Journal of Industrial and Systems Engineering
Vol. 9, special issue on supply chain, pp 17 – 29
Winter (January) 2016

Pricing strategy and return policy of one-echelon green supply chain under both green and hybrid productions

Hossein Heydaryan[1], Ata Allah Taleizadeh[1*]

[1]School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran

h_heydaryan@ut.ac.ir, taleizadeh@ut.ac.ir

Abstract

In this paper, we investigate the pricing and return policy issue of one-echelon green supply chain. The assumed supply chain contains a manufacture that produces two types of products: green and non-green products. These products represent the same function but in selling price and environmentally issues have different effects. The assumed return policy for both products stimulates the customer valuation. Different models of pricing strategy and return policy are developed in both green and hybrid production modes. System performance in both hybrid and green production mode are studied, and the return policy and its effect on these production modes are investigated. The optimal solutions are derived and several numerical examples and sensitivity analysis are performed to demonstrate the applicability of the developed model and its solution method.

Keyword: Green supply chain, return policy, pricing, hybrid production mode.

1- Introduction

In last few decades, the concept of green supply chain management (GSCM) has attracted significant attention of governments and business communities. In an attempt to address the growing environmental concerns, green practices should be implemented at every stage of the supply chain and the number of companies focusing on green products is increasing. For example a clothing company called Patagonia has devoted attention to greening its products for several years (Ghosh & Shah, 2012).

Most of previous studies on GSCM focused on qualitative analysis and theoretical research and less noticed to quantitative aspects. One of the researches that has a quantitative view is Zhang, Wang, & Ren (2014). They focus on pricing strategies for two production modes in cooperative and non-cooperative games of a two-stage green supply chain, including a manufacturer and a supplier. Manufacturer makes both green and non-green products. Return policy plays an important role for firms to ensure the customers about the satisfactory quality of product and reducing quality dissatisfaction (Balachander, 2001).

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* Corresponding Author

ISSN: 1735-8272,

This policy can also stimulate the customer demand (Y. Li, Xu, & Li, (2013), Wood, (2001)). Mukhopadhyay & Setaputra (2007) indicate that more than 70% of customers consider a product's return policy before making purchasing decision. Su (2009) study the impact of full (e.g., using 100% money-back guarantees) and partial returns policies (e.g., when restocking fees are charged) on supply chain performance. Yue & Raghunathan (2007) explore the impact of full returns policy's impact on supply chains with information asymmetry. Other application of return policy happens in online direct selling, because a customer cannot experience the product until receiving it. Li et al., (2013) examine the relationship between the return policy, product quality, and pricing strategy in online direct selling.

In this paper we consider the return policy in one-echelon green supply chain that consists of one manufacturer and one retailer. Manufacturer sells two types of products, green and non-green products to customer. Selling price and refund amount of both products are determined by the manufacture. In the case of not satisfying, the customer can return back the product to manufacturer and gets her/his money.

The rest of the paper is organized as follows. In the next section, we review the relevant literature related to the core areas of our research. In section 3 the problem is described. Section 4 and section 5 contains the mathematical modeling of green and hybrid production modes. In Section 6 the numerical example and sensitivity analysis are presented. In section 7 concluding remarks and future research ideas are provided.

2- Literature Review

The topic of this paper is closely related to the literatures of producing green product, pricing strategy and return policy in a supply chain. In this section a review of researches in two separate parts, including the green supply chain management (GSCM) and pricing strategy and return policy are presented.

In the filed of GSCM, Li et al. (2015) discuss on the pricing and greening strategies in a supply chain in both centralized and decentralized cases. Also dual channel green supply chain consisting of a manufacturer with a direct channel and an independent retailer are considered by them. Chen & Sheu (2009) show that a proper design of environmental-regulation pricing strategies is able to promote extended product responsibility for green supply chain firms in a competitive market. Panda et al. (2015) discuss about the channel coordination issues in a three-level supply chain including one manufacturer, one distributer and one retailer by proposing a contract-bargaining process. Ding et al. (2015) construct a sustainable supply chain model to evaluate the economic and environmental performance of a supply chain. Coskun et al. (2015) propose a goal programming model to optimize the supply chain network for a retailer, which includes manufacturers, carriers and distribution centers. They consider three consumer segments based on their purchasing behavior and their green consciousness i.e., green consumers, inconsistent consumers and red consumers.

Hugo & Pistikopoulos (2005) consider the multiple environmental concerns together with the traditional economic criteria. They present a multi-objective mixed integer programming model related to the designing and planning of supply chain networks.

In the field of pricing strategy and return policy in supply chain, Liu, Choi, Yuen, & Ng (2012) explore the optimal pricing, modularity level, and consumer return for a mass customization manufacturer. Mukhopadhyay and Setoputro (2004) propose a joint pricing and return policy model in an internet direct supply chain. They investigate how pricing and return policies influence customer purchaser and return decision in which they set refund amount as a decision variable. Ringbom & Shy (2004) use partial refunds in advance booking in a single-echelon supply chain. They propose a developed method for calculating profit-maximizing and optimal rates of partial refunds on customers' no-shows and cancellations.

B. Li et al. (2015) discuss the pricing and greening strategies for the chain members in both centralized and decentralized cases. Also they investigate a dual channel green supply chain consisting of a manufacturer with a direct channel and an independent retailer. In online direct selling Y. Li, Xu, & Li (2013) examine the effect of return policy, product quality and pricing strategy on the customer behavior. They develop several models showing that the return policy decision can be complementary with product quality and pricing decisions.

Xu et al. (2015) consider a two-stage supply chain including one manufacture and one retailer in which selling price, refund and return deadline as decision variables are set by retailer. Return deadline strategy depends on product lifecycle and the consumer return rate. They present a new buy-back contract in a coordinated supply chain of an upstream manufacture and downstream retailer.

To the best of our knowledge, no research was found that considers the return policy and selling price simultaneously for a one-echelon supply chain that produces two types of product; green and non-green products. This paper proposes a hybrid production mode in manufacturer supply chain that considers the return product for both type of product. Therefore, our contribution in this study is developing a hybrid production mode with considering return policy and pricing optimization for both green and non-green product.

3- Problem description

We consider a single-echelon green supply chain problem including one manufacture and one retailer in which the manufacturer produces two types of products, green and non-green products. The main difference between green and non-green products is in the price and environmental values while they are the same in their functions. Manufacturer purchases the raw material from the supplier and after producing the products sells them to the customers. In this supply chain, for stimulating the customers valuation and encourage them for enhancing the demands, manufacturer considers return policy for both products. Also manufacturer considers and determines the refund amount for products. If customers are not satisfied, they can return product to manufacturer and gets back the refund. Surely the refund amount is less than the purchasing price.

The following notations are used in this paper.

Superscripts

G denotes green products

H denotes hybrid products

Parameters

c_P Manufacturer's unit production cost for green product ($)

c_r Manufacturer's unit production cost for non green product ($)

μ_1 Sensitivity of return quantity to return policy of green product

μ_2 Sensitivity of return quantity to return policy of non-green product

ε_1 Sensitivity of return quantity to selling price of green product

ε_2 Sensitivity of return quantity to selling price of non-green product

β_1 Independent return quantity of green product

β_2 Independent return quantity of non-green product

v Consumer's valuation for products

π_m Profit of the manufacturer ($)

D Demand rate of product (unit)

R Return quantity of products (unit)

y_1 Sensitivity of utility to return policy of green product

y_2 sensitivity of utility to return policy of non green product

p_1^w Selling price of raw material of green product from the supplier ($)

p_0^w Selling price of raw material of non green product from by the supplier ($)

Decision variables

P_g	Selling price of green product ($)
P_n	Selling price of non green product ($)
r_g	Refund amount of green product to be paid by the manufacturer to customer ($)
r_n	Refund amount of non green product to be paid by the manufacturer to customer ($)

Obviously we assume that $c_P > c_r, p_1^w > p_0^w, P_g > P_n$.

The customers are assumed to have different valuations for products. Using Ferrer and Swaminathan (2006) and Zhang, Wang, & Ren (2014), Equation (1) is defined as customers' utility function for green product. v is subject to uniform distribution $[0,V]$ and also we assume that $p^w + c_m < V$ to ensure the normal profitability of the sales product. In Equation (2) customers' valuation for non-green product is defined where $0 < \lambda < 1$. In addition to customers' valuation, in the both utility functions for green and non green products, we consider the selling price and refund amount as effectible parameters. y is the sensitivity of utility to the return policy that indicates the effect of refund amount on utility function.

$$f_g^u = v - P_g + y_1 r_g \tag{1}$$

$$f_n^u = \lambda v - P_n + y_2 r_n \tag{2}$$

The return function is defined as a linear equation contains independent return quantity from the refund amount and selling price as the first term. Selling price and refund amount are two important factors that can affect the return quantity. We consider these factors have a direct correlation with the return amount. If a large refund amount is paid upon to return the products, customers' willing to return the product increases ($\partial R / \partial r > 0$) and also we consider that if the customers pay a large money for the buying the product, their willing for return the product is more than when they pay small amount ($\partial R / \partial P > 0$). So the return functions for green and non green products are given as below;

$$R_g = \beta_1 + \mu_1 r_g + \varepsilon_1 P_g \tag{3}$$

$$R_n = \beta_2 + \mu_2 r_n + \varepsilon_2 P_n \tag{4}$$

Although v is determined by consumer from the market researches, but the selling price, namely P_g, P_n and refund amount of each product, namely r_g, r_n should be determined by the manufacturer. When $f_g^u > f_n^u$ then the customers buy the green product, otherwise we expect they buys non green product. In this paper we focus on return products in hybrid and green supply chain.

4- Green production mode

In this section we explore the case when manufacturer must only produce the green product. In the following, we try to find the optimal value for selling price and refund amount for green product to maximize the manufacturer profit.

If $\lambda P_g < P_n < P_g$ then $\lambda v - P_n < \lambda v - \lambda P_g < v - P_g$ and if $y_1 r_g < y_2 r_n$ then we have $f_n^u < f_g^u$. Customer buys the green product when $f_g^u = v - P_g + y_1 r_g > 0$ and $v \geq P_g - y_1 r_g$ where $v \in [0, A]$ and one can obtain the demand for green product as below;

Now, the objective function of this case is shown in Eq. (6). This function includes the profit of

$$D_g = 1.\int_{P_g - y_1 r_g}^{V} \frac{1}{V} dv = \frac{V - P_g + y_1 r_g}{V} \tag{5}$$

selling product minus the refund amount that the manufacturer must pay for consumers for their return.

$$\max_{P_g} \pi_m^G = (P_g - p_1^w - c_P).\frac{V - P_g + y_1 r_g}{V} - r_g(\beta_1 + \mu_1 r_g + \varepsilon_1 P_g) \tag{6}$$

Theorem 1. Profit function of manufacturer is concave and has a unique optimal solution, if $\frac{-2}{V} < 0$, $4\mu_1 - \frac{{y_1}^2}{V} - V\,\varepsilon_1^{\,2} + 2y\,\varepsilon_1 > 0$. It should be noted that if the limitations are not met, then we have to use optimization software to find the optimal values of decision variables.

Proof. The first order derivatives of the profit function (6) are;

$$\frac{\delta \pi_m}{\delta P_g} = \frac{1}{V}\left(V - 2P_g + y_1 r_g + p_1^w + c_P\right) - \varepsilon_1 r_g$$

$$\frac{\delta \pi_m}{\delta r_g} = \frac{y_1}{V}\left(P_g - p_1^w - c_P\right) - \beta_1 - 2\mu_1 r_g - \varepsilon_1 P_g$$

And the second order derivatives are,

$$\frac{\partial^2 \pi_m}{\partial P_g \partial r_g} = \frac{y_1}{V} - \varepsilon_1,\ \frac{\partial^2 \pi_m}{\partial {P_g}^2} = \frac{-2}{V},\ \frac{\partial^2 \pi_m}{\partial {r_g}^2} = -2\mu_1,$$

Then the hessian matrix of the manufacturing profit is

$$H = \begin{bmatrix} \frac{-2}{V} & \frac{y_1}{V} - \varepsilon_1 \\ \frac{y_1}{A} - \varepsilon_1 & -2\mu_1 \end{bmatrix}$$

To ensure that the manufacturer has optimal solution, the hessian matrix must be negative definite and must meet the conditions $H_1 = \frac{-2}{V} < 0$, and $H_2 = \begin{vmatrix} \frac{-2}{V} & \frac{y_1}{V} - \varepsilon_1 \\ \frac{y_1}{V} - \varepsilon_1 & -2\mu_1 \end{vmatrix} > 0$ meaning that $\frac{-2}{A} < 0$ and

$$4\mu_1 - \frac{y^2}{V} - V\,\varepsilon_1^{\,2} + 2y_1\varepsilon_1 > 0.$$

According to the above theorem, the optimal price and optimal refund can be obtained as below;

$$\tilde{P}_g^G = \frac{(p_1^w + c_P)(-y_1^2 + 2V\mu_1 + V\varepsilon_1 y_1) + V^2(2\mu_1 + \beta_1\varepsilon_1) - V\beta_1 y_1}{-y_1^2 + 4V\mu_1 + 2V\varepsilon_1 y_1 - V^2\varepsilon_1^2} \tag{7}$$

$$\tilde{r}_g^G = \frac{(p_1^w + c_P + V)(y_1 + V\varepsilon_1) + 2V\beta_1}{y_1^2 - 4V\mu_1 - 2V\varepsilon_1 y_1 + V^2\varepsilon_1^2} \tag{8}$$

5- Hybrid production mode

In this section we study the second scenario in which the manufacturer produces both type of products, green and non green products simultaneously. In the following, we determine the demand quantity of products and try to find the optimal value of selling prices and refund amounts of green and non green products.

If $P_n < \lambda P_g$ or $y_2 r_n < y_1 r_g$ then manufacturer must produce both green and non green products. Also customers have two choices for purchasing each type of product based on their utility function. Therefore for calculating the demands for each type we have two conditions: (1) $f_g^u > f_n^u$; (2) $f_g^u \le f_n^u$.

If $f_g^u > f_n^u$ the consumer buys the green product then $\nu - P_g + y_1 r_g > \lambda\nu - P_n + y_2 r_n$ so $\nu > \frac{P_g - P_n + y_2 r_n - y_1 r_g}{(1-\lambda)}$ and we have $\nu \in [0, V]$ and the green market demand can be calculated using Equation (9) where $k = \frac{P_g - P_n + y_2 r_n - y_1 r_g}{(1-\lambda)}$.

$$D_g = 1.\int_k^V \frac{1}{V} dv = 1 + \frac{P_n - P_g + y_1 r_g - y_2 r_n}{(1-\lambda)V} \tag{9}$$

If $f_g^u \le f_n^u$ the consumer buys the non green product, at this time we have $f_g^u \le f_n^u$ and $f_n^u > 0$ i.e. $\frac{P_n - y_2 r_n}{\lambda} < v < k$, then the market demand for non green product can be determined as below.

$$D_n = 1.\int_{\frac{P_n - y_2 r_n}{\lambda}}^{k} \frac{1}{V} dv = \frac{\lambda P_g - P_n + y_2 r_n - \lambda y_1 r_g}{(1-\lambda)\lambda V} \tag{10}$$

By obtaining the demand of green and non green products, the objective function for hybrid production mode is:

$$\begin{aligned} \max_{P_g} \pi_m^H &= (P_g - w_1 - c_P).D_g + (P_n - w_0 - c_r).D_n - r_g R_g - r_n R_n \\ &= (P_g - p_1^w - c_P).(1 + \frac{P_n - P_g + y_1 r_g - y_2 r_n}{(1-\lambda)V}) - r_g(\beta_1 + \mu_1 r_g + \varepsilon_1 P_g) \\ &\quad + (P_n - p_0^w - c_r).(\frac{\lambda P_g - P_n + y_2 r_n - \lambda y_1 r_g}{(1-\lambda)\lambda V}) - r_n(\beta_2 + \mu_2 r_n + \varepsilon_2 P_n) \end{aligned} \tag{11}$$

Theorem 2. Profit function of manufacturer in hybrid production mode is concave and has a unique optimal solution, if the following condition is satisfied,

$$V^2 \varepsilon_1^2 (2\lambda - \lambda^2 - 1) + 2V(1-\lambda)(\varepsilon_1 y_1 + 2\mu_1) - y_1^2 > 0 \tag{12-1}$$

$$(1-\lambda)(V(1-\lambda)(V\varepsilon_1^2 - 4\mu_1 - 2\varepsilon_1 y_1) + y_1^2) < 0 \tag{12-2}$$

$$\begin{aligned} &V^3 \lambda(\lambda - 1)(\varepsilon_1^2(\lambda y_1 + y_2) + 4(\mu_1 + \mu_2) + V\lambda\varepsilon_2^2(\lambda - 1) + 2\lambda\varepsilon_2^2(\varepsilon_1 y_1 + 2\mu_1) + 8\lambda\mu_1\varepsilon_1\varepsilon_2) \\ &+ V^2 \lambda(8(1-\lambda)(\mu_2\varepsilon_2 y_1 + \mu_1\varepsilon_2 y_2 + 2\mu_1\mu_2) + 2y_1 y_2 \varepsilon_1(\varepsilon_2(2-\lambda) + \varepsilon_1) + \lambda y_1^2(\varepsilon_1 + \varepsilon_2)^2) \\ &\quad - 2V(y_2^2(2\mu_1 + \varepsilon_1 y_1) + y_1^2 \lambda(2\mu_2 + y_2(\varepsilon_1 + \varepsilon_2))) + y_2^2(y_1^2 + V^2\varepsilon_1^2) > 0 \end{aligned} \tag{12-3}$$

It should be noted that if the limitations are not met, then we have to use optimization software to find the optimal values of decision variables.

Proof 2. The first order derivatives of the profit function shown in Equation (11) are as follows.

$$\frac{\delta \pi_m}{\delta P_g} = 1 + \frac{1}{V(1-\lambda)}\left(-2P_g + 2P_n + y_1 r_g - y_2 r_n + p_1^w + c_P - p_0^w - c_r\right) - \varepsilon_1 r_g$$

$$\frac{\delta \pi_m}{\delta P_n} = \frac{1}{V(1-\lambda)\lambda}\left(2\lambda P_g - 2P_n - \lambda y_1 r_g + y_2 r_n - \lambda p_1^w - \lambda c_P + p_0^w + c_r\right) - \varepsilon_2 r_n$$

$$\frac{\delta \pi_m}{\delta r_g} = \frac{y_1}{V(1-\lambda)}\left(P_g - P_n - p_1^w - c_P + p_0^w + c_r\right) - \beta_1 - 2\mu_1 r_g - \varepsilon_1 P_g$$

$$\frac{\delta \pi_m}{\delta r_n} = \frac{y_2}{V(1-\lambda)}\left(-P_g + p_1^w + c_P\right) + \frac{y_2}{V\lambda(1-\lambda)}\left(P_n - p_0^w - c_r\right) - \beta_2 - 2\mu_2 r_n - \varepsilon_2 P_n$$

And the second order derivatives are,

$$\frac{\partial^2 \pi}{\partial P_g{}^2} = \frac{-2}{V\,(1-\lambda)},\ \frac{\partial^2 \pi}{\partial P_n{}^2} = \frac{-2}{V\,\lambda(1-\lambda)},\ \frac{\partial^2 \pi}{\partial r_g{}^2} = -2\mu_1,\ \frac{\partial^2 \pi}{\partial r_n{}^2} = -2\mu_2,\ \frac{\partial^2 \pi}{\partial P_g \partial P_n} = \frac{2}{V\,(1-\lambda)},$$

$$\frac{\partial^2 \pi}{\partial P_g \partial r_g} = \frac{y_1}{V\,(1-\lambda)} - \varepsilon_1,\ \frac{\partial^2 \pi}{\partial P_g \partial r_n} = \frac{-y_2}{V\,(1-\lambda)} - \varepsilon_1,\ \frac{\partial^2 \pi}{\partial P_n \partial r_g} = \frac{-y_1}{V\,(1-\lambda)},\ \frac{\partial^2 \pi}{\partial r_g \partial r_n} = 0$$

$$\frac{\partial^2 \pi}{\partial P_n \partial r_n} = \frac{y_2}{V\,\lambda(1-\lambda)} - \varepsilon_2,$$

The hessian matrix of the manufacturer profit for hybrid production mode is:

$$H = \left(\frac{1}{V\,(1-\lambda)}\right)\begin{bmatrix} -2 & y_1 - \varepsilon_1 V\,(1-\lambda) & 2 & -y_2 - \varepsilon_1 V\,(1-\lambda) \\ y_1 - \varepsilon_1 V\,(1-\lambda) & -2\mu_1 V\,(1-\lambda) & -y_1 & 0 \\ 2 & -y_1 & \dfrac{-2}{\lambda} & \dfrac{y_2}{\lambda} - \varepsilon_2 V\,(1-\lambda) \\ -y_2 - \varepsilon_1 V\,(1-\lambda) & 0 & \dfrac{y_2}{\lambda} - \varepsilon_2 V\,(1-\lambda) & -2\mu_2 V\,(1-\lambda) \end{bmatrix}$$

To ensure that manufacturer has optimal solution the hessian matrix must be negative definite and must meet the following conditions,

$$H_1 = -2 < 0, \quad H_2 = \begin{vmatrix} -2 & y_1 - \varepsilon_1 V\,(1-\lambda) \\ y_1 - \varepsilon_1 V\,(1-\lambda) & -2\mu_1 V\,(1-\lambda) \end{vmatrix} > 0,$$

$$H_3 = \begin{vmatrix} -2 & y_1 - \varepsilon_1 V\,(1-\lambda) & 2 \\ y_1 - \varepsilon_1 V\,(1-\lambda) & -2\mu_1 V\,(1-\lambda) & -y_1 \\ 2 & -y_1 & \dfrac{-2}{\lambda} \end{vmatrix} < 0,$$

$$H_4 = \begin{vmatrix} -2 & y_1 - \varepsilon_1 V\,(1-\lambda) & 2 & -y_2 - \varepsilon_1 V\,(1-\lambda) \\ y_1 - \varepsilon_1 V\,(1-\lambda) & -2\mu_1 V\,(1-\lambda) & -y_1 & 0 \\ 2 & -y_1 & \dfrac{-2}{\lambda} & \dfrac{y_2}{\lambda} - \varepsilon_2 V\,(1-\lambda) \\ -y_2 - \varepsilon_1 V\,(1-\lambda) & 0 & \dfrac{y_2}{\lambda} - \varepsilon_2 V\,(1-\lambda) & -2\mu_2 V\,(1-\lambda) \end{vmatrix} > 0$$

So we should have the limitations presented in equations (12-1) to (12-3). According to theorem (2), the optimal selling price and refund amount can be obtained using Equations (13) to (16) by setting the first order derivatives of profit function equal to zero.

$$P_g^H = \frac{1}{\theta}\begin{bmatrix} \lambda V^3(1-\lambda)(\lambda\varepsilon_2^2(c_r + p_0^w - p_1^w - c_P)(2\mu_1 + \varepsilon_1 y_1) + 4\mu_1(2\mu_2 + \varepsilon_2 y_2 + \beta_2\lambda\varepsilon_2) \\ +\lambda\varepsilon_2^2 y_1 + 4\beta_1\mu_2\varepsilon_1 + \varepsilon_1\varepsilon_2(2\beta_1 y_2 - \beta_2 y_1)) + (c_P + p_1^w)(Vy_2^2(y_1\varepsilon_1 + 2\mu_1) + y_1^2 y_2^2) \\ +V^2(\lambda(c_r + p_0^w - p_1^w - c_P)(\varepsilon_2 y_1(\lambda\varepsilon_2 y_1 + \varepsilon_1 y_2) + y_2^2(2\mu_1 + \beta_1\varepsilon_1) \\ -Vy_1 y_2^2\beta_1 + \lambda(\lambda-1)(c_P + p_1^w)(\varepsilon_1\varepsilon_2(y_1 y_2 + 8) + 6\mu_1\varepsilon_2 y_2 + 2\mu_2\varepsilon_1 y_1) \\ -2(\lambda\mu_1\varepsilon_2 y_2 - \mu_2\varepsilon_1 y_1)) + \lambda y_1 y_2(\beta_1\varepsilon_2(2-\lambda) + \beta_2\varepsilon_1) + 4\beta_1\mu_2\lambda y_1(1-\lambda) \\ +\lambda^2 y_1^2(2\mu_2 + \beta_2\varepsilon_2)) + V(\lambda y_1^2(2(c_R + p_1^w) - p_0^w - c_r)(2\mu_2 + y_2\varepsilon_2) - \mu_2\lambda y_1^2 y_2) \end{bmatrix} \quad (13)$$

$$P_n^H = \frac{1}{\theta}\begin{bmatrix} \lambda V^3(\lambda-1)(8\lambda\mu_1\mu_2 - \varepsilon_1^2(2\mu_2 + \varepsilon_2 y_2)(c_r + p_0^w - \lambda(c_P + p_1^w)) + \lambda V^2(2\mu_2\varepsilon_1 y_1) \\ +2\lambda(\varepsilon_1\mu_2(y_1 + 2\beta_1) + \varepsilon_2\varphi_1(y_2 + 2\beta_2)) + \beta_2\varepsilon_1^2 y_2 + \lambda\varepsilon_1\varepsilon_2(\beta_2 y_1 + \beta_1 y_2)) \\ +V^2\lambda\varepsilon_2 y_2((\lambda-2)(p_0^w + c_r) + \lambda(c_P + p_1^w))(2\mu_1 + y_1) + V^2(\lambda y_2^2(\beta_1\varepsilon_1 + 2\mu_1) \\ +\lambda^2 y_1^2(\beta_2\varepsilon_2 - 2\mu_2) + y_2\lambda(4\beta_2\mu_1(1-\lambda) + \beta_2\varepsilon_1\varepsilon_2(2-\lambda) + \beta_1\lambda\varepsilon_2 y_1)) \\ +(c_r + p_0^w)(-y_1^2 y_2^2 + V(\lambda y_1^2(y_2\varepsilon_2 + 2\mu_2) + 2y_2^2(y_1\varepsilon_1 + 2\mu_1)) \\ +V^2(\varepsilon_1^2 y_2^2 + (3\lambda-2)(2\mu_2\lambda\varepsilon_1 y_1) + (\lambda-1)8\lambda\mu_1\mu_2)) + V^4\beta_2\lambda^2\varepsilon_1^2\varepsilon_2(\lambda-1)^2 \\ -V\lambda y_1 y_2(y_1\beta_2 + y_2\beta_1) - \lambda(c_P + p_1^w)(Vy_2^2(y_1\varepsilon_1 + 2\varphi_1) + \lambda V^2(y_2^2\varepsilon_1^2)) \end{bmatrix} \quad (14)$$

$$r_g^H = \frac{1}{\theta}\begin{bmatrix} y_2^2((p_1^w + c_P)(y_1 + V\varepsilon_1) + V(V\varepsilon_1 - y_1 + 2\beta_1)) + \lambda y_1 y_2 V(\varepsilon_2(3(c_r + p_0^w) \\ -2\ p_1^w + c_P() - \lambda V) + 2\beta_2) + \lambda\varepsilon_1\varepsilon_2 V^2 y_2(3\lambda(c_P + p_1^w) - c_r - p_0^w - 2p_1^w) \\ +V\lambda(p_0^w + c_r - p_1^w - c_P)(4\mu_2 y_1 - V\varepsilon_2^2(y_1 - V\lambda\varepsilon_1(\lambda-1))) \\ +V^3(\lambda-1)(\lambda^2\varepsilon_2^2(y_1 + 2\beta_1) + 2\lambda\varepsilon_1(\varepsilon_2(\lambda\beta_2 + y_2) + 2\mu_2)) + V^4\lambda^2\varepsilon_1\varepsilon_2^2(\lambda-1)^2 \\ +\lambda V^2(4\mu_2(\lambda-1)(\varepsilon_1(p_1^w + c_P) - y_1 - 2\beta_1) + 2\varepsilon_2 y_2(-2\beta_1(1-\lambda) + y_1 - 2c_R\varepsilon_1)) \end{bmatrix} \quad (15)$$

$$r_n^H = \frac{1}{\theta}\begin{bmatrix} y_1^2(y_2(c_r + p_0^w) + \lambda V(-y_2 + \varepsilon_2(\lambda V + p_0^w + c_r) + 2\beta_2)) \\ +V^3\lambda(1-\lambda)(\varepsilon_1\varepsilon_2(\varepsilon_1(c_r + p_0^w - \lambda(c_P + p_1^w)) - \lambda(y_1 + 2\beta_1)) + 2\beta_2\varepsilon_1^2 - 4\mu_1\lambda\varepsilon_2) \\ V^2(\lambda\varepsilon_1\varepsilon_2 y_1((3\lambda-2)(c_r + p_0^w) - \lambda(p_1^w + c_P) + \varepsilon_1^2 y_2(-\lambda(c_P + p_1^w) + p_0^w + c_r) \\ +4(\lambda-1)(\mu_1\varepsilon_2(c_r + p_0^w) + \beta_2\lambda(2\mu_1 + \varepsilon_1 y_1) + \lambda\varepsilon_1 y_1 y_2) \\ +y_2 V(y_1\varepsilon_1(3\lambda(c_P + p_1^w) - 2(c_r + p_0^w)) - 4\mu_1(c_r + p_0^w + \lambda(p_1^w + c_P) + 2\lambda y_1\beta_1)) \end{bmatrix} \quad (16)$$

$$\begin{aligned} \theta = {} & V^2(8\lambda(\lambda-1)(2\mu_1\mu_2 + \varepsilon_1 y_1\mu_2 + \mu_1\varepsilon_2 y_2) + 2\lambda\varepsilon_1\varepsilon_2 y_1 y_2(2-\lambda) \\ & + \lambda^2\varepsilon_2^2 y_1^2 + \varepsilon_1^2 y_2^2) + 2\lambda V^3(\lambda-1)(\lambda\varepsilon_2^2(y_1\varepsilon_1 + 2\mu_1) + \tau_1^2(2\mu_2 + \varepsilon_2 y_2)) \\ & - V(2\lambda y_1^2(\varepsilon_2 y_2 + 2\mu_2) + 2y_2^2(\varepsilon_1 y_1 + 2\mu_1)) + y_1^2 y_2^2 + (V^2\varepsilon_1\varepsilon_2\lambda(\lambda-1))^2 \end{aligned} \quad (17)$$

6- Numerical analysis

In this section, we use several numerical examples to analyze the effect of return policy and hybrid production mode in one-echelon green supply chain. We assume $c_P = 15$, $c_r = 10$, $V = 100$, $\lambda = 0.8$,

$y_1 = y_2 = 0.9,$ and return parameter as $\beta_1 = 0.003,$ $\beta_2 = 0.002,$ $\mu_1 = 0.001,$ $\mu_2 = 0.004,$ $\varepsilon_1 = 0.0007,$ $\varepsilon_2 = 0.0009,$ and purchasing price of raw material is $p_0^w = 26, p_1^w = 30$. Results in Tables (1) and (2) show the effect of purchasing price of raw material of green and non green products on one echelon green supply chain. In Table (1) by increasing p_0^w optimal price, refund amount, demand and return amounts of green product has reduced. Similarly these values for non-green product case are increased, as presented in Table (2). But the total profit from selling the both products in both cases are decreased as presented in Tables (1) and (2).

Table 1: Results of the effect of the non-green's raw material selling price on decision variables

p_0^w	(P_g, P_n)	(r_g, r_n)	(D_g, D_n)	(R_g, R_n)	(π_g, π_n)	π
30	(76.19,69.46)	(10.95,23.58)	(0.095,0.302)	(0.067,0.159)	(2.213, 5.165)	7.379
28	(77.62, 68.70)	(24.41, 14.45)	(0.106, 0.310)	(0.072, 0.161)	(2.418, 5.573)	7.991
26	(79.05, 67.95)	(25.25, 17.96)	(0.117, 0.317)	(0.076, 0.164)	(2.623, 5.995)	8.619
24	(80.47,67.20)	(26.09,21.47)	(0.129,0325)	(0.080,0.325)	(2.830,6.431)	9.261
22	(81.90,66.45)	(26.93,24.98)	(0.140,0.332)	(0.085,0.169)	(3.036,6.88)	9.918

Table 2: Results of the effect of the green's raw material selling price on decision variables

p_1^w	(P_g, P_n)	(r_g, r_n)	(D_g, D_n)	(R_g, R_n)	(π_g, π_n)	π
34	(82.22,66.96)	(20.6,23.03)	(0.127,0.295)	(0.081,0.154)	(2.563,5.566)	8.129
32	(80.63,67.46)	(19.28,24.14)	(0.122,0.306)	(0.079,0.159)	(2.599,5.78)	8.379
30	(79.05,67.95)	(17.97,25.26)	(0.117,0.317)	(0.076,0.164)	(2.623,5.995)	8.619
28	(77.46,68.45)	(16.65,26.37)	(0.112,0.329)	(0.074,0.169)	(2.638,6.21)	8.848
26	(75.87,68.95)	(15.33,27.48)	(0.107,0.34)	(0.071,0.174)	(2.641,6.426)	9.068

Table 3: Result of the Sensitivity of return quantity to the return policy of green product

$\mu_1 (10^{-2})$	(P_g, P_n)	(r_g, r_n)	(D_g, D_n)	(R_g, R_n)	(π_g, π_n)	π
5	(75.51,63.4)	(8.44,13.61)	(0.162,0.199)	(0.098,0.113)	(4.109,3.903)	8.012
4	(75.99,64.01)	(9.73,15.18)	(0.156,0.215)	(0.095,0.12)	(3.902,4.192)	8.094
3	(76.64,64.85)	(11.49,17.33)	(0.148,0.237)	(0.091,0.13)	(3.623,4.583)	8.206
2	(77.58,66.06)	(14.02,20.42)	(0.136,0.268)	(0.085,0.143)	(3.228,5.139)	8.367
1	(79.05,67.95)	(17.97,25.26)	(0.117,0.317)	(0.076,0.164)	(2.623,5.995)	8.619

Table 4: Result of the sensitivity of return quantity to the return policy of non-green product

$\mu_2 (10^{-2})$	(P_g, P_n)	(r_g, r_n)	(D_g, D_n)	(R_g, R_n)	(π_g, π_n)	π
6	(74.88,64.33)	(7.09,15.77)	(0.082,0.291)	(0.063,0.155)	(2.015,5.807)	7.822
5	(76.48,65.72)	(11.27,19.41)	(0.096,0.301)	(0.068,0.158)	(2.25,5.878)	8.128
4	(79.05,67.95)	(17.97,25.26)	(0.117,0.317)	(0.076,0.164)	(2.623,5.995)	8.619
3	(83.83,72.1)	(30.42,36.12)	(0.157,0.348)	(0.092,0.175)	(3.311,6.22)	9.531
2	(95.82,82.52)	(61.7,63.41)	(0.258,0.424)	(0.132,0.203)	(4.99,6.831)	11.822

Tables (3) and (4) show the results of sensitivity analysis on μ_1 and μ_2. It can be seen in two tables that when μ_1 and μ_2 are increased; the total profit is decreased and also the optimal selling price, refund amount, demand and returned quantities of products for both products are reduced.

Table 5: Result of the sensitivity of return quantity to the selling price of green product

$\varepsilon_1(10^{-4})$	(P_g, P_n)	(r_g, r_n)	(D_g, D_n)	(R_g, R_n)	(π_g, π_n)	π
9	(78.02,66.69)	(15.6,22.36)	(0.13,0.288)	(0.089,0.151)	(2.908,5.447)	8.355
8	(78.52,67.31)	(16.77,23.79)	(0.124,0.302)	(0.083,0.158)	(2.765,5.717)	8.482
7	(79.05,67.95)	(17.97,25.26)	(0.117,0.317)	(0.076,0.164)	(2.623,5.995)	8.619
6	(79.6,68.62)	(19.19,26.75)	(0.111,0.333)	(0.07,0.171)	(2.483,6.283)	8.766
5	(80.17,69.3)	(20.44,28.29)	(0.104,0.348)	(0.064,0.178)	(2.342,6.582)	8.924

Table 6: Result of the sensitivity of return quantity to the selling price of non-green product

$\varepsilon_2(10^{-4})$	(P_g, P_n)	(r_g, r_n)	(D_g, D_n)	(R_g, R_n)	(π_g, π_n)	π
11	(77.86,66.9)	(15.35,22.98)	(0.109,0.314)	(0.073,0.168)	(2.455,5.839)	8.294
10	(78.44,67.42)	(16.64,24.1)	(0.113,0.315)	(0.075,0.166)	(2.538,5.914)	8.452
9	(79.05,67.95)	(17.97,25.26)	(0.117,0.317)	(0.076,0.164)	(2.623,5.995)	8.619
8	(79.67,68.51)	(19.33,26.44)	(0.122,0.319)	(0.078,0.163)	(2.713,6.082)	8.795
7	(80.33,69.09)	(20.72,27.65)	(0.126,0.321)	(0.08,0.161)	(2.807,6.174)	8.981

Results in Tables (5) and (6) show the effect of sensitivity of return quantity with respect to the selling price of green and non green products. By increasing ε_1 and ε_2 the total profit, optimal selling price and refund amount are decreased and vice versa.

Table 7: Result of the sensitivity of utility to the return policy of green product

y_1	(P_g, P_n)	(r_g, r_n)	(D_g, D_n)	(R_g, R_n)	(π_g, π_n)	π
1	(79.85,68.95)	(17.94,27.67)	(0.107,0.342)	(0.077,0.175)	(2.362,6.436)	8.798
0.95	(79.46,68.47)	(17.99,26.50)	(0.112,0.330)	(0.077,0.170)	(2.487,6.223)	8.711
0.9	(79.05,67.95)	(17.97,25.26)	(0.117,0.317)	(0.076,0.164)	(2.623,5.995)	8.619
0.85	(78.61,67.4)	(17.87,23.92)	(0.123,0.304)	(0.076,0.158)	(2.771,5.751)	8.522
0.8	(78.14,66.81)	(17.67,22.48)	(0.129,0.289)	(0.075,0.152)	(2.932,5.49)	8.422

Table 8: Result of the sensitivity of utility to the return policy of non-green product

y_2	(P_g, P_n)	(r_g, r_n)	(D_g, D_n)	(R_g, R_n)	(π_g, π_n)	π
1	(83.13,71.52)	(28.3,30.84)	(0.151,0.341)	(0.089,0.190)	(3.214,6.254)	9.468
0.95	(80.96,69.62)	(22.82,27.93)	(0.133,0.328)	(0.082,0.176)	(2.900,6.116)	9.016
0.9	(79.05,67.95)	(17.97,25.26)	(0.117,0.317)	(0.076,0.164)	(2.623,5.995)	8.619
0.85	(77.35,66.48)	(13.67,22.77)	(0.103,0.308)	(0.071,0.153)	(2.379,5.891)	8.27
0.8	(77.35,66.48)	(13.67,22.77)	(0.103,0.308)	(0.071,0.153)	(2.379,5.891)	8.27

From Tables (7) and (8), based on sensitivity of customer to the refund amount, manufacturer can increase his profit by increasing the refund amount.

Table (9) shows the effect of λ in hybrid production mode in one-echelon green supply chain by considering return policy. By increasing λ the total profit is increased and also can realize that the profit of non-green product is more sensitive rather that the profit of green product respect to the changes of λ. Moreover the effect of λ changes on profit is presented in Figure (1).

Table 9: The effect of λ

λ	(P_g,P_n)	(r_g,r_n)	(D_g,D_n)	(R_g,R_n)	(π_g,π_n)	π
09	(81.63,71.42)	(24.19,22.43)	(0.137,0.293)	(0.084,0.156)	(2.997,6.887)	9.884
0.85	(80.36,69.66)	(21.12,23.78)	(0.128,0.305)	(0.08,0.16)	(2.812,6.456)	9.268
0.8	(79.05,67.95)	(17.97,25.26)	(0.117,0.317)	(0.076,0.164)	(2.623,5.995)	8.619
0.75	(77.72,66.3)	(14.75,26.88)	(0.107,0.332)	(0.072,0.169)	(2.432,5.502)	7.934
0.7	(76.38,64.73)	(11.52,28.7)	(0.096,0.348)	(0.068,0.175)	(2.242,4.97)	7.212

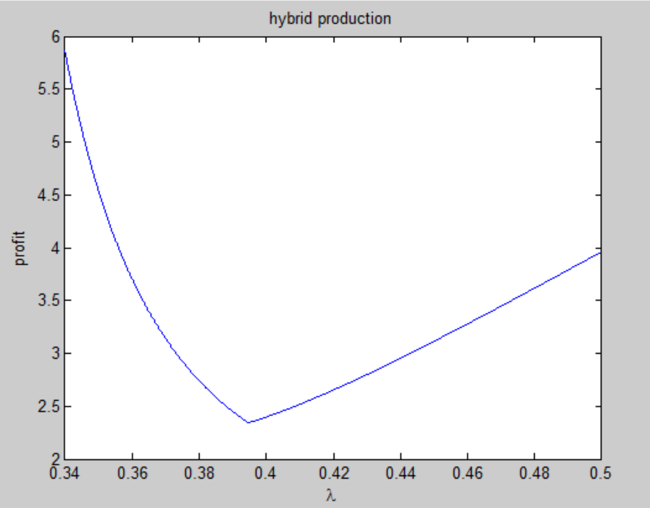

Fig. 1: Effects of λ on profit

Table 10: Effects of λ on the production mode

λ	(P_g,P_n)	(r_g,r_n)	(D_g,D_n)	(R_g,R_n)	(π_g,π_n)	π
0.36	(86.51,0)	(36.66,0)	(0.178,0)	(0.100,0)	(3.705,0)	3.705
0.39	(77.84,0)	(15.38,0)	(0.109,0)	(0.073,0)	(2.453,0)	2.453
0.4	(76.34,62.02)	(11.67,55.98)	(0.097,0.612)	(0.068,0.282)	(2.239,0.158)	2.397
0.42	(74.34,60.92)	(6.76,51.08)	(0.081,0.563)	(0.062,0.261)	(1.956,0.695)	2.651
0.44	(73.21,60.34)	(3.97,47.42)	(0.072,0.527)	(0.058,0.246)	(1.796,1.156)	2.952

7- Conclusion

In this paper we develop a one-echelon supply chain consisting of a manufacturer who produces two types of products, green and non green one. These products have a same function but in price and environmental issues are different. The raw material price, production cost, and selling price for green product are higher than non green one. Manufacturer suggests a return policy for enhancing the customers valuation and encourage them for increasing the demand for both types of product. So, in addition to the selling price, manufacturer should consider a refund amount for returned product that must be paid to the customers. So if the customers are not satisfied from the product, they can return products to manufacturer and receive the refund amount. The demand and return quantities of green and non green products depend on selling price and refund amount that must be determined by the manufacturer. Accordingly the selling price and refund amount play important role for manufacturer to maximize their profit, so in this paper we have developed and analysis a joint decision model of pricing strategy and return policy in hybrid production mode that find the maximum profit of manufacturer.

We focused on the system performance in hybrid and green production modes in a single-echelon green supply chain and on this issue that when the manufacturer must produce green product and when must use hybrid production mode. Also we consider the return policy and its effect on the proposed supply chain. We explore the sensitivity analysis of the parameter and their effects on system performance.

Considering quality as an important factor that can influence the demand and reduce the return product, this subject can be presented as a future research topic. As the green product effects on decision variables, one can consider the government attempt or advertisement efforts to pursue customers for buying the green product. We consider a single-echelon supply chain, while for future research a two or multi echelon supply chain and the extension of return policy between all levels can be considered.

Acknowledgments
The authors would like to thank the financial support of the University of Tehran for this research under Grant Number 30015-1-02.

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