Developing Theoretic Strategies of Sharing Corporate Social Responsibility Conduct in a Closed-loop Supply Chain System

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***Abstract*—Due to the environmental impacts and economic benefits, establishment of business strategies for sustainable development is getting increasing attention both in industry as well as in academia. In order to improve the corporate social responsibility (CSR), we develop an Extend Producer Responsibility (EPR) model which refers to original equipment manufacturer (OEM) takeback in a closed-loop supply chain system under incentive-dependent demand and return. The performance analysis of the system dynamics simulation model will indicate that the inclusion of incentive offer enhances the demand, collection and remanufacturing process. A numerical example and sensitivity analysis on the optimal results are presented to validate the proposed model. Finally, this study show insight on how incentive offer increases remanufacturing activity and the manufacturers' profits.**

***Keywords*—** *CSR; Closed-loop supply chain; Incentive Offers; EPR; OEM*

1. Introduction

In recent years, the concept and practices of corporate social responsibility (CSR) have been widely discussed. CSR will become crucial guidelines for various enterprises in the future, and most international enterprises already pay substantial attention to it. According to the Economist (2005), more than 85% of senior managers worldwide and 65 crucial investors considered CSR to be a crucial factor influencing their future investment choices. Generally, corporate sustainability comprises three dimensions: economic development, environmental protection, and social responsibility. Enterprises typically facilitate economic growth by emphasizing profits and earnings, cost-saving, and research and development innovations. Regarding environmental protection, enterprises employ environmental pollution prevention management when using natural resources with the aim of reducing environmental damage.

Governments have also attempted to achieve environmental–economic sustainability by introducing incentive mechanisms that encourage energy conservation and carbon reduction. Lastly, enterprises seek to improve their image through corporate social responsibility (CSR) activities that concern their labor force, their consumers, the environment, charities, and disadvantaged groups.

CSR promotes business practices that conform to social morality, emphasizing the responsibilities of an enterprise to stakeholders and not only its own shareholders. These stakeholders include any individuals and groups who are influenced by a company’s corporate decisions and actions, such as employees, customers, suppliers, communities, parent companies or subsidiaries, partners, investors, shareholders, and other indirect consumers. Therefore, CSR refers to business operations that not only comply with or exceed moral, legal, and public standards, but that also take into account the impact they have on all relevant stakeholders. CSR is based on the notion that business operations must be consistent with sustainable development, and that enterprises should contemplate their effect on society and the environment in addition to considering their own financial and operational conditions.

Extended producer responsibility (EPR) is increasingly emphasized by manufacturing enterprises to improve eco-efficiency and to satisfy the growing environmental requirements expected in the market. EPR is a policy measure that recognizes the producer’s role in reducing the impacts of their product throughout its entire life cycle, including waste management or recovery at end-of-life. EPR policies shift part, or all, of this responsibility from taxpayers, local authorities and conventional waste dealers to the producers. Effectively designed EPR programs can influence the development of more sustainable materials management systems and encourage design for environment practices such as dematerialization, the elimination of toxics, and the reuse of products and packaging.

The Organization for Economic Cooperation and Development (OECD) defines Extended Producer Responsibility as ‘‘an environmental policy approach in which a producer’s responsibility, physical and/or financial, for a product is extended to the post-consumer stage of a product's life cycle'' [9]. This approach maintains that the producers have the greatest ability to realize environmental improvements and to influence changes in the upstream, manufacturing, and downstream phases of a product's life [14]. The extension of producer responsibilities (beyond sales and distribution) is illustrated in Fig. 1.

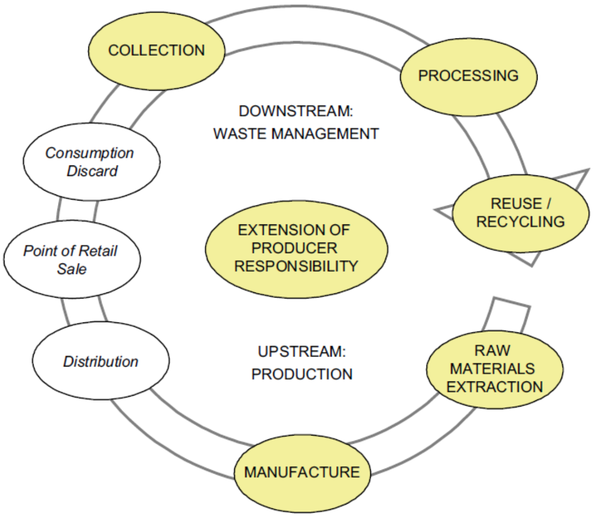

Fig. 1. EPR encompasses both the upstream and downstream stages of a product's life cycle. [13]

EPR itself can be considered an environmental strategy. The choice of policy instruments defines the character of the implemented EPR (see Table 1 for examples of policy instruments). The efficiency of EPR is dependent upon the choice of policy instrument. The different characteristics can be classified into five types of EPR, as summarized in Fig. 2.

Table 1. Examples of policy instruments [4]

Types of policy instruments	Examples
Administrative	Prohibition Regulations Take-back responsibility Recycling targets
Economic	Taxes Fees Deposit–refund systems Product disposal charge
Informational	Information Research and developme
Agreements	Social contracts Gentlemen's agreement

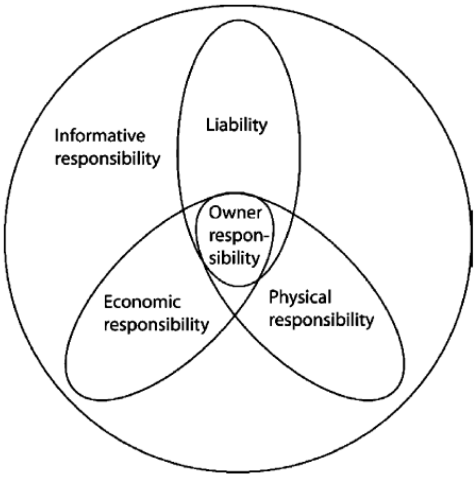

Fig. 2. Different types of EPR. [7]

- Informative responsibility implies a responsibility to provide information about the product and its environmental effects. This responsibility is based both on legal requirements and the producer's dependence on goodwill.
- Physical responsibility means that the producer is required to physically handle the end-of-life management.
- Economic responsibility is when the producer covers the whole or an extensive part of the cost associated with the end-of-life management.
- Liability implies that the producer is responsible for all damages that a good cause during its life cycle.
- Owner responsibility is a subset of all the other responsibilities. Owner responsibility arises when the producer keeps the legal ownership of the good. One obvious example is leasing.

However, minimizing the environmental impact of end-of-life from a systems point of view requires more than a policy to properly manage products when they are no longer in use. It requires product and systems design that takes end-of-life into account. In order to achieve fully the integration of product retirement concerns as design considerations, it is necessary to feedback and internalize costs and data. Specific EPR programs are now being planned and implemented in conjunction with these legislative directives. In 2000, the European Parliament passed a directive requiring its member countries to institute an EPR program for end-of-life vehicles [3]. Furthermore, an additional directive for Waste Electronics and Electrical Equipment (WEEE) is expected to be approved in early 2003. This is not only a European phenomenon, as, for example, Japan has also enacted an EPR law covering four large electrical home appliances (TV sets, refrigerators, air conditioners, and washing machines) [12].

Green supply chain management focuses on inter-organizational efforts in managing the supply chain processes to reduce adverse environmental impact from purchasing of materials, production, to distribution of finished products [10]. Green purchasing can be considered as one of the major processes of green supply chain management. As EPR manages residual values of returned products, green purchasing takes account of organizational sourcing decision with a focus on reducing use of environmentally unsustainable materials by developing purchasing policy, defining environmental objectives, and monitoring performance of suppliers [1, 15].

EPR is different from the concept of organizational environmental management that is confined to organizational efforts and practices to reduce their adverse environmental impact through product and process stewardship with an emphasis on reducing liability and costs [8]. In comparison to the environmental management standard on ISO14000 which is about process control with environmental consideration, EPR is concerned with the management practices by manufacturing enterprises on product take-back, recycling, and final disposal to reduce harms caused by their products to the environment.

One major goal of EPR is to mitigate the environmental damages by reducing disposal to landfill at the end of a product life. There are also economic values of EPR practices for manufacturers to collect and process the returned products through which to capture the residual values by remanufacturing, reprocessing, recycling, and reusing the reusable components. The return product streams cover packaging, electrical appliances and electronics, batteries, used oil, tires, and end-of-life vehicles. A major element of any EPR policy is the take-back requirement mandating individual manufacturers to collect and treat the resultant waste.

Alternatively, product manufacturers are charged with financial obligations for these take-back activities. It is highly desirable that manufacturers incorporate environmental consideration at the product design stage to facilitate their subsequent take-back activities. This product stewardship emphasis improves and expedites the treatment of returned products [11] because the responsible manufacturers need to inspect dissembled parts, separate reusable parts, recycle, reprocess, and reuse the reusable parts in the product take-back process [2]. This collection of EPR practices is expected to enhance the producer's ability to competently satisfy both the international and local requirements on environmental protection.

Many manufacturing enterprises in emerging countries (e.g., China and Brazil) produce items targeted at global markets. At the same time, they must comply with related EPR legislations enforced by different governments, e.g., European Community Directives on Waste Electrical and Electronic Equipment (WEEE), if approval is necessary for their products to enter the market. For regulatory compliance, manufacturing exporters are required to provide a program or system of collecting and processing their products sold in the markets. Such requirement aims at mitigating the environmental damages caused by manufacturers through closing the supply chain loop of their products [5, 6]. To undertake this extended responsibility needs organizational effort for coordination with downstream customers, e.g., retailers and distributors, to collect the returned products the local market. It is crucial that products are designed and made in such a way that makes it easy for the original manufacturers to recycle and remanufacture the reusable components throughout the product life cycle.

A closed-loop supply chain (CLSC) is the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time. In this study, in a CLSC, OEM (Original Equipment Manufacturer) takeback refers to EPR systems in which OEM themselves take physical and economic responsibility for the products that they have manufactured. Each company manages their own demanufacturing facilities in which their products are disassembled for remanufacturing, recycling, or other environmentally responsible outcomes. From the perspective of the objectives of extended producer responsibility, OEM takeback would seem likely to work quite well.

Feedback is assured since the manufacturers are simply directly responsible for their own products at end-of-life. They pay the costs of recovery, and they demanufacture and recycle, paying any costs that may arise from these activities. To the extent that design changes can improve the end-of-life situation for their products, manufacturers are incentivized to make those improvements. Since these demanufacturing facilities will only be responsible for what has been manufactured by one company, they will need to learn a relatively small family of products. This will promote both efficiencies and feedback. Efficiency will benefit because of expertise and specialization, while feedback will be gained through the concentration of demanufacturing wisdom that should be easily accessible to the designer.

As well, information can flow in both directions, as internal design-based data can be used to aid the demanufacturing process. Furthermore, the opportunities for higher-order, closed-loop reuse and recycling would likely be enhanced through an OEM-managed end-of-life system. If easy access to potentially reusable parts can encourage the development of plans for those components, then OEM demanufacturing facilities may have the potential to be fertile places. They could collect significant inventories of similar parts and have the knowledge and opportunities to put them to use.

The OEM takeback mode of organizing end-of-life management seems to be strong in terms of economic and information feedback, operational efficiencies, and potential for closed-loop recycling. On the other hand, the category is not without its disadvantages. OEM-managed demanufacturing can be considered to be a highly specialized mode. The demanufacturing facilities would handle a limited array of products. It is clear that the more specialized a recycling centre is, the fewer of them there will be — because they will have less supply to recycle. So, in the OEM takeback mode, there would be fewer demanufacturing centres within a given area to service particular products. Viewed from the other vantage point, products would have to travel a relatively long distance to be recycled.

This is significant since logistics can account for a large portion of recycling costs — as much as 70%. Another logistical complication of OEM demanufacturing involves the question of product return. There needs to be some way to get end-of-life products from consumers back to the demanufacturing facilities. This is most complicated for the

OEM takeback mode of EPR since there are so many different manufacturers. In fact, it seems it would be necessary for some other actors to be involved here, such as retailers, the government, or a manufacturer's association. A frequently discussed issue related to extended producer responsibility is that of orphaned products. When a manufacturer ceases to exist before all its products have been demanufactured, those products are considered to be orphaned. In the case of an OEM-focused EPR system, orphans truly have no home. A related issue involves imported products. Some EPR schemes assign responsibility to importers, but importers may be poorly equipped to conduct demanufacturing themselves. While demanufacturing may not be a core competency of importers, it is not necessarily one for manufacturers, either.

The smaller a manufacturer is, the more difficult it is for them to effectively manage their own end-of-life responsibilities. It may seem reasonable for them to subcontract this work, but depending on how this is done it can potentially dilute the ability to feedback economic costs and knowledge. Overall, takeback and recycling of products by their original equipment manufacturers seems to be viable, but not without challenges. Foremost among these is the question of reverse logistics. This, and the low interest that some manufacturers may have in becoming demanufacturing specialists, leads to the consideration of other options, including pooled takeback.

In this study, we define EPR as management practices including take-back, recycling, and final disposal of products that are helpful for manufacturing enterprises to relieve the environmental burdens bought by their products. While EPR focuses on utilizing reusable materials and components by incorporating modular design and capturing residual values from returned products, EPR is different from the notion of green supply chain management, green purchasing, and corporate environmental management. It is structured as follows: Section 1 reviews the relevant literature; Section 2 describes assumptions and notations; Section 3 develops the model scenario; Sections 4 presents a numerical example and sensitivity analysis, respectively; Section 5 concludes the study by describing its contributions and limitations and suggesting further research directions.

2. Notation and Assumptions

The following notations are used:
r: number of collected returns per year
R: annual demand of the remanufactured product
π_i : the probability function of incentive policy for consumers' takeback willingness, i = 1, 2, 3
θ_i : qualified rate for the remanufactured product L_i, i = 1, 2, 3
H_i: sensitivity parameter (>1), i = 1, 2, 3
P_{max} : the maximal price of the remanufactured product ($/unit)
m: remanufacturing cost per product ($/unit)
d : disposal cost per product ($/unit)
g: salvage value per product ($/unit)
p_1 : L_1 remanufacturing product price ($/unit)
p_2 : L_2 remanufacturing product price ($/unit)
p_3 : L_3 remanufacturing product price ($/unit)
τ_i : the implement level of Extend Producer Responsibility ($0 \le$), i = 1, 2, 3
δ : EPR penalty ($/unit)
* The superscript representing optimal value

The mathematical models in this study assume the following:

(1) After screening, collected returns can be sorted into three quality levels: L_1, L_2 and L_3
(2) Since the returns are sorted in sequence of three quality levels, consequently the qualified rate, θ_i , i = 1, 2, 3, for three levels is assumed to $0 < \theta_1 < \theta_2 < \theta_3 < 1$.
(3) The price of the reuse product is assumed to be the function of EPR level (τ). Let $p_i = a + b \cdot \tau$ for $0 < p_3 < p_2 < p_1$. The minimum price is a when $\tau = 0$; the maximum price is p_{max} when $\tau = \tau_{\max}$.

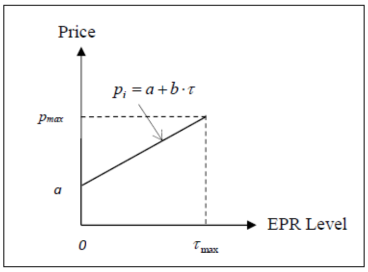

Fig. 3. The price of reuse product increases with EPR Level.

(4) Defective products exist in lot size R and are disposed of.
(5) The selling probability of recycling products decrease with the availability.
(6) The selling probability of recycling products increase with the EPR level.
(7) The return availability is up to consumers' takeback willingness, which refer to the incentive policy.
(8) Down substitution of items is considered, i.e., any unsold remanufactured product L_1 can be sold at the price of L_2 and any unsold L_2 can be sold at the price of L_3, and any unsold product must be disposed of.
(9) The substitution of items has impact on the selling probability. It is assumed that $1 < H_3 < H_2 < H_3$, meaning thereby the availability of remanufactured products has the most impact on each other.

3. Mathematical model

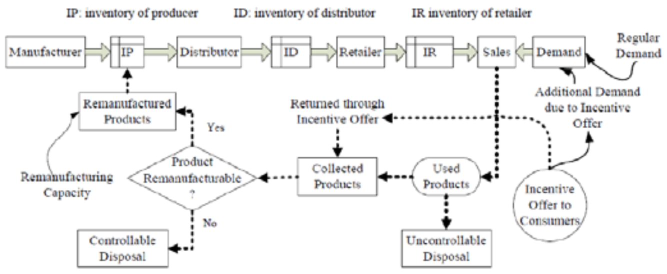

Figure 3 shows how reverse manufacturing processes behave in a closed-loop supply chain. By OEM takeback, original equipment manufacturers implement EPR. At the remanufacturing plant, returned and used products to environmental protection service industries. are inspected, screened, and sorted. And, imperfect products are discarded.

The incentive programs ensure the producer and consumer have greater responsibility for the safe disposal of products. Financial incentives offered to product holders or buy-back campaigns, influence the quantity of returns and thus, numerous companies offer financial incentives to collect more used products. To offer the correct incentive amount is crucial for a company to ensure a sufficient number of used products for remanufacturing.

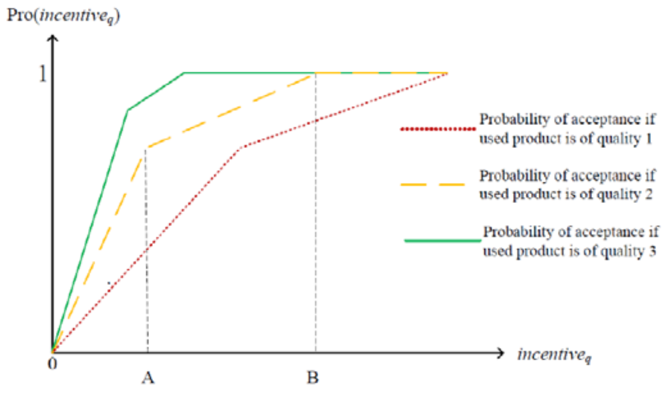

Fig.4 The probability function of incentive policy refer to consumers' takeback willingness

Assumed that v and u are constant $(0 < u \le v)$. When $0 \le incentive_q \le A$, $\frac{v}{vx + u(B-A)}$ is the expected value of the incentive policy; when $A \le incentive_q \le B$, $\frac{u}{vx+u(B-A)}$ is the expected value of the incentive policy. Figure 4 shows the probability function of incentive policy refer to consumers' takeback willingness.

$$\mathrm{E}[incentive_q] = \begin{cases} \pi_1 = \dfrac{v \cdot incentive_q}{vx + u(B-A)} & for \quad 0 \le incentive_q \le A \\ \pi_2 = \dfrac{v \cdot (incentive_q - B)}{vx + u(B-A)} & for \quad A \le incentive_q \le B \\ \pi_3 = 1 & for \quad incentive_q \ge B \end{cases}$$

During remanufacturing, parts must be completely disassembled, cleaned, and examined for wear and damage. Dilapidated, missing, or non-functioning components are replaced with new or rebuilt components. Once inspection and replacement are complete, the product is reassembled and tested for performance specification compliance. The remanufacturer then sells these remanufactured products in secondary markets.

For these recycling products, the probability of sale is a decreasing function of availability, thus, not all units will be sold. In addition, the substitution of items will impact on the selling probability of the original items and each other simultaneously. It is assumed that $1 < H_3 < H_2 < H_3$, meaning thereby the availability of remanufactured products has the most impact of all. This study determines the optimal selling price of recycling products to maximize the remanufacturer's profit.

The selling probability of remanufactured products L_1 is

$$(\frac{\tau_1}{\tau_{\max}}) \cdot (1 - \frac{r\theta_1}{\pi_1 H_1 R})(1 - \frac{r\theta_2}{\pi_2 H_2 R})(1 - \frac{r\theta_3}{\pi_3 H_3 R}) \qquad (1)$$

where P_{max} is the maximal price before the probability of sale becomes zero. Hence, demand for remanufactured products L_1 or expected number of sales Q_1 is calculated using

$$Q_1(\tau_1) = (\frac{\tau_1}{\tau_{\max}}) \cdot (1 - \frac{r\theta_1}{\pi_1 H_1 R})(1 - \frac{r\theta_2}{\pi_2 H_2 R})(1 - \frac{r\theta_3}{\pi_3 H_3 R})\theta_1 r \qquad (2)$$

The demand for remanufactured products shows that the number of unsold remanufactured products increase nonlinearly with availability. The revenue for the sold remanufactured products is

$$(\frac{\tau_1}{\tau_{\max}}) \cdot (1 - \frac{r\theta_1}{\pi_1 H_1 R})(1 - \frac{r\theta_2}{\pi_2 H_2 R})(1 - \frac{r\theta_3}{\pi_3 H_3 R})\theta_1 r p_1 \cdot \qquad (3)$$

Thus, the revenue for the unsold remanufactured products L_1 is

$$\left(1 - \left((\frac{\tau_1}{\tau_{\max}}) \cdot (1 - \frac{r\theta_1}{\pi_1 H_1 R})(1 - \frac{r\theta_2}{\pi_2 H_2 R})(1 - \frac{r\theta_3}{\pi_3 H_3 R})\right)\right)\theta_1 r p_2 \cdot \qquad (4)$$

The selling probability of L_2 is provided by

$$(\frac{\tau_2}{\tau_{\max}}) \cdot (1 - \frac{r\theta_1}{\pi_1 H_1 R})(1 - \frac{r\theta_2}{\pi_2 H_2 R})(1 - \frac{r\theta_3}{\pi_3 H_3 R}) \cdot \qquad (5)$$

Therefore, the revenue for the sold refurbished products is

$$(\frac{\tau_2}{\tau_{\max}})\cdot(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})\theta_2rp_2 \quad (6)$$

The revenue for the unsold L_2 is

$$\left(1-\left((\frac{\tau_2}{\tau_{\max}})\cdot(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})\right)\right)\theta_2rp_3\cdot \quad (7)$$

The selling probability of L_3 is provided by

$$(\frac{\tau_3}{\tau_{\max}})\cdot(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})\cdot \quad (8)$$

Therefore, the revenue for the sold refurbished products is

$$(\frac{\tau_3}{\tau_{\max}})\cdot(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})\theta_3rp_3\cdot \quad (9)$$

And the revenue for the unsold un-refurbished products is

$$\left(1-\left((\frac{\tau_3}{\tau_{\max}})\cdot(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})\right)\right)\theta_3rp_3\cdot \quad (10)$$

$$\begin{aligned}
&TP(\tau_1,\tau_2,\tau_3,\delta)\\
&=(\frac{\tau_1}{\tau_{\max}})\cdot(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})\theta_1rp_1\\
&+\left(1-\left((\frac{\tau_1}{\tau_{\max}})\cdot(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})\right)\right)\theta_1rp_2\\
&+(\frac{\tau_2}{\tau_{\max}})\cdot(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})\theta_2rp_2\\
&+\left(1-\left((\frac{\tau_2}{\tau_{\max}})\cdot(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})\right)\right)\theta_2rp_3\\
&+(\frac{\tau_3}{\tau_{\max}})\cdot(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})\theta_3rp_3\\
&+\left(1-\left((\frac{\tau_3}{\tau_{\max}})\cdot(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})\right)\right)\theta_3rg\\
&-(\theta_1r+\theta_2r)\cdot m-(1-\theta_1-\theta_2-\theta_3)\cdot rd-r\delta \qquad (11)
\end{aligned}$$

By computing these above terms, the total profit (*TP*) is constructed by the following formula: the sum of the revenue for sold remanufactured products L_1, revenue for unsold remanufactured products L_1, revenue for sold remanufactured products L_2, the revenue for unsold refurbished products L_2, and revenue for sold remanufactured products L_3, and the salvage value for unsold remanufactured products L_3, and deducted by the sum of remanufacturing cost for return products, disposal cost for return products, and EPR penalty.

ϖ is defined as a coefficient, which is in the expression $\varpi=(1-\frac{r\theta_1}{\pi_1H_1R})(1-\frac{r\theta_2}{\pi_2H_2R})(1-\frac{r\theta_3}{\pi_3H_3R})$. Our (6)

objective is to maximize the total profits.

$$\begin{aligned}
&Max\ \ TP(\tau\ \ \tau\ \ \tau,\delta)\\
&=(\frac{\tau_1}{\tau_{\max}})\quad (7)\quad \left(1-\left((\frac{\tau_1}{\tau_{\max}})\cdot\varpi\right)\right)\theta_1rp_2+(\frac{\tau_2}{\tau_{\max}})\cdot\varpi\theta_2rp_2\\
&+\left(1-\left((\frac{\tau_2}{\tau_{\max}})\cdot\varpi\right)\right)\theta_2rp_3+(\frac{\tau_3}{\tau_{ma}})\cdot\varpi\theta_3rp_3-\left(1-\left((\frac{\tau_3}{\tau_{\max}})\cdot\varpi\right)\right)\theta_3rd\\
&-(\theta_1r+\theta_2r)\cdot m-(1-\theta_1-\theta_2-\quad (8)\quad r\delta \qquad (12)
\end{aligned}$$

Subject to

$$0<p_3<p_2<p_1 \qquad (13)$$

$$0<\theta_1<\theta_2<\theta_3<1 \qquad (14)$$

$$0\le\tau_1<\tau_2<\tau_3<\tau_{\max} \qquad (15)$$

To solve the price constraints problem, we apply Karush-Kuhn-Tucker (KKT) method. The optimal selling price of the remanufactured item and the appropriate return subsidy can be obtained by deriving the KKT conditions which improve the feasible directions. In order to show the optimality of the solutions, we shall prove that the profit model of the remanufacturer is concave in p_1, p_2 and p_3, and satisfies the condition of a Hessian matrix. It is shown in Appendix A.

4. Numerical example and sensitivity analysis

The theory developed in this study can be illustrated using a numeri (11) ple, with the following parameters:

Number ted returns per year, r

Annual manufacturing capacity of the remanufacturer, R

Maximal price of remanufactured product ($/unit), p_{max}

Sensitivity parameter, H_1

Sensitivity parameter, H_2

Sensitivity parameter, H_3

Qualified rate for the remanufactured product, θ_1

Qualified rate for the refurbished product, θ_2

Qualified rate for the non-refurbished product, θ_3

Salvage value per product ($/unit), g

Remanufacturing cost per product ($/unit), m

Disposal cost per product ($/unit), d

Substituting into (12) to (15) produces an optimal solution with p_1^* = 323, p_2^*= 171, p_3^* =48 (τ_1^* = 152, τ_2^*= 76, and τ_3^* =14) and $\delta^*=10$. The total profit per year is

\$78848. For this pricing policy, the optimal values of p_1, p_2, p_3 and *TP* for fixed set of parameters $\Phi = \{r, R, p_{max}, H_1, H_2, H_3, m, g, d, \theta_1, \theta_2, \theta_3\}$ are τ_1^*, τ_2^*, τ_3^* and TP^*, respectively. Changes in τ_1^*, τ_2^*, τ_3^* and TP^* are considered when set Φ parameters vary. Tables 2 show the sensitivity analysis results when set Φ parameters change by between -30% and 30%. Additional results are shown in Table 3. From the results, there are several observations summarized below.

(1) Table 3 shows the optimal price for the reuse products have nothing to do with their remanufacturing cost.

(2) As shown in Table 3, percentage profit increase (*PPI*) is the most sensitive to $\tau_{\max}$ and θ_1. When $\tau_{\max}$ decreases or increases by 30%, the value of *PPI* tends to change from -37% to 50%. Other sensitive parameters are $p_{\max}$ and *r*. When $p_{\max}$ and *r* decreases or increases by 30%, the value of *PPI* tends to change from -23% to 29%.

(3) As shown in Table 3, the value of *PPI* is the least sensitive to parameters H_1, H_2, and H_3. When they decrease or increase by 30%, the value of *PPI* tends to change from -0.9% to 0.5%.

(4) As shown in Table 3, all parameters except *m* and *d*, are positively correlated with *PPI.*

(5) The sensitivity of *PPI* to Φ parameters is ranked as follows:
$\tau_{\max}$ and θ_1: -37% to 50%
R, *r*, θ_2 and θ_3: -24% to 30%
g, *a*, *b*: -18% to 18%
H_1, H_2, and H_3: -0.9% to 0.5%

(6) The managers should take care of the most important parameters like $\tau_{\max}$ and θ_1, which have a great effect upon profits. The maximal price of the remanufactured and that of the reuse product are up to the returns items. For the reason, managers need to decide to what kind return items to be collected.

5. Conclusions

This study derives an optimal strategy for recycling products in an OEM take-back EPR system. An optimal EPR leveling policy was formulated to maximize total profit for the remanufacturer. The global optimality of the problem proves that the profit function is strictly concave with a negative-definite Hessian matrix. Due to the complexity of the non-linear problem, the Karush-Kuhn-Tucker (KKT) conditions are applied. The sensitivity analysis demonstrates that the percentage profit increase (PPI) is extremely sensitive to the maximal EPR service level and qualified rate of the remanufactured product and least sensitive to other sensitivity parameters. This study has examined the impact of the changes of EPR maximal level and different qualified rates with the EPR strategy. With increase 30% in the level of EPR and qualified rate, the total profits tends to increase 50%. The proposed model could be used in closed-loop supply chain EPR systems. Future research could extend the model to other reverse logistics systems accounting for multiple items and a multiple market environment.

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Table 2. The changed value of parameters

Changed % / Parameter	-30%	-20%	-10%	0%	10%	20%	30%
r	1400	1600	1800	2000	2200	2400	2600
R	7000	8000	9000	10000	11000	12000	13000
$p_{\max}$	350	400	450	500	550	600	650
g	7	8	9	10	11	12	13
θ_1	0.07	0.08	0.09	0.1	0.11	0.12	0.13
θ_2	0.14	0.16	0.18	0.2	0.22	0.24	0.26
θ_3	0.21	0.24	0.27	0.3	0.33	0.36	0.39
a	14	16	18	20	22	24	26
b	1.4	1.6	1.8	2	2.2	2.4	2.6
H_1	2.8	3.2	3.6	4	4.4	4.8	5.2
H_2	2.1	2.4	2.7	3	3.3	3.6	3.9
H_3	1.4	1.6	1.8	2	2.2	2.4	2.6
d	10.5	12	13.5	15	16.5	18	19.5
m	70	80	90	100	110	120	130

Table 3. Numerical results (τ_1^*, τ_2^*, τ_3^*, δ^* and TP^*) of sensitivity analysis

Parameter	Changed %						
	-30%	-20%	-10%	0%	10%	20%	-30%
$p_{\max}$	254	276	300	323	347	371	393
	176	174	172	171	171	170	170
	48	48	48	48	48	48	48
	7	8	9	10	10	10	11
	60188	65856	72109	78848	86109	93748	101721
$\tau_{\max}$	299	307	314	323	332	339	349
	124	139	155	171	188	204	221
	48	47	48	48	48	48	48
	5	7	8	10	10	12	13
	49424	58233	68053	78848	90817	103793	118061
R	318	319	322	323	325	326	328
	162	164	168	171	174	177	181
	33	37	43	48	52	57	62
	7	8	9	10	10	10	11
	64679	69173	73929	78848	84105	89592	95320
r	323	323	323	323	323	323	323
	170	171	171	171	172	172	172
	47	48	48	48	48	48	48
	10	10	10	10	9	8	7
	68170	71622	75232	78848	82649	86449	90249
a	322	322	323	323	324	324	324
	168	169	170	171	172	173	173
	47	47	47	48	48	48	48
	8	8	9	10	10	10	10
	68657	71936	72544	78848	82439	86001	89534
b	323	323	323	323	323	323	323
	172	171	171	171	171	171	171

	48	48	48	48	48	48	48
	9	9	9	10	10	10	10
	78650	78715	78780	78848	78917	78983	79048
θ_1	314	316	319	323	326	330	333
	151	158	164	171	178	184	190
	45	46	47	48	48	48	48
	6	7	8	10	10	11	12
	52586	60491	69215	78848	89591	101404	114364
θ_2	333	329	326	323	320	319	317
	190	182	176	171	166	163	160
	43	44	46	48	48	48	48
	9	9	9	10	10	10	10
	73429	74634	76500	78848	81625	84587	87676
θ_3	323	323	323	323	323	323	323
	170	171	171	171	171	171	171
	48	48	48	48	46	45	43
	8	9	9	10	10	10	10
	68647	71974	75408	78848	82564	86413	90459
H_1	323	323	323	323	323	323	323
	172	172	172	171	171	171	170
	48	48	48	48	48	48	47
	9	9	9	10	10	10	10
	78096	78405	78646	78848	79025	79171	79294
H_2	324	323	323	323	323	323	322
	173	172	172	171	171	170	170
	48	48	48	48	48	47	47
	9	9	9	10	10	10	10
	77709	78176	78543	78848	79118	79343	79542
H_3	323	323	323	323	323	323	323

	172	172	172	171	171	171	170
	48	48	48	48	48	48	47
	9	9	9	10	10	10	10
	78096	78405	78646	78848	79025	79171	79294
g	322	323	323	323	323	323	323
	170	170	171	171	171	171	171
	46	47	47	48	48	48	48
	9	9	9	10	10	10	10
	74604	75998	77417	78848	80368	81888	83408
d	323	323	323	323	323	323	323
	171	171	171	171	171	171	171
	48	48	48	48	48	48	48
	10	10	10	10	9	9	9
	80558	79988	79418	78848	78301	77759	77218
m	323	323	323	323	323	322	322
	172	172	172	171	171	171	169
	48	48	48	48	48	47	47
	11	10	10	10	9	8	7
	102717	94409	86449	78848	71622	64744	57904