Modeling of remanufacturing system considering government incentive

S P Sarmah[a*]
S K Jena[b]
[a]Department of Industrial & Systems Engineering
IIT Kharagpur, India
[b]Goa Institute of Management, Goa India 403505
[a*]spsarmah@iem.iitkgp.ernet.in

Abstract
This paper considers government participation in re-manufacturing via subsidy and fees for improving economic efficiency. A mathematical model is developed considering two cases, namely, (i) subsidy given to the manufacturer and (ii) subsidy given to the collector. The result shows that approach one is better compared to the second approach.

Keywords: Closed-loop supply chain, Subsidies, Tax and Remanufacturing.

INTRODUCTION

Based on the environmental concerns in terms of carbon emission, discard of packaging materials, scrapped toxic materials and other industrial pollutants, manufacturers and distributors in Europe and North America are managed by law to take back their used products for remanufacturing and safe disposal (Mitra, 2015). "Remanufacturing is the process where some components of the used products are disassembled, cleaned, reprocessed, inspected, and reassembled so that it can be used again (Atasu,2008)". In practice, it is important for a (re)manufacturer to adjust his collection strategy along with sales strategies in response to switching to remanufacturing programme. For example, HP Inc. has adopted a remanufacturing program called "*HP renew Program*" for recycling and selling the remanufactured products (Wu, 2012). There are several factors those restrict the remanufacturing activities, such as low remanufacturing technology, lower environmental preferences, and low willingness of consumers to pay for the remanufactured products compared to brand new products. Therefore, most of the manufacturing enterprises in developing countries like India and China have not actively participated in remanufacturing activities. But, the Government is fully aware about the power of incentives to motivate the manufacturer for remanufacturing activities.

The main purpose of this paper is to study whether incorporating governmental participation via different subsidy and fees can increase economic efficiency of the CLSC. The manufacturer can cooperate with the collector to collect the used products from the market or assigned it only to the collector for collecting the used products. The manufacturer decides the production quantity, transfer price and selling price of the remanufactured and new products and the collector decides the acquisition cost of the used products. Government provides the subsidies and takes manufacturing tax from the manufacturer and consumption tax from the customer as shown in Figure 1.We model the problem in two–stage Stackelberg game where the manufacturer is the leader and collector is the follower. We have studied two cases for the above described system such as (i) Subsidy to the customer, (ii) Subsidy to the collector.

The paper is structured in the following order. A concise review of literature related to the work is provided in the next section. After that, mathematical models are developed and subsequently numerical study and sensitivity analysis are made. Finally, conclusions, and future scope of study are presented.

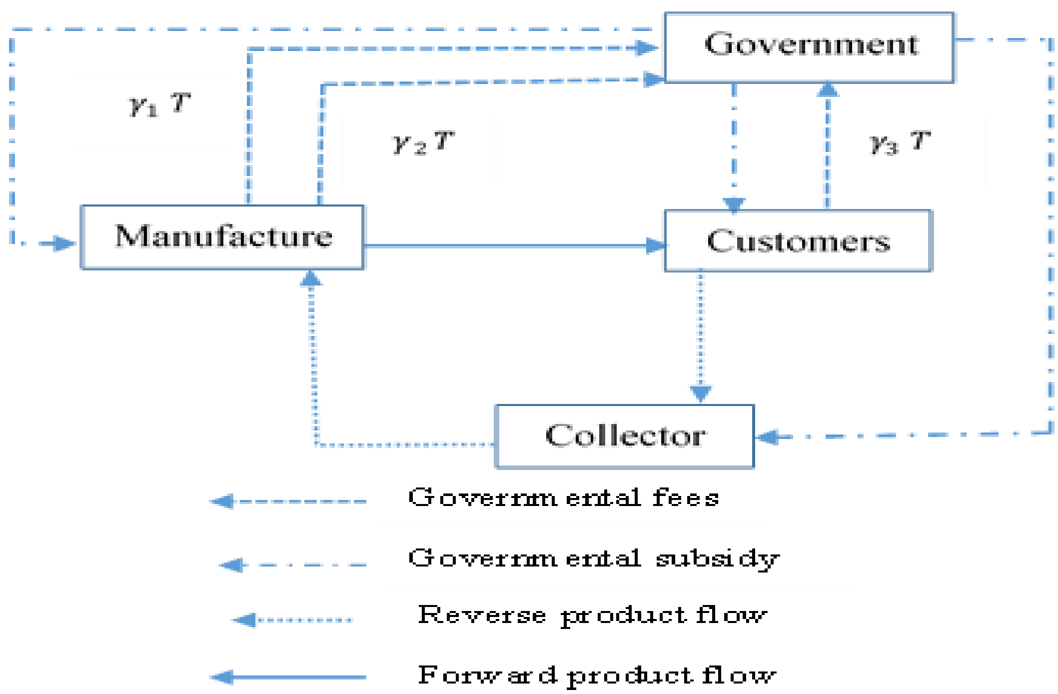

Figure 1- Conceptual model of the remanufacturing system

REVIEW OF LITERATURE

Our setting is related to the collection of used product and selling of remanufactured products problem, which has been extensively studied in the literature (Savaskan et al.2004, Shi 2011 and 2012; Atasu et al 2013). A considerable amount of research on remanufacturing and CLSC has been published in the last one decade. "The study on CLSC and remanufacturing is a relatively new field of research, and there are numerous challenging managerial problems (Atasu et al. 2008; Atasu et al. 2012; Guide and Van Wassenhove, 2006)". "The past study on CLSC used game theoretic framework to gain the insights about the decision of CLSC members and their economic consequence (Atasu et al. 2012; Webster and Mitra 2008)". "Moreover, within game theoretic framework for collection and remanufacturing, Savaskan et al.(2004) and Atasu et al. (2012) have examined various collection strategies considering different channel structure under Stackelberg game for (re) manufacturer and collector". In contrast, in this paper, we have considered a simple and fixed channel structure but have investigated the government participation in remanufacturing activities via subsidies and fees for economic and environmental consequence..

"Another stream of research related to our paper considers social welfare and government subsidies in the CLSC (Cohen et al.2015; Sheu 2011, Sheu and Chen 2012)". "In the area of CLSC considering government subsidy and fees as a tool to improve the social welfare has been widely studied (Atasu et al. 2012; Galiana et al.2003)". "Carlsson and Johansson-Stenman (2003) studied the social benefits of green technology adoption on electric vehicle in Sweden and found a pessimistic outlook for this technology in the context of net social welfare". Environmental regulation in the form of taxation on the innovation activity of firm is studied by Carraro and Topa (1995). They have examined the objective function in the form of sum of the consumer surplus and industry profit under the sets of government policy instruments. "Cohen et al.(2015) proposes a model to analyse the interaction between government and supplier considering designing the customer subsidy policies". In that paper they have examined the supplier's production and pricing decision when government offered the subsidies to consumer directly.

Considering the collection of used products and selling of the new and remanufactured products and government subsidy in CLSC literature, the possibility to collect the used product though collector and selling the new and remanufactured product under price and tax sensitivity demand should provide new structural insights into the optimal supply chain decisions.

MODEL DEVELOPMENT

The following notation are used for the development of the mathematical model (i, j=1, 2, $i \neq j$)

Table 1- List of notation used for the development of the models

Symbol	Description
D_i	Demand of products per unit time at manufacturer
c	Cost per unit production of new product
c_r	Cost per unit remanufacturing of return product
p_n	Sell price per unit of manufactured product of manufacturer
p_r	Sell price per unit of remanufactured products of manufacturer
τ	Fraction of products remanufactured from return units at manufacturer. i.e., $\mathbf{0 \leq \tau \leq 1}$
b	Transfer price per unit of product at manufacturer *i*
f	Incentive offered to the customer who returns a used product.
I	Production collection effort
γ_i	Proportion of tax given by the chain member, subscript *i* takes the value of 1 and 2, denoting the manufacturer for new and remanufactured product, and 3 for customer respectively.
X	Government incentives per unit of the product.
$\tau = \sqrt{\frac{I}{C_L}}$	

C_L	Scaling parameter.
$\delta = c - c_r$	Saving cost
$\prod_K$	Profit function of the channel member from the product. Subscript K takes the values of M and C, denoting the manufacturer and collector
$\prod_T^N$	Profit of the total system, where N= Subsidies to Customer (Model D), Subsidies to Collector (Model C), Subsidies to Manufacturer(Model M), and Subsidies to Collector and manufacturer(Model MC)

The demand functions of the substitutable products produced by the manufacturer is continuous, deterministic and price and tax sensitive and assumed to be of the following form, i.e., $D_n = (\alpha_n - \beta(p_n + \gamma_3 T))$ and the demand function of the remanufactured products is of the following form: $D_r = (\alpha_r - \beta(p_r + \gamma_3 T))$ where αn and αr describe the market base parameterizing the potential market size for the new product and remanufactured product respectively, when both prices at zero. β is a positive parameter.

In the development of the model, following assumptions are made:

- Single period is considered here.
- The manufacturer has infinite capacity.
- C_r < C, So Δ>0, It is a realistic assumption that remanufacturing cost of production is less than the cost of manufacturing of new product.
- "The reverse supply chain performance is characterized by τ, the return rate of used product from the customers. τ is the fraction of current generation product that would be returned, i.e., $0 \le \tau \le 1$ (Atasu et al. 2008)".
- "Fixed payment f is paid by the collector to consumer who returns the used product. Again fixed transfer price b is paid by the manufacturer to the collector for collecting the used product and $b > f$ (Atasu et al. 2008)"

Case 1: Subsidies To The Manufacturer

In this case, the government receives the consumption tax from the customer and manufactured and remanufactured fee from the manufacturer, whereas government provides the subsidy to the manufacturer for remanufacturing the products after collecting the used products from the market. As a result, a manufacturer performs the end-of use and end-of-life product recycling and remanufacturing in a green supply chain can be levied (re)manufacturing taxes and obtain the government subsidies to achieve government green goals for used product recycling and remanufacturing.

The collector's profit function is given by

$$\max_{\tau} \Pi_C = (\alpha_n - \beta(p_n + \gamma_3 T))\tau(b - f) - c_L \tau^2 \qquad (1)$$

From the second-order conditions, we get $\frac{\partial^2 \Pi_C}{\partial \tau^2} = -2c_L < 0 \Pi_C$ is concave in τ, whenever $c_L > 0$. Using the first-order conditions to derive the best response to the return rate gives

$$\tau = \frac{(b-f)(\alpha_n - \beta p_n - T\beta\gamma_3)}{2c_L} \qquad (2)$$

And the profit of the manufacturer can be written as follows:

$$\max_{p_r, p_n} \Pi_M = (p_n - c - \gamma_1 T - \tau b)D_n + D_r(p_r - c + \delta\tau - \gamma_2 T + X\alpha) \qquad (3)$$

When making the decision, manufacturer considers the collector best response function. Substituting (2) in (3), one can derive the optimal value of the (p_n, p_n) using the best response to the selling price and is given by

$$p_n = \frac{-(b-f)\beta(-\beta\delta p_r - 2b\alpha_n + \delta\alpha_r + 2bT\beta\gamma_3 - T\beta\delta\gamma_3) + 2c_L(\alpha_n + \beta(c + T\gamma_1 - T\gamma_3))}{2\beta(b(b-f)\beta + 2c_L)} \qquad (4)$$

$$p_r = \frac{(b-f)\beta\delta(\beta p_n - \alpha_n + T\beta\gamma_3) + 2c_L(\alpha_r + \beta(c - X\alpha + T\gamma_2 - T\gamma_3))}{4\beta c_L} \qquad (5)$$

$$b = \frac{f\beta p_n + \beta\delta p_r - f\alpha_n - \delta\alpha_r + fT\beta\gamma_3 + T\beta\delta\gamma_3}{2\beta p_n - 2\alpha_n + 2T\beta\gamma_3} \qquad (6)$$

Total profit of the CLSCs can be obtained as:

$$\Pi_T^{M^*} = \Pi_M^* + \Pi_C^*$$

Case 2: Subsidies To The Collector

In this model, the collector gathers the used products from the market and sells it to the respective manufacturer and tries to maximize his profit by putting the collection effort. Here, the government receives the consumption tax from the customer and manufactured and remanufactured fee from the manufacturer, whereas government provides the subsidy to the collector for collecting the used products from the market. As a result collector affords the collection risk without putting load on the manufacturer.

The collector's profit function is given by

$$\max_{\tau} \Pi_C = (\alpha_n - \beta(p_n + \gamma_3 T))\tau(b - f + \alpha X) - c_L \tau^2 \qquad (7)$$

From the second-order conditions, we get $\frac{\partial^2 \Pi_C}{\partial \tau^2} = -2c_L < 0 \Pi_C$ is concave in τ, whenever $c_L > 0$. Using the first-order conditions to derive the best response to the return rates gives

$$\tau = \frac{(b-f+X\alpha)(\alpha_n - \beta p_n - T\beta\gamma_3)}{2c_L} \tag{8}$$

The profit of the manufacturer can be formulated as

$$\underset{p_r p_n}{Max} \Pi_M = (p_n - c - \gamma_1 T - \tau b) D_n + D_r (p_r - c + \delta\tau - \gamma_2 T) \tag{9}$$

Because $\frac{\partial^2 \Pi_M}{\partial p_n^2} = -2\beta - \frac{b(b-f+X\alpha)\beta^2}{c_L}$, $\frac{\partial^2 \Pi_M}{\partial p_r^2} = -2\beta$

and $\frac{\partial^2 \Pi_M}{\partial p_n \partial p_r} = \frac{\partial^2 \Pi_M}{\partial p_r \partial p_n} = \frac{(b-f+X\alpha)\beta^2\delta}{2c_L}$, the profit function is a negative definite Hessian from the assumption that $\beta > 0, \delta > 0, and\ b > f$.

$$p_n = \frac{-(b-f+X\alpha)\beta(-\beta\delta p_r - 2b\alpha_n + \delta\alpha_r + 2bT\beta\gamma_3 - T\beta\delta\gamma_3) + 2c_L(\alpha_n + \beta(c + T\gamma_1 - T\gamma_3))}{2\beta(b(b-f+X\alpha)\beta + 2c_L)} \tag{10}$$

$$p_r = \frac{(b-f+X\alpha)\beta\delta(\beta p_n - \alpha_n + T\beta\gamma_3) + 2c_L(\alpha_r + \beta(c + T\gamma_2 - T\gamma_3))}{4\beta c_L} \tag{11}$$

$$b = \frac{(f-X\alpha)\beta p_n + \beta\delta p_r - f\alpha_n + X\alpha\alpha_n - \delta\alpha_r + fT\beta\gamma_3 - TX\alpha\beta\gamma_3 + T\beta\delta\gamma_3}{2(\beta p_n - \alpha_n + T\beta\gamma_3)} \tag{12}$$

Solving (10) and (11) simultaneously, the optimal solution (p_n^* , p_r^*) can be derived.

Total profit of the CLSCs can be obtained as:

$$\Pi_T^{C^*} = \Pi_M^* + \Pi_C^*$$

NUMERICAL EXAMPLE AND MANAGERIAL INSIGHTS

A numerical study is conducted here to demonstrate the proposed model. The valus of parameters are chosen as follows:

$\alpha_n = 40, \beta = 1, c = 10, \alpha_r = 40, \delta = 0.5, c_L = 200, f = 5, \alpha = 0.5\ and$

$\gamma_1 = \gamma_2 = \gamma_3 = 0.166$

Table 2 - Results of two different cases of model

Model	τ	b	p_r	p_n	X	T	Π_C	Π_M	Π_T
Case1	0.69	10.50	13.52	29.68	20	45.18	15.40	60.15	75.55
Case 2	0.80	12.50	19.57	30.19	50	53.57	25.10	30.45	55.55

The results in Table1 show that the selling prices of the product are more in Case2 whereas, it is less in Case1. From Table 1, it is seen that the manufacturer can gather more fractions of current generation products in Case2 as compared to Case1. It is observed that subsidies to the manufacturer model is better compared to subsidies to the collector.

SENSITIVITY ANALYSIS

Impact of Acquisition Cost (f):

Here, the impact of acquisition cost (*f)* on total channel profit in both the models are examined. From Figure.2, it is found that the value of total channel profit decreases as the acquisition cost increases in Case 2. The reason is that the collector collects the used product from the market by paying certain fixed amount. After that the collector sells the same product to the manufacturer by keeping certain margin. The manufacturer sells the remanufactured product to the market at a lower price compared to the manufactured products. Therefore, the total cost of the manufacturer increases as the cost of acquisition increases, and the manufacturer ultimately makes lesser profit in Case2. In this model, if acquisition cost of the used product increases then the product is to be sold at a higher pirce in the market by the manufacturer. The total channel profit appears like straight line when the cost of acquisition increases.

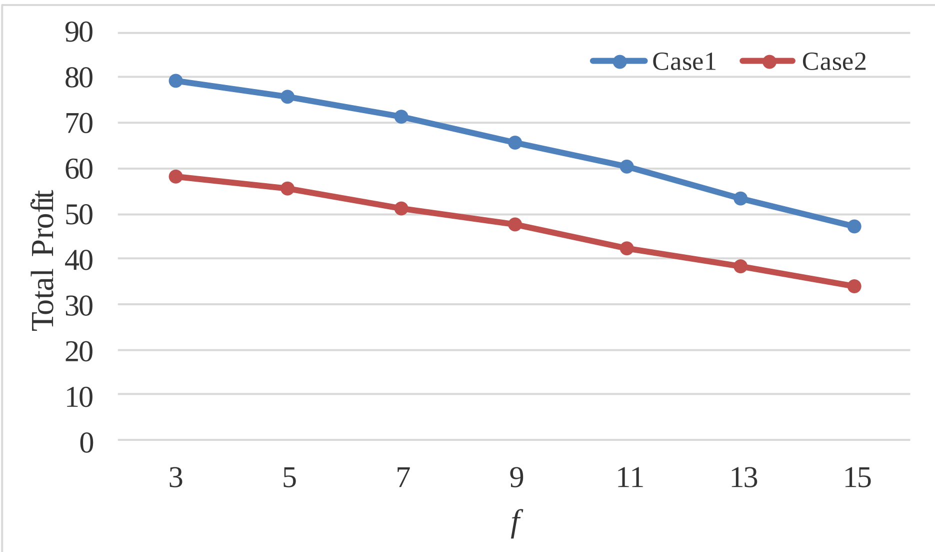

Figure 2- The total channel profit of two cases for different values of acquisition price (f)

Impact of market size (α):

We have studied here the impact of market size α on total channel profit. From Figure.3, it is observed that total channel profit marginally increases in both the models as the market size increases.

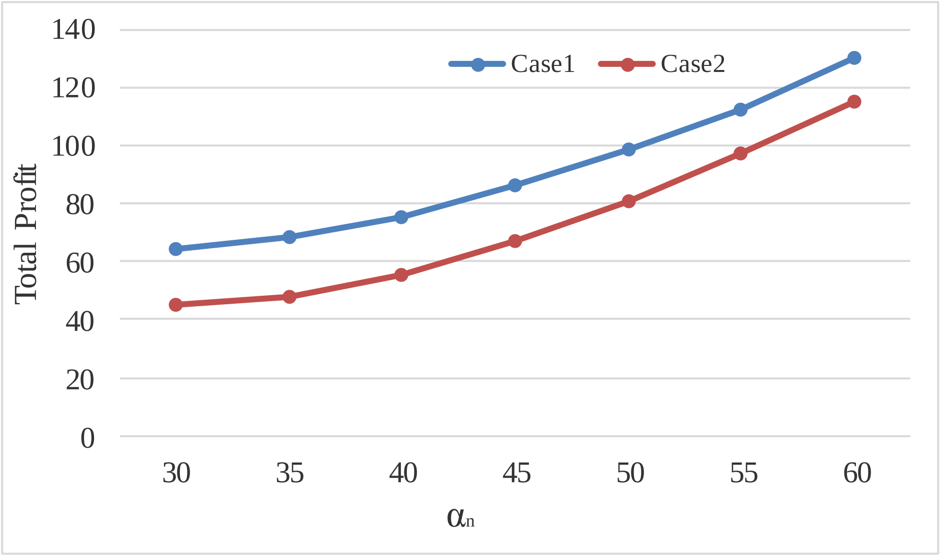

Figure 3- The total channel profit of two cases for different values of market size

When market size increases, Case1 makes more profit compared to Case2. In Case2, manufacturer sells the product with higher selling price and due to the presence of price sensitive demand; it makes less profit compared to the Case1.

CONCLUSION

In this paper, the issue of remanufacturing systems considering government subsidy and tax in a CLSC has been examined. In the studied CLSC, manufacturer collects the used products through a collector and sells their (re)manufactured products to the market directly. The result shows that manufacturer earns higher profit considering government subsidies under Case1. In Case1, the increase in total channel profit is more compared to Case2 as the market size increases. Again, in Case1, the decrease in total channel profit is less compared to Case2 as the acquisition cost increases. In Case2, total channel profit decreases as the acquisition cost increases due to lower collector's profit.

This study can be extended in many directions for further study; a linear demand curve can be modified to include many other possible non-linear curves. Price competition can be considered here which can be extended to service and price competition among the manufacturers under government incentives.

Bibliography

Atasu, A., V.D.R. Guide, L.N. Van, Wassenhove. 2008. Product reuse economics in closed-loop supply chain research. Production and Operations Management 17(5), 483–496.

Atasu, A., O. Ozdemir, L. N. Van Wassenhove. 2012. Stakeholder Perspectives under Take-Back Legislation. Production and Operations Management, 22(2), 382–396.

Carlsson F., O.Johansson-stenman.2003. The costs and benefits of electric vehicles. A 2010 Perspective. Journal of Transport Economics and Policy 37:1-28

Carraro, C., G. Topa. 1995. Taxation and environmental innovation. In Control and Game-Theoretic Models of the Environment. Annals of the International Society of Dynamic Games, Vol. 2, ed. C. Carraro, J. A. Filar. Birkhäuser, Boston.

Cohen, M.C., R. Lobel., G. Perakis. 2015. The impact of demand uncertainty on consumer subsidies for green technology adoption. Management Science. In advance 14 Sep: 1–24. http://dx.doi.org/10.1287/mnsc.2015.2173.

Guide, D., L. N. Van Wassenhove. 2006. Closed-loop supply chains: an introduction to the feature issue (Part 1). Production and Operations Management 5(3):345-350.

Galiana, D., A. Motto, F. Bouffard. 2003. Reconciling social welfare, agent profits, and consumer payments in electricity pools. IEEE Transactions On Power Systems 18(2): 452-459.

Mitra, S., S.Webster. 2008. Competition in remanufacturing and the effects of government subsidies. International Journal of Production Economics 111:287–298

Mitra, S., 2015.Optimal pricing and core acquisition strategy for a hybrid manufacturing /remanufacturing system. International Journal of Production Research, 10.1080/00207543.2015.1067376.

Savaskan, R..C., B. Shantanu, L.N. Van Wassenhove. 2004. Closed - Loop Supply Chain Models with Product Remanufacturing. Management Science 50(2): 239–52.

Shi, J., G. Zhang, J. Sha. 2011. Optimal production and pricing for a closed-loop supply chain system. Resource, Conservation and Recycling55 (1):639–4

Sheu, J-B.,2011. Bargaining framework for competitive green supply chains under governmental financial intervention. Transportation Research Part E 47:573–592.

Sheu, J-B., Y.J.Chen. 2012. Impact of government financial intervention on competition among green supply chains. International Journal of Production Economics 138(1):201–213.

Wu,Cheng-Han. 2012. price and service competition between new and remanufactured products in a two-echelon supply chain. International Journal of Production Economics 140():496–507