RAIRO-Oper. Res. 50 (2016) 175–188
DOI: 10.1051/ro/2015023

RAIRO Operations Research
www.rairo-ro.org

COMPETITIVE ANALYSIS OF COLLECTION BEHAVIOR BETWEEN RETAILER AND THIRD-PARTY IN THE REVERSE CHANNEL

Tzu-Chun Weng[1] and Cheng-Kang Chen[2]

Abstract. In recent years, the concerns of environmental issues are growing. Reverse logistic has received considerable attention due to potential of value recovery from the used products and noted that the first activity of the reverse logistic is to collect or acquire used products from public consumers. The front behavior in all the reverse logistics is the collections of the used products and reused of products or resources. In this paper, we investigate the correlation between the payment given to customers and the return rate of used product. A two-echelon supply chain model consisting of a manufacturer, a retailer and a third-party with product remanufacturing is based on game theory framework. We formulate the proposed problem as a profit maximization problem. Furthermore, we analyze the extensive model in which the unit price of retrieving a returned product is different and the corresponding analyses are carried out to illustrate the features of our model. Finally, we probe into the influence on third-party cost for collecting and handling used products.

Mathematics Subject Classification. 90Bxx, 90Cxx.

Received September 23, 2013. Accepted June 11, 2015.

1. Introduction

The environmental revolution has been evolved almost three decades in the world, and it has changed forever. Awareness of the world's environmental problems also increases but ideas of resource recycling are lacking These environmental issues cause many governments around the world lead the legislators to propose new laws related to environmental protection. Manufacturers are required to initiate product recovery programs in order to collect used products from the customers once those products reach their economic or useful lives [10]. Environmental legislation is becoming increasingly stringent, particularly in Europe [7], as can be seen from recent developments such as the WEEE (Waste Electronics and Electrical Equipment) and ELV (End of Life Vehicle) Directives.

In recent years, many companies have showed their responsibility not to damage the environment. Many corporate organizations have made their responsibility to reach the requirements of environmental performance in many cases. For example, the recovered products include copy and print cartridges (Xerox and Canon), copiers (Xerox), single-use cameras (Kodak), car battery (YUASA) and mobile phones (Re-Cellular). In these cases, product recovery activities are integrated as closed-loop supply chain with the product development and original manufacturing process of the products. Closed-loop supply chain has become more and more

Keywords. Reverse logistics, used products, remanufacturing, theoretical framework.

[1] Department of Information Management, National Taiwan University of Science and Technology, Taipei, Taiwan.
d9509303@mail.ntust.edu.tw

important today As environmental concerns increase and regulations on the wastage become stricter, it covers the making of a product, its life and subsequent handling processes [16]. Closed-loop supply chains, including recycling and reverse logistics, might be expected to enable businesses to meet the growing demands of corporate social responsibility and wider social goals to reduce the intensive use of resources in modern economy [9]. Oh and Hwang [22] dealt with inventory control for a recycling system and proposed inventory policies. Naeem *et al.* [20] developed a dynamic programming based on model with manufactured and remanufactured objective to determine the quantities. Santibanez-Gonzalez and Diabat [26] proposed improved Benders decomposition schemes for solving a remanufacturing supply chain design problem.

Over the last few decades, there has been an increase in the number of publications on reverse logistics. Abdallah *et al.* [1] proposed the uncapacitated closed-loop location inventory model, which captures the interdependency between location inventory decisions in the forward and reverse supply chains. Prahinski and Kocabasoglu [24] indicated that reverse logistics is the process of retrieving the product from the end consumer in order to pursue the purposes of capturing value or proper disposal. Pokharel and Mutha [23] investigated the current development in research and practice in reverse logistics. Jayant [15] addressed that reverse logistics is a process through recycling, reusing, and reducing the amount of materials to become more environmentally efficient. Kannan [17] developed a mixed integer linear model for a carbon footprint based reverse logistics network design. Alshamsi and Diabat [3] proposed a mixed-integer linear program to address the complex network configuration of a reverse logistics system.

The front behavior in all the reverse logistic is the collections of the used products and reused of products or resources. How to increase the amount of the collection is an important issue. We model the supply chain in a game theory framework. The retailer and the third-party company compete for the collection of used products in Nash equilibrium. Furthermore, we consider that the unit prices of retrieving a returned product are different from the retailer and the third-party company. The contribution of this paper consists in (a) analyzing of interactions in collection competition between retailers and third-parties, as well as of the incentives that prompt agents to invest in different reverse channel members, (b) inquiring how competition affects the payment given to the customer and the return rates of used products, we consider a two-echelon supply chain that includes one manufacturer, one retailer and a third-party company providing product remanufacturing services, (c) exploring how the result affects used product return rate and profit for the retailer and the third-party and (d) investigating the influence of the cost of third-party for the collecting and handling used products is lower than retailer.

The rest of this paper is organized as follows. In the following section, we discuss the related literature of this paper. In Section 3, basic assumptions and mathematical notation descriptions are presented. In Section 4, we formulate the problem as a profit maximization problem with the competition for collection. We extend our basic model to formulate the problem as a profit maximization problem which has different unit prices of retrieving a returned product. Then, we examine the comparison of the models and several investigation and the corresponding analyses are carried out to illustrate the features of our model in Section 5. In Section 6, we probe into the influence on the cost of third-party for collecting and handling used products. We outline the conclusion and possible directions for future research in Section 7.

2. Literature review

Remanufacturing has been a critical activity in the closed-loop supply chain. There exists an extensive literature that reviews remanufacturing green product development and supply-chain management [30,31]. Remanufacturing of used products could both save natural resources; and contribute to the sustainable development goals [5]. Remanufacturing is a process of restoring a used product to its like-new condition with a warranty It disassembles recovers products at the module or component levels [14]. Remanufacturing is the basis of profit-oriented reverse logistics in which recovered products are restored to a marketable condition in order to be resold to the primary or secondary market [4]. The worn out or obsolete components and modules are repaired or replaced. Product remanufacturing can especially be profitable if it results in as-good-as-new products or as-good-as-new parts which can be resold to consumers to satisfy demand for new products [33]. Takahashi *et al.* [32] proposed an adaptive pull strategy to improve performance of remanufacturing systems. Numerous researchers have studied the environmental benefits of remanufacturing [8] and claimed that remanufacturing can be profitable as material and energy savings can be translated into cost savings [12].

Remanufacturing used products compared to manufacturing new products requires less energy and materials, so it can benefit the environment. In addition, the profitability of remanufacturing can be increased by improving remanufacturing efficiency through design and implementing a more viable and lucrative product end-of-life strategy [11]. A variety of reverse channel formats are deployed by manufacturers [28]. The recycling systems may be different because of product characteristics and/or the structure of the supply chain. For instance, the collection of used products can be conducted by manufacturer, retailer or independent third-party. Fuji Xerox Corporation provides customers with prepaid boxes for returning used copiers or print cartridges to the company [6]. Eastman Kodak Company receives single-use cameras from large retailers that also provide for customers film developing services [18]. Third-party logistics providers such as GENCO Distribution System which is the second largest third-party logistics provider in North America, are also preferred by some consumer goods manufacturers for their experience in collecting used products [29]. A retailer collection model whereby the retailer collects end-of-life products and a non-retailer collection model whereby a third-party firm is subcontracted by the manufacturer for collection work are proposed [13].

The model of retailing competition is proposed with strategic product pricing decisions in the forward channel [27]. The optimal pricing decision problem is considered with retail competition in a fuzzy closed-loop supply chain [34]. Afterwards, the optimal decisions of the manufacturer, the retailer, and the third party are explored to examine a closed-loop supply chain in fuzzy environment over three different used products collection modes [35]. In contrast, a wide spectrum of waste IT product recycling channels is offered, able to utilize third-party resource recycling organizations, and recycling locations established at IT product retail sales sites [2]. While we specifically model the reverse channel of collection competition decisions, in the cited papers, such decisions are assumed exogenous to the model structure. Next, we present our modeling notation and describe detailed assumptions of our models.

3. Model assumptions and notation description

The goal of this paper is to deepen the understanding of the competition of collection behavior between retailers and third-party companies who both try to maximize their profits. We model that retailer and third-party collect used products in the closed-loop supply chain. In this section, we introduce the notation that will be used throughout the paper.

- c_m The unit cost of manufacturing a new product.
- c_r The unit cost of remanufacturing a returned product into a new one and, *i.e.*, $c_r < c_m c_r$ is the same for all remanufactured products and $\varDelta = c_m - c_r$.
- w The unit wholesale price from the manufacturer to retailer (decision variable for manufacturer).
- p The retail price of the product.
- A_R A fixed payment given by retailer to the customer who returns a used product (decision variable for retailer).
- A_{3P} A fixed payment given by third-party to the customer who returns a used product (decision variable for third-party).
- b The unit price of retrieving a returned product from the retailer or third-party to the manufacturer.
- $D(p)$ The demand for the new product in the market as a function of product price, $D(p) = \varphi - \beta p$, in which φ is the maximum demand of new products and β is the price sensitivity to affect the decrease in demand for a unit increase in price p (decision variable for retailer).
- τ_R The return rate of used products from the customers to retailer, $\tau_R = \theta - \delta(A_R - \rho A_{3P})$. θ represents the market size of retailer and third-party for collection of used-products. δ and ρ denote the product substitution effect.

τ_{3P} The return rate of used products from the customers to third-party $\tau_{3P} = \theta - \delta(A_{3P} - \rho A_R)$. θ represents the market size of retailer and third-party for collection of used-products. δ and ρ denote the product substitution effect.

II^i The profit function for channel member i in the supply chain. Channel members denote the manufacturer, the retailer, and the third-party, respectively and take values M, R, and 3P. Then, the T means the total profit of the supply chain members.

The following assumptions are made in developing the proposed model:

1. In this paper, we focus on behavior of collection used products. The planning horizon is infinity and the closed-loop supply chain decisions are considered in a single-period setting. We assume the previous existence of the product in the market. Product sales is smooth and in a stable state. Those products sold in the previous periods can be returned to the manufacturer. Finally, we can analyze and investigate the average supply chain profits per period when similar products are introduced to the market repeatedly Previous research has used similar suppose [13, 27].
2. The manufacturer has incorporated a remanufacturing process for used products and the quality of remanufactured products is the same as of new products. Manufacturer remanufactures part or whole of a returned unit into a new product, so the unit cost of remanufacturing a returned product is less than the unit cost of manufacturing a new product. Both new products and remanufactured products are sold the same price for consumers. The consumers can't distinguish difference between new products and remanufactured products.
3. We consider that the demand is a function of the retailing price of the product. Specifically, the demand rate is assumed to be a linear function of the retailing price The demands for products in the market and the profits of all channel members are both positive. $D(p) = \varphi - \beta p$, with φ and β being positive parameters and $D(p) > 0$. There are numerous researchers who set the demand as a price-dependent function [25, 28, 35].
4. We characterize the return rates of used products from the customers by τ_{R} and τ_{3P} which denotes the fraction of current generation products remanufactured from returned units and should satisfy $0 \leqslant \tau_{\mathrm{R}} \leqslant 1, 0 \leqslant \tau_{3P} \leqslant 1$, and $0 \leqslant \tau_{\mathrm{R}} + \tau_{3P} \leqslant 1$ We collect the used products come from the consumers. When the summation of return rate is 100%, it means that all products which were sold to consumers were collected. There are many researches indicated that return rate is between zero and one hundred percent [13, 28, 36]. The optimal solution should satisfy the two constraints.
5. The Stackelberg model is a strategic game in economics. There are two roles including leader and follower in the model. The leader has sufficient market power over the reaction function of the follower to decide the optimal amounts. The Stackelberg leader is sometimes referred to as the Market Leader. We assume that the manufacturer is the leader and the retailer and third-party are followers. The manufacturer has sufficient channel power over the retailer and the third-party to act as a Stackelberg leader picking its output level And then other followers are free to choose their optimal profits given their knowledge of the leader's output in the supply chain model with remanufacturing.

4. Supply chain model with the competition behavior of collection

In this section, we present the supply chain model where the collection of used products is contracted by the manufacturer to a retailer and a third-party who both are engaged in the collection of used products from the market. The retailer and the third-party compete for the collection of used products. The manufacturer can manufacture a new product directly from raw materials and incorporate a remanufacturing process for used products into original production system to remanufacture part or whole of a returned unit into a new product. The retailer distributes new products to consumers and engages in the promotion and collection of used products. Third party is engaged only in the collection of the used products from the market. The forward and reverse flows of closed-loop supply chain are shown as Figure 1.

Based on the decision-making systems, the manufacturer being the Stackelberg leader decides the wholesale price w. For a given w, the retailer decides the retail price p and the fixed payment A_R and the third-party

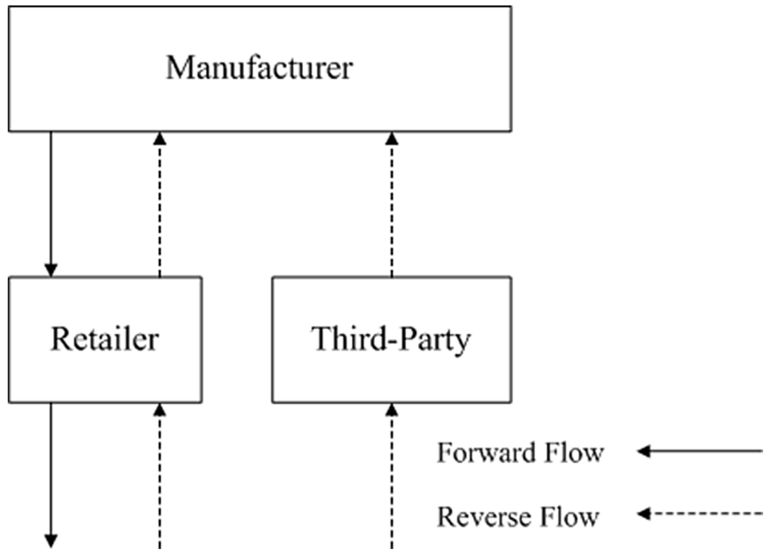

FIGURE 1. The forward and reverse flows of closed-loop supply chain.

decides the fixed payment A_{3P}. In competing behavior, the third-party maximizes its profits to determine the fixed payment given by third-party to the customer who returns a used product. The retailer maximizes its profits to determine the fixed payment given by retailer to the customer who returns a used product. The third-party planner optimizes

$$\max_{A_{3P}} \Pi^{3P}(A_{3P}) = b\tau_{3P}(\phi - \beta p) - A_{3P}\tau_{3P}(\phi - \beta p). \tag{4.1}$$

The retailer planner optimizes

$$\max_{A_R, p} \Pi^{R}(A_R, p) = (p - w)(\phi - \beta p) + b\tau_R(\phi - \beta p) - A_R\tau_R(\phi - \beta p). \tag{4.2}$$

In order to solve the proposed nonlinear programming problem (4.1) and (4.2), we take the first partial derivatives of equation (4.1) with respect to A_{3P} and equation (4.2) with respect to A_R, respectively. The corresponding first order necessary conditions are given by equations (4.3) and (4.4)

$$\frac{\partial \mathrm{Max}\Pi^{3P}(A_{3P})}{\partial A_{3P}} = (b\delta\rho - 2\delta\rho A_{3P} - \theta + \delta A_R)(\phi - \beta p) = 0 \tag{4.3}$$

$$\frac{\partial \mathrm{Max}\Pi^{R}(A_R, p)}{\partial A_R} = (b\delta\rho - 2\delta\rho A_R - \theta + \delta A_{3P})(\phi - \beta p) = 0. \tag{4.4}$$

By solving the set of equations (4.3) and (4.4) simultaneously, we can have the optimal A_{3P}^* and A_R^*, which are expressed in equations (4.5) and (4.6)

$$A_{3P}^* = \frac{\delta\rho b - \theta}{\delta(2\rho - 1)}, \tag{4.5}$$

$$A_R^* = \frac{\delta\rho b - \theta}{\delta(2\rho - 1)}. \tag{4.6}$$

The retailer maximizes its profits for a given A^*_{3P} and A^*_R. We take the first partial derivatives of equation (4.4) with respect to p. The corresponding first order necessary condition (F.O.N.C) is given by equation (4.7)

$$\frac{\partial \mathrm{Max} \Pi^R (A_R, p)}{\partial p} = \phi - 2\beta p + \beta w - \beta (b - A_R)(\theta - \delta (A_{3P} - \rho A_R)) = 0 \tag{4.7}$$

Because the objective function is concave in p, the retailer's first-order condition characterizes the best response is:

$$p^* = \frac{\phi}{2\beta} + \frac{w - (b - A^*_R)(\theta - \delta (A^*_{3P} - \rho A^*_R))}{2} \tag{4.8}$$

The manufacturer's problem can be stated as:

$$\underset{w}{\mathrm{Max}}\ \Pi^M (w) = (w - c_m + \Delta (\tau_R + \tau_{3P}))(\phi - \beta p) - (b\tau_R + b\tau_{3P})(\phi - \beta p) \tag{4.9}$$

From the concavity of the objective functions, the best response functions are determined by the simultaneous solution of first-order conditions for p^*, A^*_R and A^*_{3P}. Given p^*, A^*_R and A^*_{3P}, the manufacturer optimizes the profit. The optimal value of the wholesale price can then be used to compute the profits for the manufacturer. The manufacturer's profits are given by

$$\Pi^{M^*} = \frac{\beta}{2}\left(\frac{(\phi - \beta c_m) + \beta b\theta}{2\beta} + \frac{\rho(\Delta - b) Z}{Y} - \frac{X(\delta bY - \rho X)}{2\delta Y^2}\right)^2. \tag{4.10}$$

The optimal value of w^*, p^*, A^*_R and A^*_{3P} are given by

$$w^* = \frac{(\phi + \beta c_m) + \beta b\theta}{2\beta} - \frac{\rho(\Delta - b) Z}{Y} - \frac{X(\delta bY - \rho X)}{2\delta Y^2}, \tag{4.11}$$

$$p^* = \frac{(3\phi + \beta c_m) - \beta b\theta}{4\beta} - \frac{\rho(\Delta - b) Z}{2Y} + \frac{X(\delta bY - \rho X)}{4\delta Y^2}, \tag{4.12}$$

$$A^*_{3P} = \frac{X}{\delta Y}, \tag{4.13}$$

$$A^*_R = \frac{X}{\delta Y}, \tag{4.14}$$

$$\tau_R = \tau_{3P} = \frac{\theta\rho + \delta\rho b(\rho - 1)}{(2\rho - 1)}. \tag{4.15}$$

According to Assumption 4, we have two constrains. Which are showed as follow

$$\theta\rho + \delta\rho b(\rho - 1) > 0 \text{ and } 2\rho - 1 > 2(\theta\rho + \delta\rho b(\rho - 1))$$

With the optimal values of w^*, p^*, A^*_R and A^*_{3P}, we have the retailer's and third-party's profits given by

$$\begin{aligned}\Pi^{R^*} = &\left(\frac{(\phi - \beta c_m) + \beta b\theta}{4\beta} - \frac{\theta X}{\delta Y} + \frac{(4 - 7\rho) X^2}{4\delta Y^2} + \frac{b(4\rho - 1) X + 2\rho(\Delta - b) Z}{4Y}\right)\\ &\times\left(\frac{(\phi - \beta c_m) + \beta b\theta}{4} + \frac{\beta\rho(\Delta - b) Z}{2Y} - \frac{\beta X(\delta bY - \rho X)}{4\delta Y^2}\right),\end{aligned} \tag{4.16}$$

$$\begin{aligned}\varPi^{3P^*} = &\left(b\theta - (\delta b(1-\rho)+\theta)\left(\frac{X}{\delta Y}\right) + \delta(1-\rho)\left(\frac{X}{\delta Y}\right)^2\right)\\ &\times\left(\frac{(\phi-\beta c_m)+\beta b\theta}{4} + \frac{\beta\rho X^2}{4\delta Y^2} + \frac{\beta(2\rho(\varDelta - b)Z - bX)}{4Y}\right),\end{aligned} \tag{4.17}$$

$$X = \delta\rho b - \theta \tag{4.18}$$

$$Y = 2\rho - 1 \tag{4.19}$$

$$Z = \theta - \delta b(1-\rho) \tag{4.20}$$

The following proposition states that the point (A_R^*, p^*) is the optimal solution such that total profit for retailer is maximized

Proposition 4.1. *The Hessian Matrix for equation* (4.2) *is negative definite at point.*

(A_R^*, p^*). The point (A_R^*, p^*) is a local maximum of equation (4.2)

Proof. The Hessian matrix $\mathbf{H}$ is obtained as shown in equation (4.21)

$$\mathbf{H} = \begin{bmatrix} \frac{\partial^2 \varPi^R(A_R,p)}{\partial A_R^2} & \frac{\partial^2 \varPi^R(A_R,p)}{\partial A_R \partial p} \\ \frac{\partial^2 \varPi^R(A_R,p)}{\partial A_R \partial p} & \frac{\partial^2 \varPi^R(A_R,p)}{\partial p^2} \end{bmatrix}. \tag{4.21}$$

The first principal minor of the Hessian matrix $\mathbf{H}$ is expressed as equation (4.22)

$$|H_{11}| = \frac{\partial^2 \varPi^R(A_R,p)}{\partial A_R^2} = -2\delta\rho(\phi - \beta p) < 0. \tag{4.22}$$

The second principal minor of the Hessian matrix $\mathbf{H}$ can be expressed as equation (4.23)

$$\begin{aligned}|H_{22}| &= \frac{\partial^2 \varPi^R(A_R,p)}{\partial A_R^2}\frac{\partial^2 \varPi^R(A_R,p)}{\partial p^2} - \left(\frac{\partial^2 \varPi^R(A_R,p)}{\partial A_R \partial p}\right)^2\\ &= -2\beta(-2\delta\rho(\phi-\beta p)) - (\beta(\theta - \delta(A_{3P} - \rho A_R) - \delta\rho(b - A_R)))^2 > 0\end{aligned} \tag{4.23}$$

Since the first principal minor is negative and the second principal minor is positive, the Hessian Matrix (4.21) is negative definite. We note that Proposition 4.1 also shows the point (A_R^*, p^*) is a local maximum of equation (4.2). □

5. Differential with the unit price of retrieving a returned product

In reality, the manufacturer may formulate a different contract following its strategy/planning with regard to retailer or a third-party for the collection of used products from the market. This section considers that the unit prices of retrieving a returned product from the retailer and third-party to the manufacturer are different.

Based on the basic model assumptions and notation, the extend model presents different unit prices of retrieving a returned product from the retailer and third-party to the manufacturer. We denote b_R unit price from the retailer and b_{3P} unit price from the third-party. The third-party planner optimizes

$$\operatorname*{Max}_{A_{3P}} \Pi^{3P}(A_{3P}) = b_{3P}\tau_{3P}(\phi - \beta p) - A_{3P}\tau_{3P}(\phi - \beta p). \tag{5.1}$$

The retailer planner optimizes

$$\operatorname*{Max}_{A_R,p} \Pi^{R}(A_R, p) = (p - w)(\phi - \beta p) + b_R\tau_R(\phi - \beta p) - A_R\tau_R(\phi - \beta p). \tag{5.2}$$

The manufacturer's problem can be stated as

$$\operatorname*{Max}_{w} \Pi^{M}(w) = (w - c_m + \Delta(\tau_R + \tau_{3P}))(\phi - \beta p) - (b_R\tau_R + b_{3P}\tau_{3P})(\phi - \beta p). \tag{5.3}$$

From the concavity of the objective functions, the best response functions are determined by the simultaneous solution of first-order conditions for p, A_R and A_{3P}. Given p, A_R and A_{3P}, the manufacturer optimizes the profit. The optimal value of the wholesale price can then be used to compute the profits for the manufacturer. The optimal values of w, p, A_R and A_{3P} given by

$$A_{3P^*} = \frac{2b_{3P}\delta\rho^2 + b_R\delta\rho - \theta(2\rho + 1)}{\delta(4\rho^2 - 1)}, \tag{5.4}$$

$$A_R^* = \frac{2b_R\delta\rho^2 + b_{3P}\delta\rho - \theta(2\rho + 1)}{\delta(4\rho^2 - 1)}, \tag{5.5}$$

$$w^* = \frac{\phi + \beta c_m}{2\beta} + \frac{(b_R + b_{3P} - A_R^* - \Delta)(\theta - \delta(A_{3P}^* - \rho A_R^*)) - (\Delta - b_R)(\theta - \delta(A_R^* - \rho A_{3P}^*))}{2} \tag{5.6}$$

$$p^* = \frac{\phi}{2\beta} + \frac{w^* - (b_R - A_R^*)(\theta - \delta(A_{3P}^* - \rho A_R^*))}{2}. \tag{5.7}$$

We compare the return rate of used products for the two models and conduct sensitivity analysis to investigate how the changes in parameters affect the profit in the two models. The channel member seeks to maximize its profit but the channel structure designer, for example, the manufacturer, may focus on the return rate of a closed-loop supply chain. Based on the results, some interesting observations can be made about performance.

The return rate of used products with retailer and third-party for the basic model can be stated as

$$\tau_{3P}^{\text{Basic}^*} = \frac{\theta\rho + \delta\rho b(\rho - 1)}{(2\rho - 1)}, \tag{5.8}$$

$$\tau_{R}^{\text{Basic}^*} = \frac{\theta\rho + \delta\rho b(\rho - 1)}{(2\rho - 1)}, \tag{5.9}$$

The return rate of used-products with retailer and third-party for the extended model can be stated as

$$\tau_{3P^{\text{Extend}^*}} = \frac{\theta\rho(2\rho + 1) - b_R\delta\rho^2 + b_{3P}\delta\rho\left(2\rho^2 - 1\right)}{(4\rho^2 - 1)}, \tag{5.10}$$

$$\tau_{R^{\text{Extend}^*}} = \frac{\theta\rho(2\rho + 1) - b_{3P}\delta\rho^2 + b_R\delta\rho\left(2\rho^2 - 1\right)}{(4\rho^2 - 1)}. \tag{5.11}$$

We compare the total return rate with retailer and third-party from the two models which can be showed as

$$\left(\tau_{3P^{\text{Basic}^*}} + \tau_{R^{\text{Basic}^*}}\right) - \left(\tau_{3P^{\text{Extend}^*}} + \tau_{R^{\text{Extend}^*}}\right) = \frac{((b_{3P} - b) + (b_R - b))\delta\rho(\rho - 1)}{(2\rho - 1)}. \tag{5.12}$$

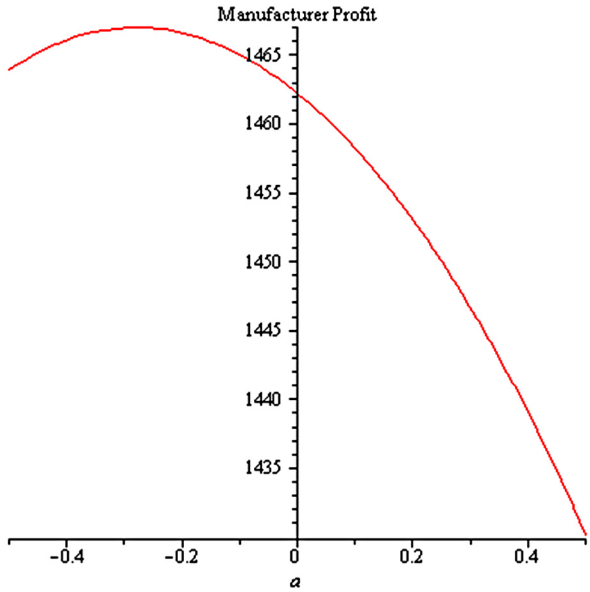

FIGURE 2. The optimal profit of manufacturer on the variation with the unit price of retrieving a returned product.

Observation 1. If the summation of the unit price of retrieving a returned product from the retailer and third-party which manufacturer pay in the basic model is the same as in the extended model, the summations of the total return rate with retailer and third-party from the two models are equivalent.

This research undertakes numerical example that examine the total profits and the return rates by adjusting parameters b_R, and b_{3P}. We assume that the summation of the unit price of retrieving a returned product in the basic model is the same as in the extended model which means that $2b = b_R + b_{3P}$. We provide numerical examples to illustrate the features of the proposed model. The values of parameters are $c_m = 15$, $c_r = 8$, $b = 3, \varphi = 1000$, $\beta = 30$, $\theta = 0.3$, $\delta = 0.5$ and $\rho = 0.9$. We change the unit price of retrieving a returned product $b_R = 3 - a$ and $b_{3P} = 3 + a$, a from -0.5 to 0.5, then the optimal profit of manufacturer in the extended model considered in this paper can be shown in Figure 2.

Observation 2. When the manufacturer gives the total amount of the unit price of retrieving a returned product to the retailer and third-party unchanged, $b_R + b_{3P} = 2b$. In order to obtain the optimal profit, the manufacturer should give the retailer more than third-party

From looking the trend of Figure 2, the optimal profit of the manufacturer is located in the area of $a < 0$. It illustrates the manufacturer does not change the total amount of the unit price of retrieving a returned product to the retailer and third-party, only change the individual unit price of retrieving a returned product. The more unit price the retailer obtains, the more profit the manufacturer achieves.

We provide numerical examples to illustrate the features of the proposed model. All the parameters are the same as in the above example. We change the unit price of retrieving a returned product $b_R = 3 - a$ and $b_{3P} = 3 + a$, a from -0.5 to 0.5, and the comparison of the optimal total profit with the two models considered in this paper can be shown in Figure 3.

As a benchmark case, the basic model is compared to analyze the influence on the variation with the unit price of retrieving a returned product with retailer and third-party for the extended model.

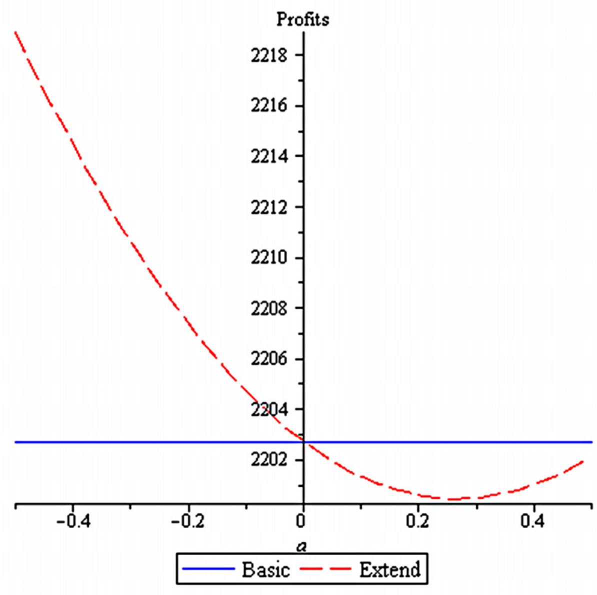

Figure 3. The total profits on the variation with the unit price of retrieving a returned product.

Observation 3. Based on the condition that the unit price of retrieving a returned product should be higher than the fixed payment given to the customer who returns a used product, the unit price of retrieving a returned product from the retailer increases, and then the optimal total profits for all channel members increase.

The analysis shows that the retailer which is closer to the demand can efficiently reflect unit cost savings from remanufacturing to the final price of the product. When the manufacturer sets for the retailer a higher unit price for retrieving a returned product, the retailer can jointly optimize the investment in used products collection more than third-party. Under the condition of the retailer and third-party do the product collection activity, if the cost structure is the same, it provides the better profit model when the retailer does the collection. This study approximately the same as the previous scholars [13,28]. Under this model, the contribution of third-party in the entire channel is gradually decline In reality, there are many case that third-party does the collection because the cost structure of third-party is consequently lower than the retailer's and the third-party can possess more high coordination ability, enabling it to manage efficiently the flow of goods. Next section, we are going to discuss the cost structure issue

The product demand from customers is influenced by the retail price of the product. In strategy, the cost of retailer is decreased more and more, the retailer can be willing to reduce the retail price to increase product demand. In addition, the product demand increases, the unit cost savings from remanufacturing can be efficiently reflected and the total profits will be increased.

Next, in the same way, we change the unit price of retrieving a returned product $b_R = 3 - a$ and $b_{3P} = 3 + a$, a from -0.3 to 0.3, then the return rate of used products with retailer and third-party in the extended model can be shown in Figure 4.

Figure 4 demonstrates the result that the unit price of retrieving a returned product increases and then the return rate of used-products increases.

Observation 4. If the unit price of retrieving a returned product increases, the retailer or the third-party will increase the fixed payment to the customer who returns a used product to increase the return rate of used-products.

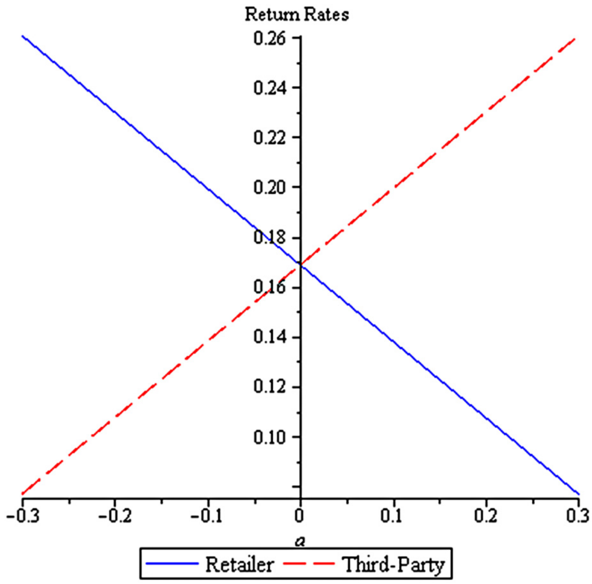

FIGURE 4. The return rates on the variation with the unit price of retrieving a returned product.

6. Influence on third-party cost

According to above result, we know that third-party has less competition if retailer and third-party based on the same market condition with collection behavior. However, it is always that the third-party cost structure is consequently lower than the retailer's [19]. The third-party possesses high coordination ability, enabling it to manage efficiently the flow of goods [21].

In this section, we consider that the third-party who has lower cost than the retailer to handle a returned unit can get the same return rates of used products from the customers as the retailer. The fixed payment is not only a variable unit cost of collecting but also a variable unit cost of handling a returned unit [28]. We define that A_R and A_{3P} denote the summation of a fixed payment given to the customer who returns a used product and a handling cost for a returned unit. The return rates of the retailer and the third-party are based on original assumption but the third-party can pay less for collecting and handling.

Based on the assumption, we consider that collecting and handling cost for the third-party is rA_{3P}. r denotes the fraction of collecting and handling cost and should satisfy $0 \leqslant r \leqslant 1$. We can define that total cost for collecting and handling is $rA_{3P}\tau_{3P}D(p)$. The third-party planner optimizes

$$\underset{A_{3P}}{\text{Max}}\ \Pi^{3P}\left(A_{3P}\right) = b\tau_{3P}\left(\phi - \beta p\right) - rA_{3P}\tau_{3P}\left(\phi - \beta p\right) \tag{6.1}$$

The retailer planner optimizes

$$\underset{A_R,p}{\text{Max}}\ \Pi^{R}\left(A_R, p\right) = \left(p - w\right)\left(\phi - \beta p\right) + b\tau_R\left(\phi - \beta p\right) - A_R\tau_R\left(\phi - \beta p\right). \tag{6.2}$$

The manufacturer's problem can be stated as

$$\underset{w}{\text{Max}}\ \Pi^{M}\left(w\right) = \left(w - c_m + \Delta\left(\tau_R + \tau_{3P}\right)\right)\left(\phi - \beta p\right) - \left(b\tau_R + b\tau_{3P}\right)\left(\phi - \beta p\right). \tag{6.3}$$

We determine the best response by the simultaneous solution of first-order condition for p, A_R and A_{3P} from the concavity of the objective functions. The manufacturer optimizes the profit by given p, A_R and $A_{3P.}$ The optimal

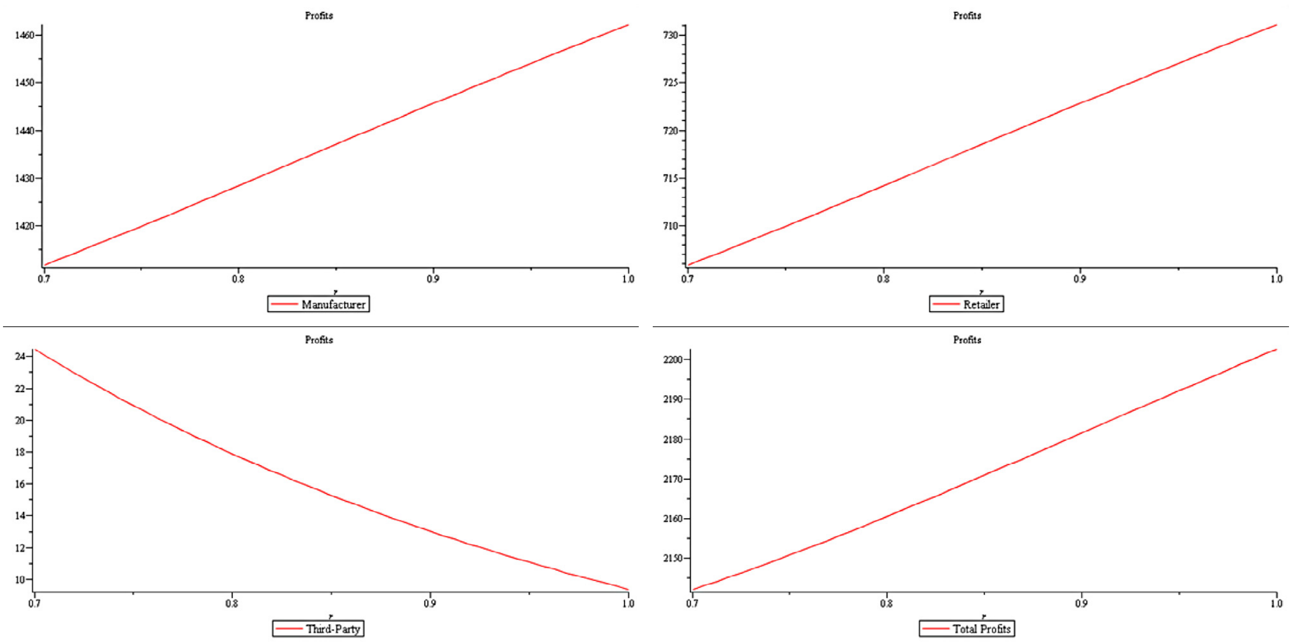

FIGURE 5. The trend with the optimal profits of the supply chain channel members and the demand rate.

value of the wholesale price can then be used to compute the profits for the manufacturer. The optimal values of w, p, A_R and A_{3P} given by:

$$w^* = \frac{(\phi + \beta c_m) + \beta b\theta}{2\beta} - \frac{\rho\,(\Delta - b)\,Z}{Y} - \frac{X\,(\delta bY - \rho X)}{2\delta Y^2}, \tag{6.4}$$

$$p^* = \frac{\phi}{2\beta} + \frac{w^* - (b - A_R^*)\,(\theta - \delta\,(A_{3P}^* - \rho A_R^*))}{2}, \tag{6.5}$$

$$A_{3P}^* = \frac{\delta\rho b\,(2\rho + r) - r\theta Y}{r\delta\,(4\rho^2 - 1)}, \tag{6.6}$$

$$A_R^* = \frac{X}{2\delta\rho} + \frac{\delta\rho b\,(2\rho + r) - r\theta\,(2\rho + 1)}{2r\delta\rho\,(4\rho^2 - 1)} \tag{6.7}$$

We provide numerical examples to illustrate the features of the proposed model. The values of parameters are $c_m = 15$, $c_r = 8$, $b = 3$, $\varphi = 1000$, $\beta = 30$, $\theta = 0.3$, $\delta = 0.5$ and $\rho = 0.9$. We change the fraction of collecting and handling cost $r$from 0.9 to 1 and then the trend with the optimal profits of the supply chain channel members and the demand rate can be shown in Figure 5.

Observation 5. If the third-party can efficiently decrease the fixed payment given to the customer who returns a used product and handling cost for a returned unit to obtain the equal return rate of used products, the profit of third-party can increase.

When the third-party can spend less for collecting and handling used products to achieve the higher return rate, the profit can be increased. As a results, profit for the retailer and manufacturer will decrease. The retailer and third-party compete for the collection of used products. When the third-party has an advantageous position, the retailer is not willing to make effort for collection. The retailer can not be by way of retrieving the used products to decrease cost, so the retail price of the product will increase and the result brings about decrease on the demands of products. Finally, the profit of manufacturer will decrease.

7. Conclusions and future research

In this paper, we consider that there is no distinction between a remanufactured and a manufactured product. In order to inquire how competition affects the payment given to the customer, and the return rates of used products, we consider a two-echelon supply chain that includes one manufacturer, one retailer and a third-party company providing product remanufacturing services. We model the supply chain in a game theory framework. The retailer and third-party compete for the collection of used products in Nash equilibrium.

Next, we consider that the unit prices of retrieving a returned product are different between retailer and third-party We explore how the result affects the total profits and the return rates of used products. We analyze the influence on the variation with the unit price of retrieving a returned product with retailer and third-party for the extend model. In addition, we consider that the third-party company has a lower cost to handle a returned unit than the retailer. The return rates of the retailer and the third-party are of the same cost structure, but the third-party can pay less for collecting and handling. We probe into the influence on third-party cost for collecting and handling used products.

In this paper, we consider some assumptions in order to deal with and analyze easily Afterwards, we can relax some assumptions in the future research. The problem proposed in this paper could be extended by considering that the investments in collection activities for retailer and third-party are different. Probably, we can assume that the structure of the product demand is non-linear. Furthermore, the proposed problem can be extended to consider that government plays a role of a social planner and affects the decisions.

References

[1] T. Abdallah, A. Diabat and D. Simchi-Levi, Sustainable supply chain design: a closed-loop formulation and sensitivity analysis. *Prod. Plan. Control* **23** (2012) 120–133.

[2] Acer, Product Recycling, Acer Corporation (2012).

[3] A. Alshamsi and A. Diabat, A reverse logistics network design. *J. Manuf. Syst.* (2015) Doi:10.1016/j.jmsy.2015.02.006.

[4] A. Diabat, T. Abdallah, A. Al-Refaie, D. Svetinovic and K. Govindan, Strategic closed-loop facility location problem with carbon market trading. *IEEE Trans. Eng. Manage.* **60** (2013) 398–408.

[5] I. Dobos and A. Floriska, The efficiency of remanufacturing in a dynamic input-output model. *Cent. Eur. J. Oper. Res.* **16** (2008) 317–328.

[6] Fuji Xerox, Corporation Environmental Report 2002. Fuji Xerox Corporation (2002).

[7] V. Guide, T. Harrison and L.N. Van Wassenhove, The challenge of closed-loop supply chains. *Interfaces* **33** (2003) 3–6.

[8] T. Gutowski, S. Sahni, A. Boustani and S. Graves, Remanufacturing and energy savings. *Environ. Sci. Technol.* **45** (2011) 4540–4547.

[9] S.L. Hart, Beyond greening: strategies for a sustainable world. *Harvard Business Review* (1997) 66–76.

[10] P. Hasanov, MY Jaber and S. Zolfaghari, Production, remanufacturing and waste disposal models for the cases of pure and partial backordering. *Appl. Math. Model.* **36** (2012) 5249–5261.

[11] G.D. Hatcher, W.L. Ijomah and J.F.C. Windmill, Design for remanufacture: a literature review and future research needs. *J. Clean. Prod.* **19** (2011) 2004–2014.

[12] H. Heese, K. Cattani, G. Ferrer, W. Gill and A Roth, Competitive advantage through take-back of used products. *Eur. J. Oper. Res.* **164** (2005) 143–157.

[13] I.H. Hong and J.S. Yeh, Modeling closed-loop supply chains in the electronics industry: A retailer collection application. *Transp. Res. Pt. E-Logist. Transp. Rev.* **48** (2012) 817–829.

[14] W.A. Ijomah, Model-Based Definition of the Generic Remanufacturing Business Process. The University of Plymouth (2002).

[15] A. Jayant, Reverse logistics: perspectives, empirical studies and research directions. *Int. J. Ind. Eng.* **19** (2012) 369–388.

[16] G. Kannan, P. Sasikumar and K. Devika, A genetic algorithm approach for solving a closed loop supply chain model: A case of battery recycling. *Appl. Math. Model.* **34** (2010) 655–670.

[17] D. Kannan, A. Diabat, M. Alrefaei, K. Govindan and G. Yong, A carbon footprint based reverse logistics network design model. *Resources Conservation and Recycling* **67** (2012) 75–79.

[18] Kodak Corporation, Kodak Park Environmental Annual Report. Kodak Corporation (2006).

[19] Kodak Service and Support, Advantages of third-party maintenance. Kodak Corporation (2010).

[20] M.A. Naeem, D.J. Dias, R. Tibrewal, P.C. Chang and M.K. Tiwari, Production planning optimization for manufacturing and remanufacturing system in stochastic environment. *J. Intell. Manuf.* **24** (2013) 717–728.

[21] T. Nemoto and K. Tezuka, Advantage of Third Party Logistics in Supply Chain Management. Graduate School of Commerce and Management, Hitotsubashi University (2002).

[22] Y.H. Oh and H. Hwang, Deterministic inventory model for recycling system. *J. Intell. Manuf.* **17** (2006) 423–428.

[23] S. Pokharel and A. Mutha, Perspectives in reverse logistics: a review. *Resources Conservation and Recycling* **53** (2009) 175–182.

[24] C. Prahinski and C. Kocabasoglu, Empirical research opportunities in reverse supply chains. *Omega* **34** (2006) 519–532.

[25] M.S. Sajadieh and M.R. Akbari Jokar, Optimizing shipment, ordering and pricing policies in a two-stage supply chain with price-sensitive demand. *Transport Res. E* **45** (2009) 564–571.

[26] E.D. Santibanez-Gonzalez and A. Diabat, Solving a reverse supply chain design problem by improved Benders decomposition schemes. *Comput. Ind. Eng.* **66** (2013) 889–898.

[27] R.C. Savaskan and L.N. Van Wassenhove, Reverse channel design: The case of competing retailers. *Manage. Sci.* **52** (2006) 1–14.

[28] R.C. Savaskan, S. Bhattacharya and L.N. Van, Wassenhove Closed-loop supply chain models with product remanufacturing. *Manage. Sci.* **50** (2004) 239–253.

[29] Seegrid Corporation, GENCO Supply Chain Solutions. Seegrid Corporation (2008).

[30] S. Srivastava, Green supply-chain management: a State-of-the-art literature review. *Int. J. Manage. Rev.* **9** (2007) 53–80.

[31] R. Subramoniam, D. Huisingh and R.B. Chinnam, Remanufacturing for the automotive aftermarket-strategic factors: literature review and future needs. *J. Clean Prod.* **17** (2009) 1163–1174.

[32] K. Takahashi, Y. Doi, D. Hirotani and K. Morikawa, An adaptive pull strategy for remanufacturing systems. *J. Intel. Manuf.* (2012) 1–17.

[33] R.H. Teunter, Economic order quantities for stochastic discounted cost inventory systems with remanufacturing. *Int. J. Logistics Res. Appl.* **5** (2002) 161–175.

[34] J. Wei and J. Zhao, Pricing decisions with retail competition in a fuzzy closed-loop supply chain. *Expert Syst. Appl.* **38** (2011) 11209–11216.

[35] J. Wei and J. Zhao, Reverse channel decisions for a fuzzy closed-loop supply chain. *Appl. Math. Model.* **37** (2013) 1502–1513.

[36] C.H. Wu, Price and service competition between new and remanufactured products in a two-echelon supply chain. *Int. J. Prod. Econ.* **140** (2012) 496–507.