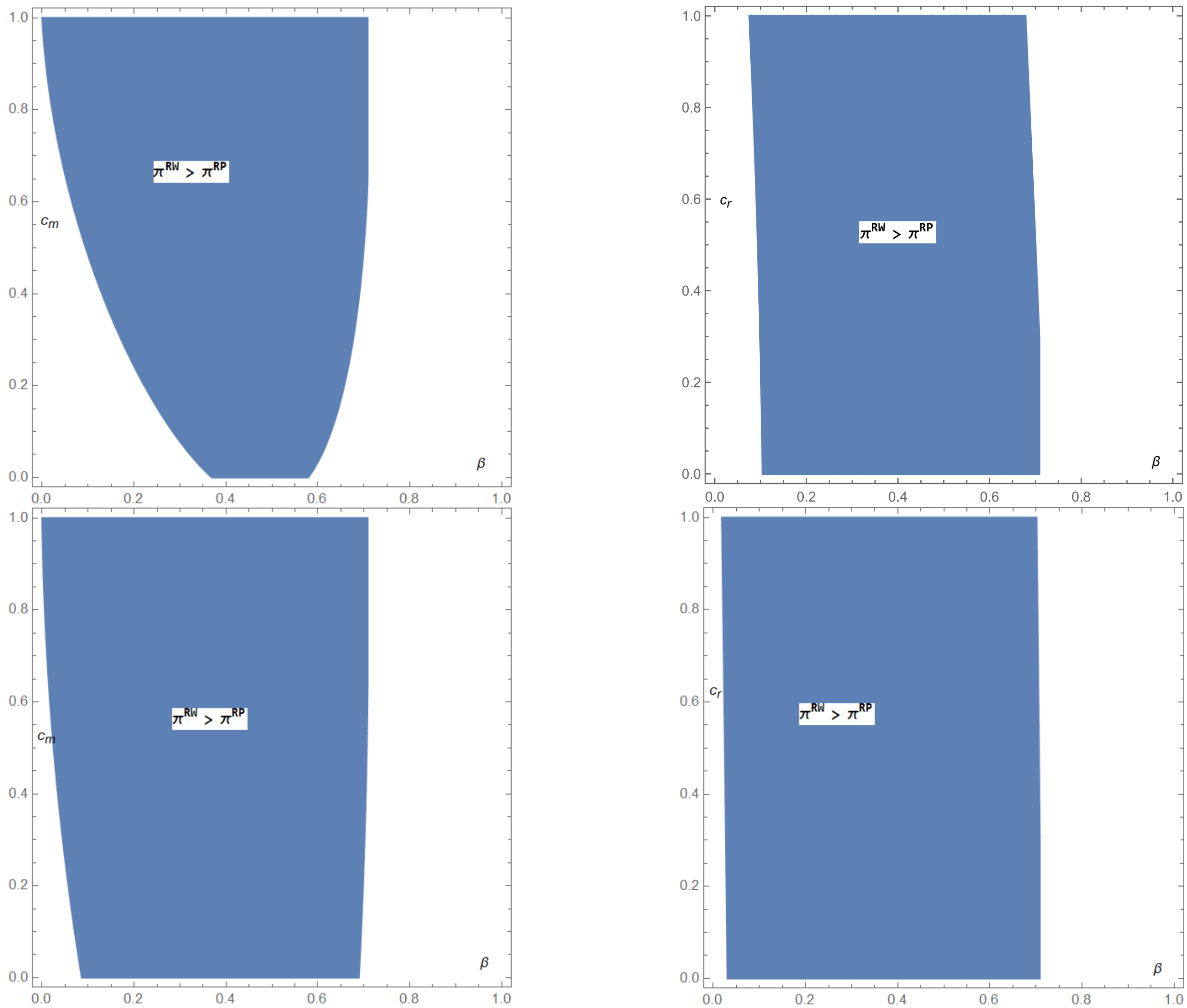
$$\frac{\partial \pi_{R1}^{RW}}{\partial c_m} = \frac{-(1-c_m)}{8} < 0, \frac{\partial \pi_{R1}^{RR}}{\partial c_m} = \frac{-(1-c_m)(1-\theta)}{2(2-\theta)^2} < 0, \frac{\partial \pi_{R1}^{RP}}{\partial c_m} = \frac{-(8+\beta^2)\left[8+\beta(-1+c_r+\beta)-c_m(8+\beta^2)\right]}{8(7+\beta^2)^2} < 0, \frac{\partial \pi_{R1}^{RP}}{\partial c_r} = \frac{\beta\left[8+\beta(-1+c_r+\beta)-c_m(8+\beta^2)\right]}{8(7+\beta^2)^2} < 0.$$

(3) In the second period, for the remanufacturer, we have: $\frac{\partial \pi_{M2}^{RR}}{\partial c_r} < 0$. the effect of costs on $\frac{\partial \pi_{M2}^{RW}}{\partial c_r}$, $\frac{\partial \pi_{M2}^{RP}}{\partial c_r}$, $\frac{\partial \pi_{M2}^{RW}}{\partial c_m}$, $\frac{\partial \pi_{M2}^{RR}}{\partial c_m}$, and $\frac{\partial \pi_{M2}^{RP}}{\partial c_m}$ as β increases, the relation between the positive and the negative effects will gradually change.

(4) In the second period, for the retailer, we have:

(5) $\frac{\partial \pi_{R2}^{RW}}{\partial c_r} < 0, \frac{\partial \pi_{R2}^{RR}}{\partial c_r} < 0, \frac{\partial \pi_{R2}^{RP}}{\partial c_r} < 0$. the effect of costs on $\frac{\partial \pi_{R2}^{RW}}{\partial c_m}$, $\frac{\partial \pi_{R2}^{RR}}{\partial c_m}$, and $\frac{\partial \pi_{R2}^{RP}}{\partial c_m}$ as β increases, the relation between the positive and the negative effects will gradually change.

Proposition 6 presents that, in the first period, as β increases, due to symmetry, it has the same impact on all channel member's profits under three different contracts as in the manufacturer refurbishing scenario. In the second period (Figure 6), for the manufacturer, the cost increase of refurbished production c_r has a negative impact on the manufacturer's profit. That's because, as the refurbishing cost increase, it will push up the unit price of the refurbished product, which harms the demand of the refurbished product market and ultimately lead to a lower revenue sharing from retailer to manufacturer. However, as the β is sufficiently high, an increase in c_m and c_r the relation between the positive and the negative effects will gradually change. Which



(a) where $c_r = 0.5, \sigma = 3$ (up) and $c_r = 0.5, \sigma = 6$ (down).

(b) where $c_m = 0.6,\ \sigma = 3$ (up) and $c_m = 0.6, \sigma = 6$ (down).

FIGURE 9. Comparisons the performance of RW and RP in the retailer refurbishing scenarios.

means, the negative impact of an increase in c_m and c_r underperforms its positive impact, which leads all of the channel members to benefit from such an increase. For the retailer, due to symmetry, the production costs have the same impact on all of the channel member's profits under three different contracts as in the manufacturer refurbishing scenario. In addition, as production cost increases, the retailer's profit is almost stable. Only the manufacturer's profit becomes more and more sensitive under different contracts in such the competition parameter β increases.

C. COMPARING ON THE TOTAL CLSC PROFIT

In this section, we examine the refurbishing effect of the supply chain structure on the total CLSC profit under three different contracts, $\pi^M = \pi^M_{M1} + \pi^M_{R1} + \pi^M_{M2} + \pi^M_{M2}$ in the manufacturer refurbishing and $\pi^R = \pi^R_{M1} + \pi^R_{R1} + \pi^R_{M2} + \pi^R_{M2}$ in the retailer refurbishing model. Proposition 7 comparisons of the performance under which contract is better off in manufacturer and retailer refurbishing model.

Proposition 7: Comparisons of performance in different refurbishing models.

(1) In the manufacturer refurbishing, we have: $\pi^{MW} < \pi^{MP} < \pi^{MR}$.

(2) In the retailer refurbishing, we have: $\pi^{MR} < \pi^{MW} < \pi^{MP}$.

Proof of Proposition 7: Comparison of the performance between wholesale price and revenue sharing contracts we have

$$\pi^{MW} - \pi^{MR} - \frac{\begin{bmatrix} 3+\sigma^2-4c_m+2c_m^2-2c_r+c_r^2 \\ -2(1-c_m)(1-c_r)\beta-(1-c_m)^2\beta^2 \end{bmatrix}\theta(-4+3\theta)}{16(-1+\beta^2)(-2+\theta)^2} < 0,$$

and compare the performance between wholesale price and reward points contracts we have $\pi^{MW} - \pi^{MP} = \frac{\sigma^2(-29+6\beta)-(2-c_m-c_r)[94-65c_m-29c_r+6(-4+3c_m+c_r)\beta]}{64(-3+\beta)^2} < 0.$Other observation results through extensive numerical studies are presents in Figures 7-10. □

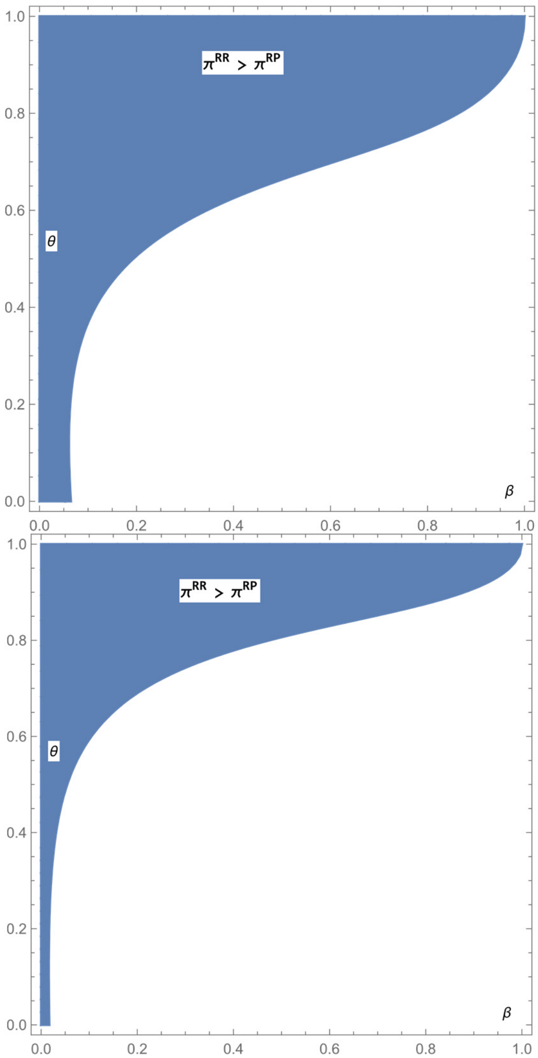


FIGURE 10. Comparisons the performance of RR and RP in the retailer refurbishing scenarios, where $c_m = 0.6, c_r = 0.5, \sigma = 3$ (up) and $c_m = 0.6, c_r = 0.5, \sigma = 6$ (down).

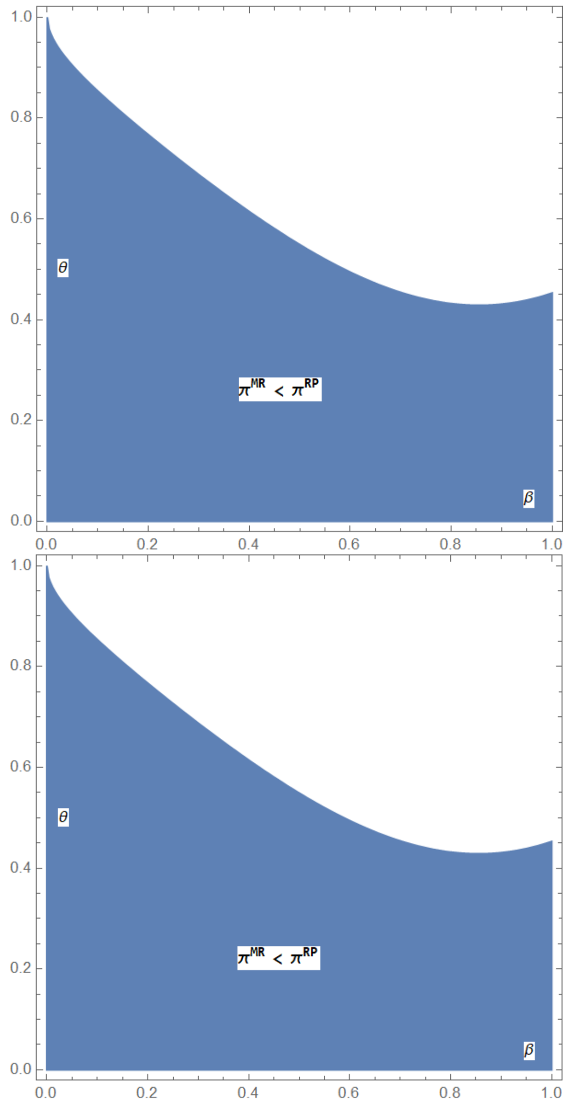


FIGURE 11. Comparisons the performance of MR and RP, where $c_m = 0.6, c_r = 0.5, \sigma = 3$ (up) and $c_m = 0.6, c_r = 0.5, \sigma = 6$ (down).

We have shown in proposition 7 that the revenue sharing contract always makes the best performance for the whole CLSC in the manufacturer refurbishing model, followed by a reward point contract. Profit under wholesale contract is always the lowest. When β is small and sharing parameter θ is high, the reward points contract performs better than the revenue sharing contract. However, the refurbished and new products are substitutable, which means β is sufficiently large. Therefore, the revenue sharing contract makes the best performance in the manufacturer refurbishing model (Figure 7). In other words, the channel members always prefer revenue-sharing contracts in the manufacturer refurbishing scenarios. On the other hand, as the uncertainty for the refurbished products becomes large, the retailer revenue sharing percentage is reduced. The prime reason is demand uncertain of the refurbished product makes the new product more attractive and increases the demand for the new product, which the positive impact outperforms the negative impact. Figure 8 indicates that in the retailer refurbishing scenarios, as β is sufficiently large, the total CLSC under the wholesale price contract is always better than the revenue-sharing contract. As the uncertainty for the refurbished products becomes large, the percentage for the retailer revenue sharing increases because the positive impact on new product profit increase underperforms the negative effects on refurbished product profit decrease. Figures 9 and 10 present that in the retailer refurbishing scenarios, as β is sufficiently large, reward points contract performs better than others.

Corollary 1: Under reward points contract, the manufacturer, the retailer, and the environment are all better off in the retailer refurbishing scenarios.

Corollary 1 presents that retailers refurbishing CLSC can simultaneously align manufacturer, retailer, and the environment achieve Pareto-improving under reward points contract strategy. On the other hand, through reward points contracts in the retailer refurbishing scenarios can push up both the new and refurbished product, which incentivizes the retailer to increase the quantity of the refurbished product and save materials and protect the environment.

V. CONCLUSION AND MANAGERIAL IMPLICATIONS

Nowadays, for environmental and economic purposes, WEEEs refurbished developed rapidly, which leads to channel competition with new and refurbished products. Meanwhile, how and whom to effectively refurbish the used products and how to achieve environmental, economic, and social performance become one of the most significant issues for the manufacturer and retailer. Prior research on two-period refurbishing strategies mostly based on manufacturer or third-party refurbishing didn't consider retailer refurbishing, and researchers didn't consider the quality uncertainty of the refurbished products, either. Moreover, previous studies did not compare the performance under different contracts either. Therefore, this study compares two-period manufacturer and retailer refurbishing CLSC.

Following the analytical observations derived from our two-period economic model, we present that the manufacturer should allow his retailer to refurbish used products under the condition of using reward points contract strategies, which means retailer refurbishing can achieve a better off performance than manufacturer refurbishing for the whole CLSC performance. On the demand uncertainty side, we present that even if the large of the refurbished product demand uncertainty, contract incentive cooperation mechanism still is a mandatory and highly valuable approach to be utilized to alleviate conflict and all of the channel members could benefit in the two periods CLSC. Consequently, it is suggested that all the channel members should seek incentive contract cooperation mechanism. On the other hand, production cost increase has a negative effect on demand, which means production cost will influence the attractiveness of refurbishing. Therefore, valuable managerial insights to business managers are that manufacturers can afford some technology support in practice to keep refurbishing moderately attractive, such as Apple afford proprietary spare parts at Best Buy.

Due to the limitations and other important issues outside the scope of this research, the future study can be extended in several directions. In this paper, we develop a linear demand function study of the two-period CLSC. Demand function can also be used in other kinds of distributions in the future. Besides, the difference between new and refurbished products should also be considered in the future. As online technology rapidly develops, the online channel can also be extended. Furthermore, it should be more interesting to information sharing, lead time decisions, and inventory policies in the future study.

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