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OPTIMAL DECISIONS ON PRICING AND GREENING POLICIES OF MULTIPLE MANUFACTURERS UNDER GOVERNMENTAL REGULATIONS ON GREENING AND CARBON EMISSION

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Abstract: *This paper determines the optimal decisions on pricing and greening strategies of substitutable products which are manufactured by duopoly competitor firms in a consumer sensitive market where a consumer can choose a particular product by its retail price and greening level. The firms simultaneously produce these substitute products under carbon emission regulations enacted by government administration. Government's carbon emission regulation like carbon tax or cap and trade may not be enough to direct optimization of social greening welfare but may force to mandate the firms to satisfy a standard greening level to handle it. A penalty or subsidy is levied per unit difference in greening standards as well as with the cape and trade regulation on carbon emission. The contesting firm managers face the problem of fixing the conflicts on carbon penalty and greening investment to decide the optimum policies. For numerical examples, the optimal decisions of the firm managers are obtained by maximizing the profit following government's mandatory regulations. Some managerial insights are outlined and sensitivity analyses on key parameters of the model are graphically presented.*

Key words*: Green product, Carbon emission, Substitute product, Duopoly firm, Government regulations.*

1. Introduction

The commercial ecological conflict has taken a new dimension especially when sustainability standards of operations are part of practice. Generally, in a production firm, products are made by means of continuing responsibility to ecological standards in their affirmation and operations because those impact on the global or local

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environment, community, society, or economy. Thus, constitution of a state obviously narrates that it is the commitment of the state to anchor and improve the nature and to conserve the green environment and untamed existence of the country. It powers a commitment on every local to guarantee and upgrade the normal territory for regular life and to deal with violators. It accommodates creation of vitality through advancement of sustainable power source assets as per the states of condition, full scale financial conditions and atmosphere to decrease the carbon emissions and in addition to diminish reliance on the non-renewable energy sources. Regarding issues on Government impositions of green cess, a tax earmarked for special purposes, across different states is also under-lining green activism towards achieving goals of greener environment. Inconvenience of green cess is one such choice to influence citizens and stakeholders to take part towards green activism for protecting environment although many of the cases are challenges to the stake-holders who are affected commercially by such imposition.

In this article, we would base on the law of issues relating to green cess. We investigate for optimal decisions on prices and green levels for two competing co-firms which produce substitute products with different greening levels.

2. Literature Review

In the past two decades, various government directions were established to ensure the earth and check carbon flows into the atmosphere. For instance, the Canadian central government prohibited brilliant lights from being made or imported into Canada; however, a couple of claims to fame radiant lights were exempted. The arrangement was planned to diminish vitality utilization. Therefore, the approach prompted the expanded utilization of conservative bright lights (CFLs) and Light Emitting Diodes (LED) lights, which are more vitality productive (Blackwell 2015). Another case of how the administration assumes a job in ensuring the earth is exhibited through the boycott of plastic froth holders in Zimbabwe because of the thing discharging harmful synthetic substances when warmed. Because of these worries, Zimbabwe's Environment Management Agency requested eateries to utilize recyclable or biodegradable bundles (Mhofu 2017). The agency recommends restaurants to use paper packaging or encourage patrons to partake of their food on site. The change in consumer demand for green products and processes, non-official pressures on government legislation and business, make it challenging for organizations to process their supply discipline and re-orient the products. Ghosh and Shah (2012), Swami and Shah (2013) and Ghosh et al. (2018) studied a channel for the manufacturer and the retailer who invested in greening efforts, and this phenomenon is reflected in the expression of the demand.

The study of product replacement (Maity and Maiti (2009), Krommyda et al. (2015), De et al. (2016), De et al. (2018)) has gained significant attention of the researchers, because it contributes to the success of the company's decisions regarding material/product planning, price and inventory control. Recently, substitute products dependent on the stock-level displayed to each other was investigated by Pan et al. (2018).

The decision of the production firms to produce more eco-friendly products stems from their desire to raise profit through improving customer satisfaction. Hafezi and Zolfagharinia (2018) investigated a green product development model where product types, market price(s) and quality dimensions were considered as decisions of the production firm. The main objective was to derive how governmental regulations can be set as a driver of green production and for the benefit of the environment.

Krass et al.(2013) investigated the technology selection and production decisions model of a profit-maximizing firm under carbon tax. The increase of the tax rate does not necessarily induce the firm to adopt cleaner technology. Zhang and Xu (2013) discussed a firm's optimal production quantities under cap-and-trade regulation. They found that cap-and-trade regulation can induce the firm to produce more carbon efficient products. After that, He et al. (2015) focused on a production lot-sizing problem for a carbon-intensive firm under cap-and-trade regulation. The most relevant studies in a competitive environment were carried out by Hua et al. (2011) and Sun (2012) who solved their problems through game theory. A few studies provided a comprehensive analytical investigation on the role of government control (e.g., Chen 2001, Zhang et al. 2012, Gouda et al. 2016).

In this paper, we formulate a model where two competitive firms manufacture two substitute products and sell these products separately in a consumer sensitive market. The model is solved by simultaneous Nash Game theory. In addition to being confined to a competitive environment, the current study evaluates the role of government regulations on green level and carbon emission and meets some important gaps in literature, where different optimal strategies on prices and green levels are found out for the firms and associated green development costs are numerically investigated and presented graphically.

3. Formulation of Model

3.1 Assumptions

a) Two competitive firms produce two substitute products and sell their products separately in the market.
b) Products are substitutable on the basis of their prices and green levels.
c) Demand of each firm is considered to be linearly decreasing in price and increasing in greening level.
d) The effect of one firm's own price on its market demand is greater than that of its competitor.
e) The effect of product greening level on quantity demanded for a firm is more than that of its competitor.
f) Total potential demand of the market is divided into two parts provided by the significant loyalty of product to the customers.
g) The firms incur a cost of greening which is a quadratic function of green level of the product.
h) Government mandates to the firms to keep a standard greening level and limiting amount of carbon emission. A penalty or subsidy is levied per unit difference in greening standards and carbon emission per unit product produced.

3.2. Notations

s_i : Selling price per unit product (dollar/unit).

c_i : Production cost per unit product (dollar/unit).

g_i : Greening level of each product (per unit).

g_0 : Government mandated standard greening level (per unit).

R_g : Penalty or subsidy levied per unit difference in greening standards per unit produced (dollar/unit).
C_0 : Government mandated limiting amount of carbon emission per unit product (ton/unit).
R_c : Tax or reward levied per unit difference in amount of carbon emission per unit produced (dollar/unit).
D_i : Demand of each product in the market (unit).
Ce_i : Amount of carbon emission to produce a product (ton/unit).
I_i : Investment parameter of greening (dollar-unit^2).
a : Potential demand in the market (unit).
λ : Degree of customer loyalty to a product, $0 \le \lambda \le 1$.
α, β : Demand sensitivity to price of the product, $\alpha > \beta > 0$, (unit^2/dollar).
γ, δ : Demand sensitivity to product greening level, $\gamma > \delta > 0$, (unit^2).

3.3. Model Development

In our model, two manufacturers act as competitors by producing substitute product with different quality in a duopoly green sensitive market where customers choose one type of product on the basis of its retail price and greening level. Therefore, demands confronted by the manufacturers are linear functions of selling prices and green levels of the substitute products. Both demands to the manufacturers are considered downward sloping in own selling price and upward sloping in own green degree. This consideration is similar to Ghosh and Shah (2012). The impact of a manufacturer's own price on its market demand is greater than that of its competitor i.e., $\alpha > \beta$ and also the impact of greening level on demand for a manufacturer is more than that of its competitor ($\gamma > \delta$) [cf. Chen (2001)]. Further, according to Li et al. (2016) the potential market demand a of the green products is assumed to be constant and it is fractionally divided into two parts λa and $(1-\lambda)a$ on the basis of the degree of customer loyalty λ to a desire product. Thus, the demand functions for two competitive manufacturers can be written as follows:

$$\begin{aligned} D_1(s_1, g_1, s_2, g_2) &= \lambda a - \alpha s_1 + \beta s_2 + \gamma g_1 - \delta g_2 \\ D_2(s_1, g_1, s_2, g_2) &= (1-\lambda) a - \alpha s_2 + \beta s_1 + \gamma g_2 - \delta g_1 \end{aligned} \tag{1}$$

Moreover, the manufacturers acquire an expense $I_i g_i^2$ of greening which is a quadratic function of green level g_i of the product [cf. Savaskan et al. (2004), Ghosh and Shah (2012), Swami and Shah (2013)]. Further, Government regulates the manufacturing firms to keep a standard greening level g_0 and constraint measure of carbon emission C_0 per unit production. The firm is penalized if it does not acquire the standard greening level g_0 or it excesses greater carbon than the permitted cap C_0. While in a case where the firm provides more greening level and less carbon emission than mandated standards, a reward or subsidy proportional to the difference is awarded to the firm by the Government. Following Yang and Xiao (2017) and Ghosh et al. (2018), penalties or rewards (R_g and R_c) are imposed per unit difference in greening benchmarks ($g_0 - g_i$) and carbon emission (Ce_i-C_0) per unit production. Thus, the profit functions of each firm under these government regulation schemes are:

$$\Pi_1(s_1, g_1) = (s_1 - c_1)D_1 - I_1 g_1^2 - R_g(g_0 - g_1)D_1 - R_c(Ce_1 - C_0)D_1$$
$$\Pi_2(s_2, g_2) = (s_2 - c_2)D_2 - I_2 g_2^2 - R_g(g_0 - g_2)D_2 - R_c(Ce_2 - C_0)D_2 \quad (2)$$
$$s_1, g_1, s_2, g_2 \geq 0$$

Here, the objective is to maximize (2) with respect to key decision variables selling price and greening level of a product under Government mandated regulations.

Table 1. Different indices

Term	Expression
A	$\frac{1}{4\alpha^2 - \beta^2}[\{2\lambda\alpha + (1-\lambda)\beta\}a + 2\alpha^2\{c_1 + R_g g_0 + R_c(Ce_1 - C_0)\} + \alpha\beta\{c_2 + R_g g_0 + R_c(Ce_2 - C_0)\}]$
B	$\frac{1}{4\alpha^2 - \beta^2}[\{2(1-\lambda)\alpha + \lambda\beta\}a + 2\alpha^2\{c_2 + R_g g_0 + R_c(Ce_2 - C_0)\} + \alpha\beta\{c_1 + R_g g_0 + R_c(Ce_1 - C_0)\}]$
A_1	$\frac{1}{4\alpha^2 - \beta^2}[2\alpha(\gamma - \alpha R_g) - \beta\delta]$
A_2	$\frac{1}{4\alpha^2 - \beta^2}[2\alpha\delta - \beta(\gamma - \alpha R_g)]$
A_3	$2I_1 + 2(A_1 + R_g)(\alpha A_1 + \beta A_2 - \gamma)$
A_4	$(A_1 + R_g)(\alpha A_2 + \beta A_1 - \delta) + A_2(\alpha A_1 + \beta A_2 - \gamma)$
A_5	$2I_2 + 2(A_1 + R_g)(\alpha A_1 + \beta A_2 - \gamma)$
E	$(\alpha A_1 + \beta A_2 - \gamma)\{A - c_1 - R_g g_0 - R_c(Ce_1 - C_0)\} - (A_1 + R_g)(\lambda a - \alpha A + \beta B)$
F	$(\alpha A_1 + \beta A_2 - \gamma)\{B - c_2 - R_g g_0 - R_c(Ce_2 - C_0)\} - (A_1 + R_g)\{(1-\lambda)a - \alpha B + \beta A\}$

Proposition 1.

(a) The optimal greening levels for maximum profit achieved by the manufacturers under competition are

$$g_1^* = \frac{A_5 E + A_4 F}{A_4^2 - A_3 A_5},\ when\ I_1 + (A_1 + R_g)(\alpha A_1 + \beta A_2 - \gamma) > 0$$
$$g_2^* = \frac{A_4 E + A_3 F}{A_4^2 - A_3 A_5},\ when\ I_2 + (A_1 + R_g)(\alpha A_1 + \beta A_2 - \gamma) > 0 \quad (3)$$

(b) The optimal selling prices for maximum profit achieved by the manufacturers under competition are

$$s_1^* = A + A_1 g_1^* - A_2 g_2^*$$
$$s_2^* = B + A_1 g_2^* - A_2 g_1^* \quad (4)$$

where g_1^* and g_2^* are given in equation (3). All the helping symbols are described in Table 1.

Proof. We utilize in reverse induction technique to tackle the objectives. Firstly, optimum selling prices s_i's are obtained by given greening levels g_i's. We determine the objective functions in the following form:

$$\begin{aligned}\Pi_1(s_1,g_1) = \;& \{s_1 - c_1 - R_g(g_0 - g_1) - R_c(Ce_1 - C_0)\}(\lambda a - \alpha s_1 \\ & +\beta s_2 + \gamma g_1 - \delta g_2) - I_1 g_1^2 \\ \Pi_2(s_2,g_2) = \;& \{s_2 - c_2 - R_g(g_0 - g_2) - R_c(Ce_2 - C_0)\}\{(1-\lambda)a - \alpha s_2 \\ & +\beta s_1 + \gamma g_g - \delta g_1\} - I_2 g_2^2 \\ & s_1, g_1, s_2, g_2 \geq 0\end{aligned} \tag{5}$$

The first order partial derivatives of Π_1 and Π_2 with respect to s_i are

$$\begin{aligned}&\frac{\partial \Pi_1(s_1,g_1)}{\partial s_1} = \lambda a - 2\alpha s_1 + \beta s_2 + g_1(\gamma - \alpha R_g) - \delta g_2 \\ &+\alpha\{c_1 + R_g g_0 + R_c(Ce_1 - C_0)\} \\ &\frac{\partial \Pi_2(s_2,g_2)}{\partial s_2} = (1-\lambda)a - 2\alpha s_2 + \beta s_1 + g_2(\gamma - \alpha R_g) - \delta g_1 \\ &+\alpha\{c_2 + R_g g_0 + R_c(Ce_2 - C_0)\}\end{aligned} \tag{6}$$

Also, we have

$$\frac{\partial^2 \Pi_i}{\partial^2 s_i} = -2\alpha < 0, \; for\, i = 1,2$$

Thus, the profit function Π_i is strictly concave in s_i. Equating to zero the first order partial derivatives $\frac{\partial \Pi_1}{\partial s_1}$ and $\frac{\partial \Pi_2}{\partial s_2}$ given in (6), we get

$$\begin{aligned}2\alpha s_1 - \beta s_2 = \;& \lambda a + g_1(\gamma - \alpha R_g) - \delta g_2 + \alpha\{c_1 + R_g g_0 + R_c(Ce_1 - C_0)\} \\ -\beta s_1 + 2\alpha s_2 = \;& (1-\lambda)a + g_2(\gamma - \alpha R_g) - \delta g_1 + \alpha\{c_2 + R_g g_0 + R_c(Ce_2 - C_0)\}\end{aligned} \tag{7}$$

Solving the equations (7) for s_1 and s_2 simultaneously, we obtain the equilibrium price for the manufacturers as

$$\begin{aligned}s_1 &= A + A_1 g_1 - A_2 g_2 \\ s_2 &= B + A_1 g_2 - A_2 g_1\end{aligned} \tag{8}$$

where A, B, A_1 and A_2 are given in Table 1.

The corresponding profits of the manufacturers at the equilibrium prices are:

$$\begin{aligned}\Pi_1(g_1,g_2) = \;& \{A - c_1 - R_g g_0 - R_c(Ce_1 - C_0) + (A_1 + R_g)g_1 - A_2 g_2\}\{(\lambda a \\ & -\alpha A + \beta B) - (\alpha A_1 + \beta A_2 - \gamma)g_1 + (\alpha A_2 + \beta A_1 - \delta)g_2\} - I_1 g_1^2 \\ \Pi_2(g_1,g_2) = \;& \{B - c_2 - R_g g_0 - R_c(Ce_2 - C_0) + (A_1 + R_g)g_2 - A_2 g_1\}\{(1-\lambda)a \\ & -\alpha B + \beta A - (\alpha A_1 + \beta A_2 - \gamma)g_2 + (\alpha A_2 + \beta A_1 - \delta)g_1\} - I_2 g_2^2\end{aligned} \tag{9}$$

To find the optimal green level, we differentiate the profit function Π_i given in (9) partially with respect to g_i and equating it to zero. The best activities for the manufacturers in equilibrium are given by

$$\begin{aligned} -A_3 g_1 + A_4 g_2 &= E \\ A_4 g_1 - A_5 g_2 &= F \end{aligned} \tag{10}$$

where A_3, A_4, A_5, E and F are given in Table 1.

The solution of the above equation (10) for g_1 and g_2 are

$$\begin{aligned} g_1 &= \frac{A_5 E + A_4 F}{A_4^2 - A_3 A_5} \\ g_2 &= \frac{A_4 E + A_3 F}{A_4^2 - A_3 A_5} \end{aligned} \tag{11}$$

The second partial derivatives of the profit functions with respect to green level are $\frac{\partial^2 \Pi_1}{\partial^2 g_1} = -A_3$ and $\frac{\partial^2 \Pi_2}{\partial^2 g_2} = -A_5$.

This shows that the profit functions are strictly concave in the green level when $A_3 > 0$ and $A_5 > 0$.

Proposition 2. The impact of own greening level on its optimal selling price decision is greater or less than that of its competitor according as $R_g < or > \frac{\gamma - \delta}{\alpha}$.

Proof: The difference between the coefficients of g_1^* and g_2^* in equation (4) is $A_1 - A_2$ and which is given by

$$A_1 - A_2 = \frac{1}{4\alpha^2 - \beta^2}[2\alpha(\gamma - \alpha R_g) - \beta\delta] - \frac{1}{4\alpha^2 - \beta^2}[2\alpha\delta - \beta(\gamma - \alpha R_g)]$$

$$= \frac{1}{4\alpha^2 - \beta^2}(2\alpha + \beta)(\gamma - \delta - \alpha R_g)]$$

As $\alpha > \beta$ and $\gamma > \delta$ by our assumption, we have $A_1 - A_2 >$ or < 0 according as $R_g < or > \frac{\gamma - \delta}{\alpha}$. Hence, the proof is complete.

4. Numerical Results

In the preceding section, we have obtained the optimal values of different decision variables and objective functions. We choose the following parameter-values for our numerical analysis: Let the base demand in the market be a=1500 units, degree of customer loyalty to order a product λ=0.50, demand response to own price α=0.750 unit^2/dollar, demand response to competitor's price β=0.50 unit^2/dollar, demand response to own greening level γ=5.00 unit^2, demand response to competitor's greening level δ=2.75 unit^2, government standard greening level is mandated by g_0 = 8.0/unit, penalty or subsidy levied per unit difference in greening standards per unit product R_g=1.5 dollar/unit, production cost for both products c_1=5 dollar/unit, c_2=4 dollar/unit, amount of carbon emission to produce both products Ce_1=40 ton/unit and Ce_2=50 ton/unit, government offered limiting amount of carbon emission C_0=10 ton/unit, tax or reward levied per unit difference in amount of carbon emission R_c=30 (dollar/unit), investment parameters of greening for both products I_1=700 dollar-unit^2 and I_2=600 dollar-unit^2.

In this set-up, the optimal solution is obtained as follows: optimal selling prices $s_1^* = 1468.25$ dollar/unit, $s_2^* = 1523.90$ dollar/unit, optimal greening levels $g_1^* = 2.20957$, $g_2^* = 2.14343$ and the optimal profits $\pi_1^* = 227235$ dollar, $\pi_2^* = 156715$ dollar. The concavity property and contour plot of profit function is graphically shown in Figure 1.

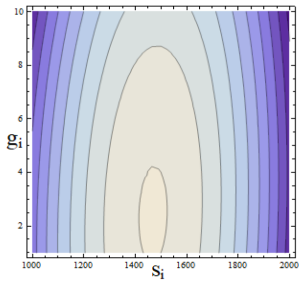


Figure 1(b): Contour plot of profit function against selling price and

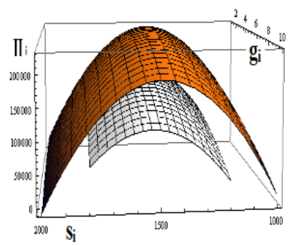


Figure1(a): Concavity of manufacturer's profit function against selling price and green level.

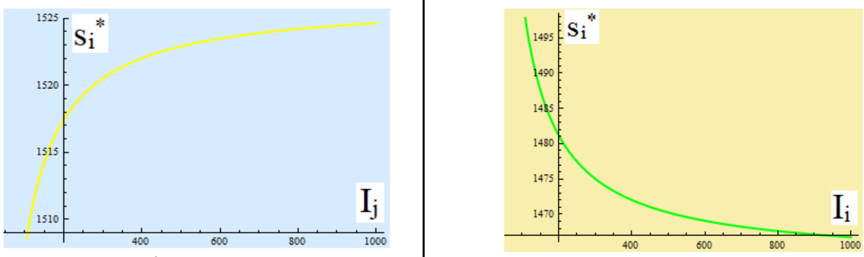
Figure 1. Concavity property and contour plot of profit function.

4.1 Impacts of greening investment cost

Observation 1:

a) Given greening investment cost I_i of its own, the optimal pricing s_i^* of the product is increasing in competitor's cost of greening investment I_j. Refer to Figure 2(a).

b) Given greening investment cost I_j of its competitor, the optimal pricing s_i^* of the product is decreasing in its own cost of greening investment I_i. Refer to Figure 2(b).



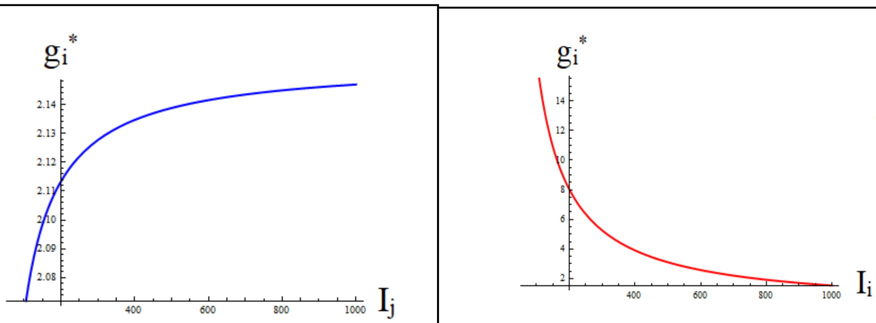
a) s_i^* vs. I_j b) s_i^* vs. I_i

Figure 2. Optimal selling price against greening investment.

Observation 2:

a) Given manufacturer's own greening investment cost, the level of greening of each manufacturer is increasing in its competitor's greening investment cost. Refer to Figure 3(a).

b) Given greening investment cost of its competitor, greening level of a product is decreasing in its own greening investment cost. Refer to Figure 3b.



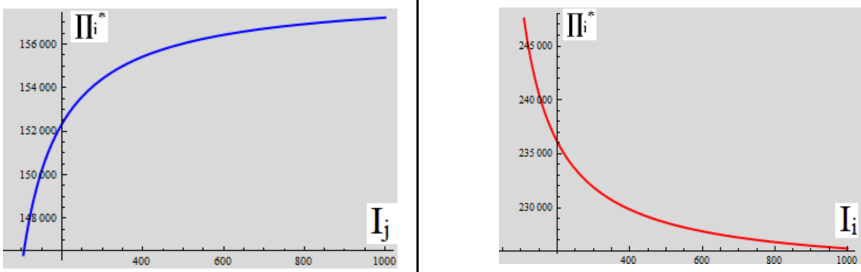
a) g_i^* vs. I_j b) g_i^* vs. I_i

Figure 3: Optimal greening level against greening investment.

Observation 3

a) Given greening investment cost I_i of its own, the optimal profit Π_i^* of the manufacturer is increasing in competitor's cost of greening investment I_j. Refer to Figure 4(a).

b) Given greening investment cost I_j of its competitor, the optimal profit Π_i^* of the manufacturer is decreasing in its own cost of greening investment I_i. Refer to Figure 4(b).



a) Π_i^* vs. I_j

b) Π_i^* vs. I_i

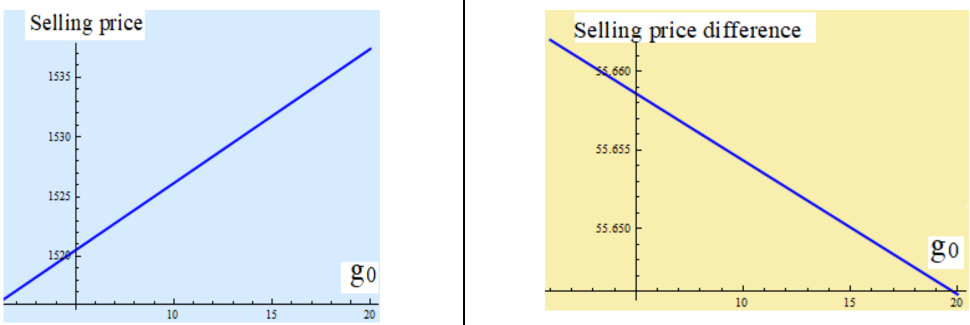
Figure 4: Optimal profit against greening investment.

4.2. Impacts of Government regulations on greening and carbon emission

Observation 4

a) For given one manufacturer's selling price, it competitor's selling price is increasing with the Government mandated greening level g_0. Refer to Figure 5(a).

b) The relative optimal selling price difference between the two manufacturers is decreasing in mandated greening level g_0. Refer to Figure 5(b).



a) Manufacturer's selling price vs. g_0

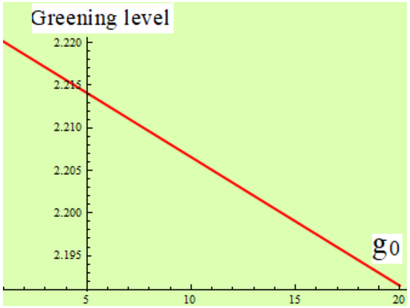
b) Relative selling price vs. vs. g_0

Figure 5. Selling price vs. govt. standard greening level

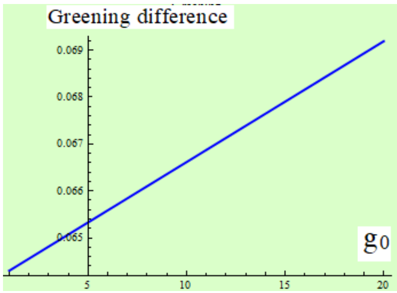
Observation 5

a) For given one manufacturer's greening level, it competitor's greening level is decreasing with the Government mandated greening level g_0. Refer to Figure 6(a).

b) The relative optimal greening level difference between the two manufacturers is increasing in mandated greening level g_0. Refer to Figure 6(b).



a) Product's greening level vs. g_0



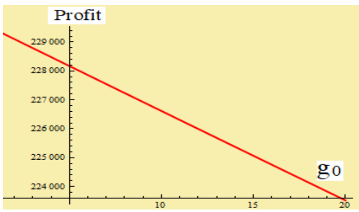
b) Relative greening level vs. g_0

Figure 6. Manufacturer's greening level vs. govt. standard greening level.

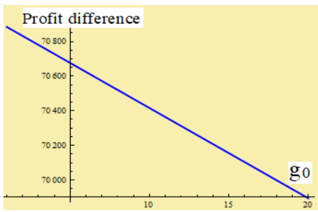
Observation 6

a) Each manufacturer's optimal profit is decreasing with the Government mandated greening level g_0. Refer to Figure 7(a).

b) The relative optimal profit difference between the two manufacturers is decreasing in mandated greening level g_0. Refer to Figure 7(b).



a) Manufacturer's profit vs. g_0

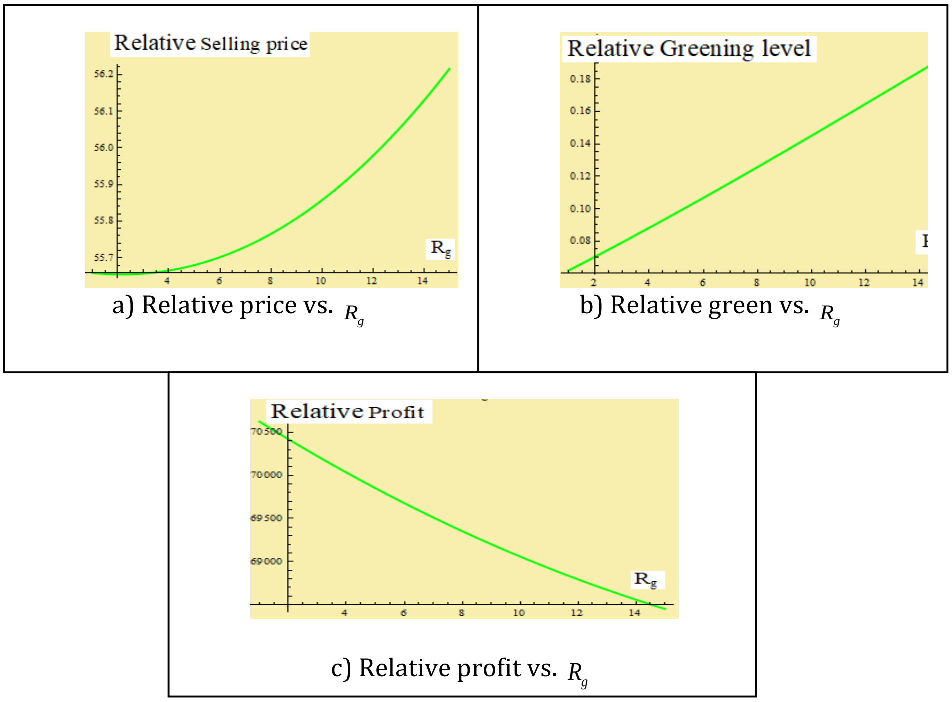


b) Relative profit vs. g_0

Figure 7. Manufacturer's profit vs. govt. standard greening level.

Observation 7

a) The relative optimal selling price difference between the two manufacturers is increasing in government penalty or subsidy on greening. Refer to Figure 8(a).
b) The relative optimal greening level difference between the two manufacturers is increasing in government penalty or subsidy on greening. Refer to Figure 8(b).
c) The relative optimal profit difference between the two manufacturers is decreasing in government penalty or subsidy on greening. Refer to Figure 8(c).



a) Relative price vs. R_g

b) Relative green vs. R_g

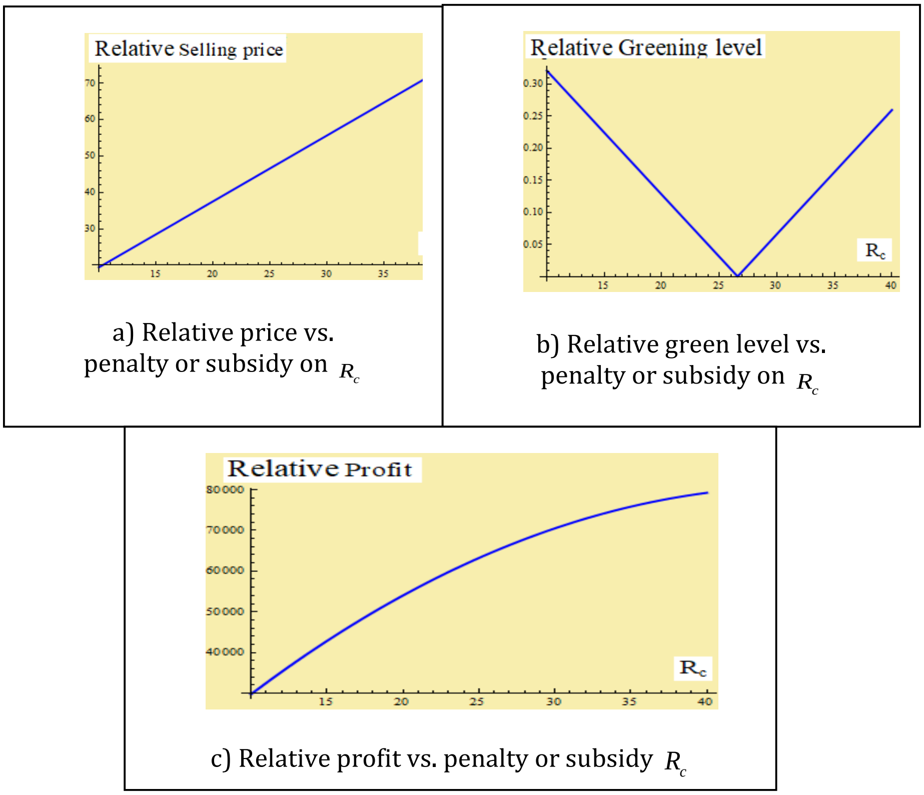
c) Relative profit vs. R_g

Figure 8: Relative price, greening and profit vs. penalty or subsidy on greening.

Observation 8

a) The relative optimal selling price difference between the two manufacturers is increasing in government penalty or subsidy on carbon emission. Refer to Figure 9(a).
b) The relative optimal greening level difference between the two manufacturers is decreasing first and then increasing in government penalty or subsidy on carbon emission. Refer to Figure 9(b).

c) The relative optimal profit difference between the two manufacturers is increasing in government penalty or subsidy on carbon emission. Refer to Figure 9(c).



a) Relative price vs. penalty or subsidy on R_c

b) Relative green level vs. penalty or subsidy on R_c

c) Relative profit vs. penalty or subsidy R_c

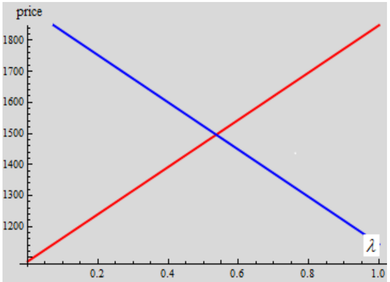
Figure 9. Relative price, greening and profit vs. penalty or subsidy on carbon emission.

4.3. Impacts of customer loyalty λ on price, green level, demand and profit of manufacturer

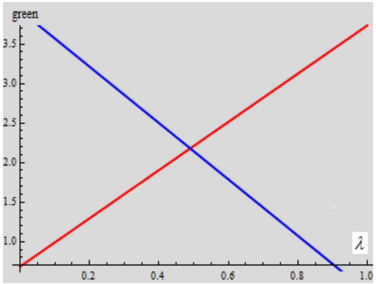
The degree of customer loyalty λ to the competitors in the market is very important. A reasonable number of customer's loyal to a product may affect the manufacturer's decision for both competitors. Varying the value of λ in the interval [0,1] the following observation are made:

Observation 9

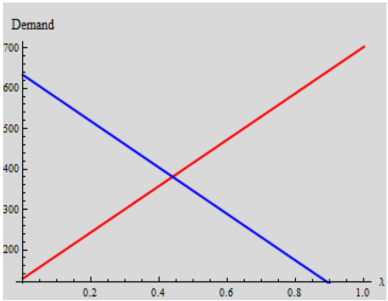
Manufacturer's optimal price, greening level, demand and profit are having opposite characteristics compared to those of its competitor for changing customer loyalty parameter λ. Refer to Figures 10(a)-10(d).



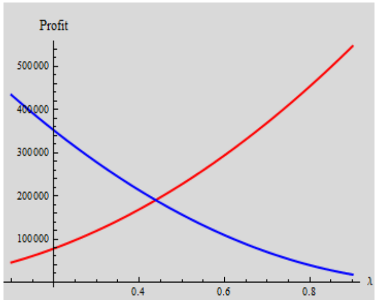
a) Manufacturer's prices vs. λ



b) Manufacturer's greening levels vs. λ



c) Manufacturer's demands vs. λ.



d) Manufacturer's profits vs. λ

Figure 10. Manufacturer's prices, greening levels, demands and profits vs. customer loyalty parameter.

4.4. Impacts of demand keys on optimum decisions and profit

Table 2 presents some sensitivity analysis on demand keys for optimum decision variables and profits of the model by changing the key values -30%, -15%, 15% and 30%, respectively, taking one at a time and keeping the other parameters unchanged. From Table 2, the following observations are made:

Observation 10

a) As α increases, the selling price and the greening level decrease. As a result, demands and profits decrease more sensitively.
b) β plays negative role compared to α. It increases the market demands and profits of the manufacturers.
c) Increasing in γ marginally increases the values of optimal decisions and profit.
d) Similar to comparing between price keys α and β, δ follows negative sense of γ because it decreases optimum results of the model.

Table 2. Sensitivity analysis of demand keys (ΔX denotes % change in X)

Keys	Changes in %	Δs_1^*	Δs_2^*	Δg_1^*	Δg_2^*	Δd_1^*	Δd_2^*	$\Delta \Pi_1^*$	$\Delta \Pi_2^*$
	-30.00	56.55	54.28	139.36	168.02	75.38	96.38	337.41	447.99
α	-15.00	20.00	19.16	48.81	59.00	30.26	39.17	99.30	127.45
	15.00	-12.63	-12.06	-31.41	-38.15	-23.66	-31.16	-49.27	-58.73
	30.00	-21.33	-20.36	-53.85	-65.54	-43.82	-58.05	-75.68	-86.43
	-30.00	-13.49	-12.72	-34.86	-41.39	-35.91	-42.34	-58.95	-66.77
β	-15.00	-7.21	-6.82	-18.65	-22.16	-19.19	-22.68	-34.71	-40.23
	15.00	8.37	7.94	21.81	25.94	22.28	26.43	49.54	59.87
	30.00	18.21	17.31	47.82	56.92	48.47	57.61	120.47	148.47
	-30.00	-0.20	-0.20	-30.77	-30.85	-0.74	-0.86	-0.70	-0.82
γ	-15.00	-0.12	-0.11	-15.48	-15.54	-0.41	-0.49	-0.41	-0.48
	15.00	0.16	0.14	15.71	15.81	0.51	0.60	0.53	0.63
	30.00	0.35	0.33	31.70	31.96	1.12	1.31	1.18	1.39
	-30.00	0.14	0.14	5.97	6.06	0.40	0.49	0.64	0.78
δ	-15.00	0.07	0.07	2.97	3.02	0.20	0.24	0.31	0.38
	15.00	-0.06	-0.06	-2.96	-3.00	-0.19	-0.23	-0.29	-0.35
	30.00	-0.12	-0.12	-5.89	-5.96	-0.37	-0.44	-0.56	-0.69

5. Managerial Insights

From the analysis of the results given in the previous section, the following managerial insights can be derived:

a) In competition, more greening investment parameter leads to a lower greening level of own product under the Government regulation. Therefore, it is less beneficial to the firms as well as environment.

b) Decreasing of standard greening level mandated by Government attracts the firms to increase their products' greening levels.

c) Increasing of penalty or subsidy on unit difference of greening level increases the relative price and green level of the product. As a result, the relative profits of the firm decrease. This phenomenon indicates a hard competition between the contesting firms.

d) Increasing of penalty or subsidy on unit difference of carbon emission increases the relative price in all over range but relative green level decreases first and then it is increases. Thus, resulting profit follows a concave nature with increasing of penalty or subsidy on carbon emission. So, for increasing in penalty or subsidy on carbon emission, soft competition is found up to a certain growth of it and after that, competition becomes tightened to the manufacturer.

6. Conclusion

The commitment of investigation lies in multi-manufacturer models including competitive greening costs and standard Government regulations in a duopoly price and green sensitive market. The models are promptly connected to different ventures of demand and evaluated numerically in a deterministic setting of parameter. The formulated models are solved through simultaneous move game between the contesting firms. Several observations are made on the basis of numerical results and graphical presentations. Some managerial insights are also derived for the competing firms.

One can extend this model to the case with competing manufacturers-retailers supply chain model. It can prompt extra bits of knowledge of sequential game theory. This model may be considered with uncertain demand like stochastic or fuzzy due to asymmetry information about consumer's loyalty.

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