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Coordinations Policy for Collector, Re-manufacturer and Retailer in Decentralize Scenario with Complete Information

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Abstract

Reverse supply chain management and re-manufacturing play a significant role in the real life. In this paper we developed coordinations policy for reverse supply chain which consists collector, retailer and re-manufacture assuming supply of used product depends on acquisition price and demand of used product depends on retail price. The paper deals the problem of how to manage acquisition, acquisition wholesale, wholesale and retailing price in a decentralized reverse supply chain to optimize of all member of supply chain incorporating holding cost which assumed different rates in different stages. A mathematical model is developed under complete information scenario. We have illustrated the model by numerical example and also analyze by analytically and graphically.

Key Words and Phrases: Reverse supply chain, complete information, net profit, holding cost, acquiring price.

AMS Subject Classification: 90B05, 90B30, 90B50 [1]

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1 Introduction

There are many product/items in the world that can be re-manufacturer after less/minor efforts other than manufacturer new one and increasing awareness of consumer's with environment causes many business organizations. Firm, practitioner researcher have attracted to develop literature and theories to achieve their goals. Therefore a lot of literature are available on reverse supply chain management. But there is no literature available for considering holding cost and three layer supply chain which formed by collector, retailer and re-manufacturer (Here working of collector and retailer is independent).

Specially in this model our attention is going with the following basic questions:
(1) What should be the acquisition price and effort level in the reverse supply chain for collector, according to the supply of used product from end consumer ?
(2) What should be the acquisition wholesale price and wholesale price of used and re-manufactured product in the reverse supply chain for re-manufacturer, according to the supply of used product and demand of re-manufactured product respectively ?
(3) What should be the retailing prices of re-manufactured in the supply chain for retailers, according to the demand of re-manufactured product in the market ?
We review the following literature, Savaskan *et al.* (2004) developed model for closed loop supply chain in which re-manufacturing of used product considering the collection of used product, is collect by re-manufacturer in three different methods (i) used product is collected by re-manufacturer directly from end users (ii) used product is collected by retailer form end users (iii) used product is collected by third party from end users. Lau *et al.* (2005) developed a two layer supply chain gaming model in which they studied many implausible effects of demand pattern, how can change the demand pattern considering symmetric information and deterministic game structure. Yang *et al.* (2006) developed model for pricing and quantity decisions of a two layer echelon system considering duopolistic retailers in various competitive behaviors. Authors considered a stackelberge pattern between two echelon which formed by single manufacturer, who work as leader and two competitive retailers.

Bakal *et al.* (2006) developed a price sensitive supply and demand model for automotive parts re-manufacturing industry. The authors assuming that at the end of product life, a certain part of product can be re-manufactured/recycled for reuse. For this they find optimal acquisition price of used product and retailing price of re-manufactured/recycled parts. Savaskan *et al.* (2006) developed two structure of reverse supply chain, first one is direct collection of used product system in which used product is directly collected by manufacturer from end consumer, second one is indirect collection used product system in which retailer work as a collector of used product form end users.

Dai *et al.* (2007) designed a model for manufacture who arrange a single product to multiple suppliers. Authors developed an acquisition policy in limited time period. Daniel *et al.* (2007) proposed a model for closed loop supply chains with a strong business view, they focused on profitable value recovery from returned products and evaluate of research in this area over the last 15 years. Karakayali *et al.* (2007) designed the reverse supply chain model durable goods industries in which they analyzed decentralized collection and and processing operations for end of life of life products. They consider a particular part is dismantled and re-manufactured and remainder of the product is processed for part and material recovery incorporating price sensitive demand of re-manufactured product. Johan *et al.* (2008) developed seven different types of closed loop supply chain for collecting cores for re-manufacturing of used product. The supply chains are categorized as ownership- based, service-contract, direct-order, deposit-based, credit-based, buy-back and voluntary based. A theory is built around this different types of supply chain relationships and several advantage/ disadvantage are given by authors

Chung *et al.* (2011) developed integrated supply chain model in which they investigated green products design and efforts of re-manufacturing in short life cycle. Giovanni *et al.* (2014) developed closed-loop supply chain in which re-manufacturer returns the residual value of used product and also re-manufacturer outsources of used product from either retailer or any third party. Further extensive analysis is presented by authors. Galbreth et al. (2010) developed a model in which they analyzed the trendoff of acquisition and scrapping cost vs re-manufacturing costs when acquiring conditions of used product are varying and uncertain. They also derived optimal acquisition quantity that optimized the re-manufacturing cost.

Esmaeili et al. (2010) designed a seller buyer supply chain model in non cooperative and cooperative schemes with deterministic and symmetric information pattern. in this article several seller-buyer supply chain models are developed with asymmetric information. Numerical examples are presented including sensitive analysis by authors. Hong *et al.* (2011) suggested a retailer and third party collection model in which retailer and third party collect end-of-life product however manufacturer prefer the third party collection model. For this they have developed a closed loop supply chain in the electronic industry. they also suggested E. waste create a major and critical environment problem it can be minimized by recovery increment from the waste through reverse supply chain. Sharma *et al.* (2012) presented reverse supply chain model in which recovery/recycling process of e-waste is designed for decreasing environmental issue. A complete framework is proposed for end of life computer recycling operations by authors. Authors identified that factor which mainly affects for implementing computer recycling operations Govindan *et al.* (2013)introduced a revenue sharing contract in reverse supply chain coordination model which is designed for personal computer industry. Study explored an analytical model to make the implication of recycling on the reverse supply chain.

Atasu *et al.* (2013) studied the effect of collection cost structure on reverse supply channel when manufacturer, re-manufactures their own product. They considered (1) Retailer managed collection (2) Manufacturer managed collection (3) Third party managed collection for re-manufacturing. Sarkar *et al.* (2013) presented two vendor-buyer supply chain model in which first one is probability distribution based demand model with lead time and second one is distribution free approach for the lead time demand. For this mathematical model is developed and analyze by authors. Wei *et al.* (2014) presented two competing supply chains model in which they considered competition between both manufacturers and retailers level. In this article pricing and re-manufacturing decision are optimize by authors in a duopoly market. Further they considered a manufacturer manufacture a new product while other one re-manufacturers used product incorporating some new features. Mathematical model is developed and results verified by numerical examples.

Wei *et al.* (2015) developed a closed loop supply chain in which they optimize pricing and collecting decisions for symmetric and asymmetric information. They analyzed the model by a sensitive analysis with respect model's key parameters. Li *et al.* (2016) developed a model of supply chain in which they analyzed two decision strategies
First one is re-manufacturing then pricing (FRTP)
second one is First pricing then re-manufacturing (FPTR).
The optimal quantity of re-manufacturing and retailing price of re-manufactured product are found by authors.

Maiti *et al.* (2016) developed a retail price and quality dependent closed loop supply chain model incorporating hybrid manufacturing and re-manufacturing variable market demand. The model is developed in centralized and decentralized scenario.

Zheng *et al.* (2016) suggested a reverse supply chain model in which they addressed the problem what should be the pricing, collecting and contract design for re-manufacturing of used product with incomplete information incorporating price and effort level dependent supply of used product and price dependent demand of re-manufactured product. They concluded the incomplete information might be reason for loss of reverse supply chain.

The re-manufacturing process of used product has mainly three stages which are (1) collection of used product (2) re-manufacturing of used product and (3) retailing of used product. All these above task are different in nature moreover. Due to maintaining quality and quantity the above all different task should be assigned different agencies/members, Moreover each stages (collection stage, re-manufacturing stage and retailing stage) product has different characteristic and therefore it required different rate of holding cost. In this article for smooth running of business affairs we develop a three layer reverse supply chain model consisting collector, manufacturer and retailer(shown in the fig.1) assuming different rates of holding cost for each supply chain member, for a single product in decentralized scenario (because collector and retailer empowered with taking own decisions about decision variables).

The market survey reveals that the collection quantity of used product is affected by the acquiring price, which is paid to end user of fresh product by collector. Furthermore efforts of collector such as collection of used product from door to door policy, advertising campaign etc. are also impact on collection volume of used product. If p^c be the acquiring price and e be the effort level of collector. we considered the deterministic linear supply function $s = a + bp^c + \gamma e$ (bakal *et al.* (2006), Zheng *et al.* (2017)) and the collection efforts cost is function $a(e) = \frac{de^2}{2}$. Parameter's discussion is separately given in the assumptions section.

Analysis of market the demand of re-manufactured product is affected by retailing price, therefore we consider the demand function as deterministic linear function of the retailing price p^r of retailer's is $D^r = \alpha - \beta p^r$ (bakal *et al.* (2006) and Zheng *et al.* (2017)).

The main objective of this research is to developed coordinations policy for collector's retailer's and re-manufacturer's by obtaining optimal acquiring price p^c, optimum effort level e , optimum acquiring wholesale price w_c, optimal wholesale price w^m, and retailer's optimal retailing price p^r in the decentralized scenario with complete information. Complete information means, all informations about business activity are fully shared by re-manufacturer, retailer and collector.

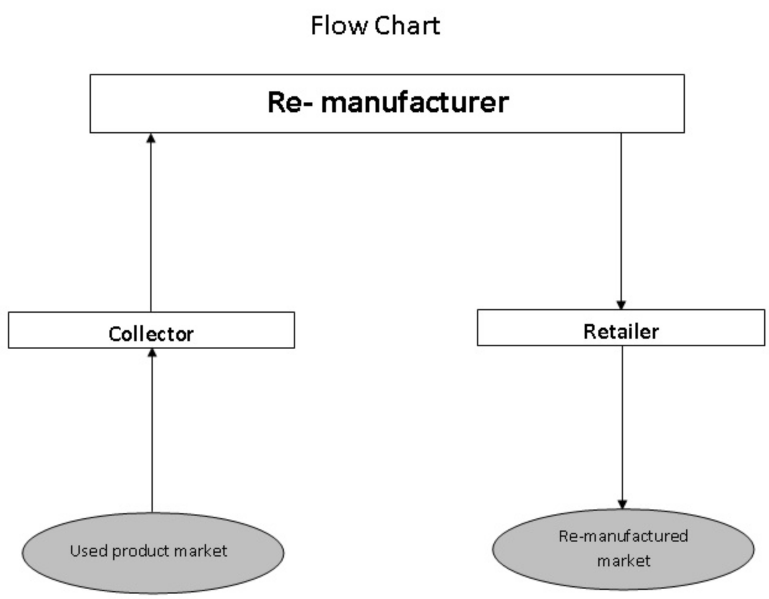


Figure 1: Reverse supply chain distribution flow chart

2 Notations and Assumptions

Following notations are used in this model.

p^c : Acquiring price of the collector per unit of the used product,

e : Collection effort level per unit of the collector,

s : Supply of used products at collector's end,

w_c : Acquiring wholesale price of re-manufacturer for collector,

p^r : Selling price of the re-manufactured product at retailer's end,

D^m : Demand of the re-manufactured product at re-manufacturer's end ,

w^m : Re-manufacturer's wholesale price per unit of the re-manufactured product for retailer's end ,

c : Per unit re-manufacturing cost of used product,

c^c : Per unit collection cost of used product at collector's end,

h : Per unit hulk salvage value of the used product,

s^r : Per unit salvage value of re-manufacturable part of used product,

c_l : Cleaning inspection and sorting cost per unit of used product,

d : Scale parameter of the collection effort level

$a(e)$: Assemblage effort costs $a(e) = \frac{de^2}{2}$, (Gao *et al.* 2015)

π_c : Net profit of collector,

π_m : Net profit of re-manufacturer,

π_r : Net profit of the retailer,

h_r : Holding cost per unit per unit time for retailers,

h_c : Holding cost per unit per unit time for collectors,

h_m : Holding cost per unit per unit time for re-manufacturer.

Assumptions

The following assumptions are made in this model

- Holding cost is considered different for all reverse supply chain members,
- Supply of used product at collector's end is $a + bp^c + \gamma e$, (bakal *et al.* (2006), Zheng *et al.* (2017),) where a is base supply of used product which represents awareness with environment of final users, p^c is the acquisition price which is paid by collector to final user b be the sensitivity parameter of acquisition price, e denotes the efforts level which is executed by collector to collect more and more collection of used product. γ be the sensitivity parameter of effort level,
- Demand of re-manufactured product at retailer's end is $\alpha - \beta p^r$, (bakal *et al.* (2006), Zheng *et al.* (2017)) where α, $\beta > 0$ and parameter α denotes base demand of the re-manufactured product, β be the sensitivity parameter of retailing price,

- Effort level cost considered as $a(e) = \frac{de^2}{2}$, (Gao *et al.* (2015)), where, parameter d is sensitive parameter of effort level cost,
- Re-manufacturing cost of used product is less costly than manufacturing new one,
- Re-manufacturer is a leader of supply chain, he can decide the acquisition whole sale of used product and wholesale price of re-manufactured product according to re-manufacturing cost,
- While in the process of optimization of their objective, all reverse supply chain member have access to the same informations.

3 Proposed Model for Collectors

Collector who engage in collecting the used product from those customers who are use fresh product and after use the fresh product, they sale the product to collector. For more profit, collector may be use his personal efforts to collect more collection of used product. If w_c is the acquiring wholesale price, p^c is the acquiring price, c_c is the collection cost and h_c is the holding cost per unit of used product, moreover $(a + bp^c + \gamma e)$ acquiring price and effort level depended supply of used product and $\frac{de^2}{2}$ effort level cost of collectors, then collector's profit function is

$$max\, \pi_c = (w_c - p^c - c^c - h_c)(a + bp^c + \gamma e) - \frac{de^2}{2} \tag{3.1}$$

Lemma 3.1 *The collector's profit π_c is concave with respect to acquiring price p^c of collectors and effort level e if $2bd - \gamma^2 > 0$.*

Proof The first order partial derivative of collector's profit π_c in p^c and e respectively are

$$\frac{\partial \pi_c}{\partial p^c} = (w_c - p^c - c^c - h_c)b - (a + bp^c + \gamma e) \tag{3.2}$$

and

$$\frac{\partial \pi_c}{\partial e} = (w_c - p^c - c^c - h_c)\gamma - de \tag{3.3}$$

To ensure that profit π_c is concave with respect to p^c and e, we show that $rt - s^2 > 0$. For this

$$\frac{\partial^2 \pi_c}{\partial p^{c2}} = -2b,\ \frac{\partial^2 \pi_c}{\partial p^c \partial e} = -\gamma,\ \frac{\partial^2 \pi_c}{\partial e^2} = -d$$

Hence $rt - s^2 > 0$, if $2bd - \gamma^2 > 0$.
Hence, the profit π_c is concave with respect to p^c and e. This complete the proof of lemma.

3.1 To Find Optimal Acquisition Price and Efforts Level

Optimal acquisition price p_c and optimal collection effort level e of collector can be obtained as follows, if $2bd - \gamma^2\eta > 0$, where the partial derivative of collector's profit π_c with respect to p^c and e respectively are

$$\frac{\partial \pi_c}{\partial p^c} = (w_c - p^c - c_c - h_c)b - (a + bp^c + \gamma e) \tag{3.4}$$

and

$$\frac{\partial \pi_c}{\partial e} = (w_c - p^c - c_c - h_c)\gamma - de \tag{3.5}$$

Equation (3.5) and (3.6) equating to zero, we get the following homogeneous equations in p^c and e

$$(w_c - p^c - c_c - h_c)b - (a + bp^c + \gamma e) = 0 \tag{3.6}$$

$$(w_c - p^c - c_c - h_c)\gamma - de = 0 \tag{3.7}$$

solving above homogeneous system yields desired result which is given by equations (3.8) and (3.9) respectively.

$$p^{c*} == \frac{(w_c - c_c - h_c)(bd - \gamma^2) - ad}{2bd - \gamma^2} \tag{3.8}$$

$$e^* = \frac{(w_c - c_c - h_c)b\gamma + \gamma a}{2bd - \gamma^2} \tag{3.9}$$

if $2bd - \gamma^2\eta > 0$,

4 Proposed Model for Retailers

Retailers who retails the re-manufactured product in the market in which re-manufactured product is used by customers. If wholesale price w^m be the rate per unit of re-manufactured product, p^r be the retailing rate of re-manufactured product at retailer's end and demand is $\alpha - \beta p^r$, where α be the basic requirement re-manufactured product at retailer's end and β price sensitive parameter of retail price, then the profit function of retailer is

$$max\ \pi_r = (\alpha - \beta p^r)(p^r - w^m - h_r) \tag{4.1}$$

4.1 Concavity and Optimal Value of p^r

For showing retailer's profit function is concave in retailing price p^r, we find the first order partial derivative of of equation (4.1) is

$$\frac{\partial \pi_r}{\partial p^r} = (\alpha - \beta p^r) - \beta(p^r - w^m - h_r) \tag{4.2}$$

and second order partial derivative of equation (4.1) is

$$\frac{\partial^2 \pi_r}{\partial p^{r2}} = -2\beta, \tag{4.3}$$

hence if $\beta > 0$, π^r shows concavity in p^r, and for optimal values of p^r equation (4.2) equate to zero

$$(\alpha - \beta p^r) - \beta(p^r - w^m - h_r) = 0 \tag{4.4}$$

solving equation (4.4) yields required result which is given by (4.5)

$$p^{r*} = \frac{\alpha + (w^m + h_r)\beta}{2\beta} \tag{4.5}$$

if $\beta > 0$

5 Proposed Model for Re-manufacturer

Re-manufacturer obtains the lot of used product from collector's end, after cleaning and inspection, he re-manufacturers the used product and then re-manufacturer dispatch the lot of re-manufactured product to retailers for retailing it into market. The profit of re-manufacturer is depends on acquiring wholesale price w^c for collectors and wholesale price w^m for retailers which are decision variable for re-manufacturer. Then the re-manufacturer's profit function is

$$\begin{aligned} max\ \pi_m =& \frac{\alpha - (w^m + h_c)\,\beta}{2}\,(w^m - s_r - c - h_m) \\ &+ \frac{bd\,[a + b(w_c - c_c - h_c)]}{2bd - \gamma^2}\,(h + s_r - w_c - c_l) \end{aligned} \tag{5.1}$$

subject to

$$\frac{\alpha - (w^m + h_c)\,\beta}{2} \le \frac{bd\,[a + b(w_c - c_c - h_c)]}{2bd - \gamma^2} \tag{5.2}$$

where

5.1 Supply for Re-manufacturer

Supply of re-manufacturer's end is equal to supply of used product form collectors, it is given by

$$S^m = \frac{bd\,(a + b(w_c - c_c - h_c))}{2bd - \gamma^2} \tag{5.3}$$

5.2 Demand for Re-manufacturer

The demand of re-manufacturer's end is equal to demand of re-manufactured product at retailer's end is

$$D^m = \frac{\alpha - (w^m + h_r)\,\beta}{2}, \tag{5.4}$$

Demand of re-manufactured product always dominated by supply of used product i.e re-manufacturing of used product hasn't over the supply of used product, because it may be possible the used product is in scrap form and it can not be re-manufacture, therefore we assumed that the supply of used product is always sufficient for re-manufacturing.

5.3 Concavity and Optimal Values of w_c and w^m

For showing re-manufacturer's profit π^m is jointly concave in w_c and w^m. The first and second order partial derivatives are

$$\frac{\partial \pi_m}{\partial w_c} = -\frac{bd\,(a + b(w_c - c_c - h_c))}{2bd - \gamma^2} + \frac{b^2 d}{2bd - \gamma^2}(h + s_r - w_c - c_l) \tag{5.5}$$

$$\frac{\partial \pi_m}{\partial w^m} = \frac{a - (w^m + h_r)\beta}{2} - \frac{\beta}{2}(w^m - s_r - c - h_m) \tag{5.6}$$

It is ensure that profit function π_m is jointly concave in w^m, and w_c, if $rt - s^2 > 0$

$$r = \frac{\partial^2 \pi_m}{\partial w_c^2} = -\frac{2b^2 d}{2bd - \gamma^2},\; s = \frac{\partial^2 \pi_m}{\partial w^m \partial w_c} = 0 \text{ and } t = \frac{\partial^2 \pi^m}{\partial w^{m2}} = -\beta$$

Hence $rt - s^2 > 0$ if $\beta > 0$, and $2bd - \gamma^2 > 0$. For optimal values of w^c and w^m solving the following homogeneous equations

$$-\frac{bd\,(a + b(w_c - c_c - h_c))}{2bd - \gamma^2} + \frac{b^2 d}{2bd - \gamma^2}(h + s_r - w_c - c_l) = 0 \tag{5.7}$$

$$\frac{a - (w^m + h_r)\beta}{2} - \frac{\beta}{2}(w^m - s_r - c - h_m) = 0 \tag{5.8}$$

the required result is

$$w_{c*} = \frac{b(c_c + h_c + h + s_r - c_l)m - a}{2b}, \tag{5.9}$$

$$w^{m*} = \frac{\alpha - h_r \beta n + \beta n(s_r + c + h_m)}{2\beta}. \tag{5.10}$$

Finally all decision variables of all supply chain members are obtained after substituting the optimal values of w^c and w^m from equations (5.9),(5.10) into equations (3.8), (3.9), (4.5), (5.3) and (5.4)

$$\begin{aligned}
p^c &= \frac{(h+s_r-c_l-c_c-h_c-\frac{a}{b})(bd-\gamma^2)-2ad}{2(2bd-\gamma^2)}, \\
e &= \frac{(h+s_r-c_l-c_c-h_c)b+\gamma a}{2(2bd-\gamma^2)} \\
s^m &= \frac{bd(a+(h+s_r-c_l-c_c-h_c)}{2(2bd-\gamma^2\eta)} \\
d^m &= \frac{\alpha-h^r\beta-\beta(s_r+c+h_m)}{4\beta} \\
p^r &= \frac{[3n\alpha+\beta(s_r+c+h^m+h_r)]}{4\beta},
\end{aligned}$$

and w_c and w^m are also decision variables which are given by equations (5.9) and (5.10) respectively.

6 Numerical Example and Sensitive Analysis

We set values of the cost and basic parameters are $a = 125$, $c_c = 1.3$, $h_c = 0.12$, $b = 15$, $\gamma = 1$, $d = 0.8$, $\alpha = 400$, $\beta = 0.8$, $h_r = 0.7$, $h_m = 0.9$, $s_r = 11$, $c_l = 2$, $c = 105$, $h = 15$ the optimum results is shown in following table 1

Table 1: Numerical Values

Optimal Values	$Collector$	$Retailer$	$Re-manufacturer$
Acquiring price	3.84	-	-
Effort level	16.60	-	-
Acq. wholesale price	-	-	18.54
Wholesale price	-	-	308
Retailing price	-	404	-
Profit	2535	7311	15710
Supply	199	-	199
Demand	-	76.48	76.48

6.1 Sensitive Analysis

In this section we will discuss about various profits of supply chain members analytically and graphically. What much affected the profits of re-manufacturer retailer and collector, by associated parameters. Partial derivative of all profit functions with respect to b, and γ are

$\frac{\partial \pi^c}{\partial b} > 0$, $\frac{\partial \pi^r}{\partial b} = 0, \frac{\partial \pi^m}{\partial b} > 0$ $\frac{\partial \pi^c}{\partial \gamma} > 0$, $\frac{\partial \pi^r}{\partial \gamma} = 0$, $\frac{\partial \pi^m}{\partial \gamma} > 0$ and from fig. 2, fig. 3 show that increment b and γ increase linearly the profit of collector and re-manufacturer however the retailer's profit remaining constant. Similarly first order partial derivative of various profits with respect to β are $\frac{\partial \pi^c}{\partial \beta} = 0$, $\frac{\partial \pi^r}{\partial \beta} < 0$, $\frac{\partial \pi^m}{\partial \beta} < 0$ and from fig. 4 show that increment of β highly decreases the profits of retailer and re-manufacturer accordingly and profit of collector remaining constant. It is also analyzed that if the collector increases his personal efforts to collect more collection volume of used product, it will be reason of loss making. It is verified by graphically in fig. 5

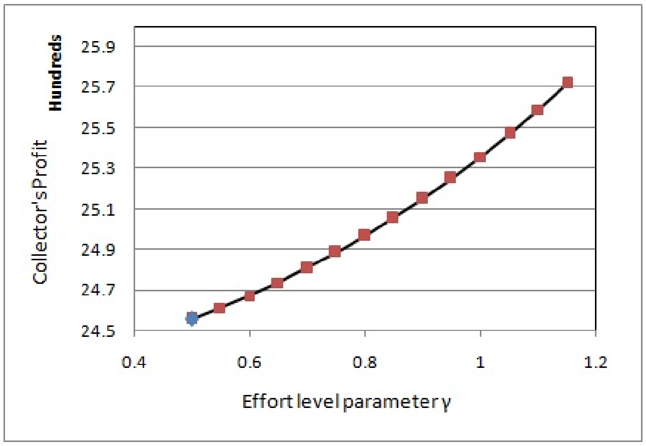
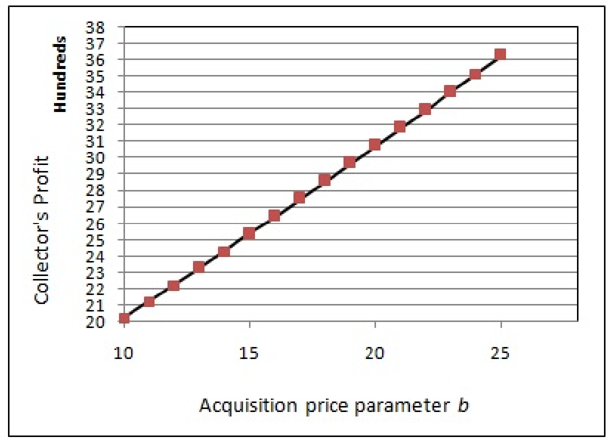


Figure:2



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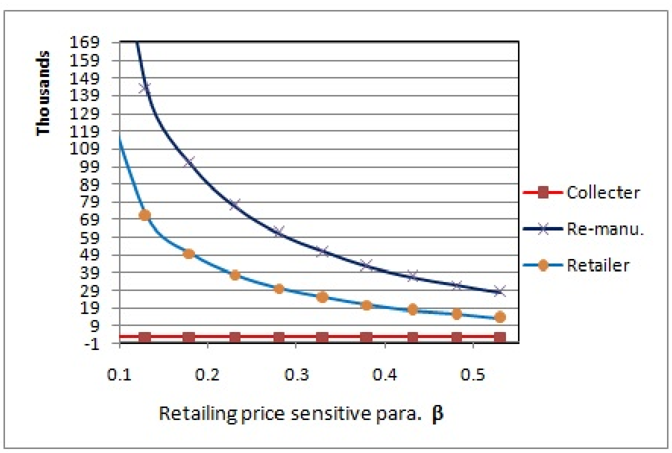

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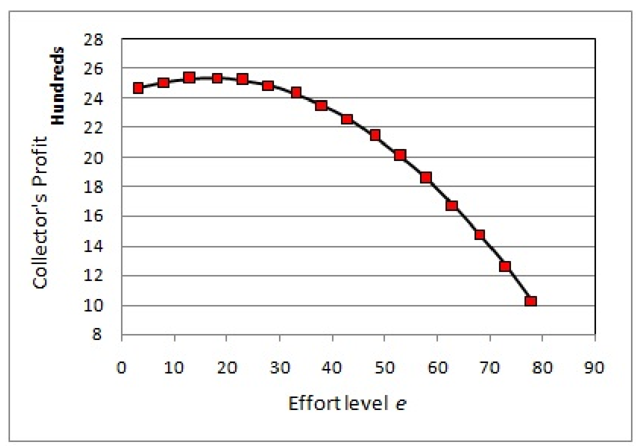

Figure:5

7 Conclusion

In this paper, we have proposed the optimum decisions for collector, retailers and re-manufacturer to optimize their advantages in complete information scenario. We have assumed supply of used product is deterministic linear function of acquiring price and effort level and demand of re-manufactured product is also deterministic linear function of retail price. The model analyzed in the situations that supply of used product is always sufficient for re-manufacturing. but due to less profit of collector than re-manufacturer, it is advised to re-manufacturer that they must pay to effort level cost to promoting business activity. By sensitive analysis it is observed that profits of re-manufacturer and retailer are highly sensitive with retail price therefore retail price must be retain in low amount. The valid information for key parameters are made for supply chain members accordingly. Research can be extended to incorporating quality, warranty and revenue sharing factors of re-manufactured product.

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