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Product Greening, Competition and Cooperation under Environmental Regulations

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1 Introduction

During the past two decades `sustainability' has emerged as the new paradigm of conducting business. From increased Government pressure to societies demanding more responsible behaviour from corporate houses towards environmental issues, the voices are pouring in. Under such growing demand for change in products and processes of organisations, businesses realise that the dynamics of world economy are changing. Those companies which cannot fully leverage this may have serious socio-economic manifestations in the form of over-dependence on resources which may be very scarce and costly to procure and utilize. Further, sustainable development has the potential to change the economics of supply chains and may compromise the competitiveness of companies by a ecting the cost structure of industries and restricting market access. Policies of governments across the world are rapidly changing course and the implications of such change for companies can be far fetched. Those companies which already envision a change in the policy, will undertake investments much earlier than their competitors. These investments will have signi cant impact in terms of product prices, strategic decisions on product improvement levels and so on. On the other hand, Government legislations, once they come into force, will increase the costs of rms several folds. Given these prospects, we explored various policy changes that Governments across the world have initiated fairly recently and we zeroed down to two observations.

Our problem is primarily motivated by the recent developments in two markets of the world namely, India and the United States. The Finance bill 2010-11 in India created a corpus called \"*National Clean Energy Fund which will invest in entrepreneurial ventures and research in the eld of clean energy technologies. The money for this will be garnered through a so-called `clean energy cess' of Rs* 50 *on every tonne of coal, both domestic and imported.* " (*Economic Times*, Feb 2010). In the United States, `Corporate Average Fuel Economy(CAFE)' regulations underwent a sea change when they included light trucks under the stringent CAFE standards. The rules state that \"*if the average fuel economy of a manufacturer's annual eet of car and/or truck production falls below the de ned* *standard, the manufacturer must pay a penalty currently $5.50 USD per 0.1 mpg under the standard, multiplied by the manufacturer's total production for the U.S. domestic market*" (*www.nhtsa.gov*). In the U.S, the National Highway Traffic Safety Administration (NHTSA) regulates CAFE standards and in return helps automobile manufacturers in several ways. The administration advertises on its website those companies which follow these norms, displays to the consumer the total fines collected from various auto makers and assigns a green score to each vehicle type from each auto maker. The aim is to increase awareness of the consumer towards greener vehicles and also help the complying auto makers generate more sales. The increasing consumer preference towards green vehicles is an important consideration in this study.

It was further observed that for each model year heavy fines were collected from leading auto makers like Porsche, Fiat, Mercedes-Benz, Daimler Chrysler,Volkswagen, Aston Martin, Jaguar and many more. Surprisingly from model year 1983 till 2003, auto maker Toyota had not been fined. Studies on the highest quality standards of Toyota definitely speak volumes in support of this observation. Also, the cost of greening for Toyota, subject to these regulations may be far lesser as compared to that of its competitors. The differentiated cost of greening is another important consideration in our study[3].

From the above discussion, the following key inferences are:

1. Government norms for pollution/fuel efficiency .
2. Increasing consumer preference towards less polluting (greener) vehicles.
3. Differentiated cost of greening between competitors.

The inferences although primarily derived from the auto sector are prevalent in several other sectors like steel manufacturing , consumer goods production , chemical and dye manufacturing etc. These industries are typically characterized by price competition and now, increased competition in greening their products. In this study, we consider the impact of competition on product greening levels and prices of the green product.

Inspite of the intense competition, interestingly several companies within these industries have come together to counteract the Government legislations. Several of them have

[3]Note however, that recently Toyota has been involved in several product recalls raising questions on the quality standards maintained by the company (www.economist.com/blogs/schumpeter/2014/04/toyota)

formed joint ventures in order to develop cleaner technologies, few have invested in third party research organisations to develop environmental friendly technologies while some have shared best practices and knowledge of their processes with their competitors and suppliers in order to build a better knowledge base for green technologies and products. To cite few examples, project ULCOS (*Ultra Low* CO_2 *emiion*) is a research venture by major EU steel companies and TATA Steel aimed at developing technologies for reduction of carbon dioxide emissions by at least 50 percent. The companies would be nancing the research conducted by scientists and research schools in Europe (*ulco.org*). In another example, in a di erent set up of co-operative model, General Motors Corp. and Ford Motor Co., teamed up in a unique partnership to develop a new six-speed automatic transmission. The two companies cooperated on designing, engineering and testing the new transmission as well as working with suppliers to develop and buy components. The high-volume, front-wheel-drive transmission o ers an estimated 4 - 8 percent improved fuel economy over traditional four-speed transmissions in front-wheel-drive cars (*wbnetcom*).

Thus, several questions arise. What is the impact of Government regulation and cost of greening on a rm's decision on the level of product greening to be achieved. Further, how do they impact the price of the green product? What happens when there is price and greening competition between two manufacturers as noticed in the auto sector? What is the impact on the level of greening and price of the green products in such a case. Are the results any di erent when the two players cooperate in the market to develop a cleaner technology/product but compete on prices? How do contracts between two competitor rms impact their decisions? Which strategy can best suit a rm under prevailing regulations and costs?

In order to answer the above questions we adopt an analytical approach. We rst analyse the case of a single rm incurring greening costs and facing Government penalty. We extend this model to a duopoly under price and greening competition. We study

where rms cooperate in setting quality levels. Our modeling approach though quite similar to theirs addresses a di erent problem of greening under government legislation. We incorporate price and greening competition under the presence of government penalisation. The complexity of the problem increases manifold as even under linear demand and deterministic settings, the impact of government legislation is now considered along with price and product competition. Further, we do not model competitive intensity in terms of market share as greening initiatives are still an evolving process where competitive intensity has set in more in terms of pricing and greening levels of the product. Tsay and Agrawal (2000) study a distribution system in which a manufacturer supplies a common product to two independent retailers who use service and retail price to directly compete for the end customers. The authors study the impact of competitive intensity on total sales, market share and pro tability. The authors also introduce wholesale price contract as a means to coordinate the channel between the manufacturer and two retailers. In contrast we study price and product competition under government legislation between two manufacturers under varying costs of greening, cooperation and contracts. We rst study a single rm setting and extend this to a duopoly. Corbett and Karmarkar (2001) examine the impact of xed and variable costs on the structure and competitiveness of supply chains with a serial structure and price sensitive linear demand. The authors derive price and production quantity decisions based on the number of entrants at each tier in the supply chain. The model competition in supply chain through number of players in each tier. Chen, Federgruen and Zheng (2001) model a two echelon distribution system in which the sales volumes of the retailers are endogenously determined on the basis of known demand functions. The demand of the retail market is assumed to be a decreasing function of the retail price in the market. The authors characterise the centralized channel and the decentralized channel optimal strategies. The authors propose a xed fee contract and discount schemes through which the channel can be coordinated.

In the marketing stream, channel literature dealing with competition between two manufacturers or retailers have been dealt with extensively. Jeuland and Shugan (1983) did

optimal strategies of two manufacturers selling competing products both carried by two competing retailers. Padmanabhan and Png (1997) discuss manufacturer's return policies with uncertain demands, limited shelf life and retail competition. The retailers compete in prices. The authors discuss various cases under which the returns policy is pro table for the manufacturer. Trivedi (1998)discusses various models of distribution channels , one of them being two competing manufacturers and two competing retailers. Using linear demand function, the competition is modeled on prices. The author analyses the impact of competitive intensity on both pro ts and prices. Iyer (1998) studies price and service competition between a single manufacturer and two retailer channel. The author represents individual consumer behaviour in terms of value of service and disutility of travel and from this derives each retailer's demand function. The author also discusses various channel coordination mechanisms.

Our work largely focusses on greening as a product attribute and models pricing and greening strategies of rms under rising costs and government penalty. Further, we address concerns of rms in designing contractual terms with their competitors to undergo greening. We also evaluate the surplus generated for consumers as a result of penalisation of rms. Lastly, we evaluate the impact of collaboration between competing rms on greening investment decisions and also explore a contract for greening cost sharing between the partner rms.

3 The Case of a Single Firm

We begin our analysis with the case of a single rm. We assume that all the activities in the markthe of6tr-27(he)-383(wi[(in)-34ace)-333(single)4370(p)-27(armo)-28(r)-339(Tsa(b)27(y)-
by41the41 he41832(uth)1rhe41835(pro)-27(duct41)23(greening)1assud(y41)27o(y41)2[(b)-27el418

often considered for analytical tractability as such models throw interesting insights into problem parameters. The demand faced by the rm is given by

$$q = a \quad bp + \qquad \text{where} \qquad a > bp; \; ; b > 0 \qquad (1)$$

Here a denotes the total market demand faced by the rm, p denotes the price of the product and denotes the `level of greening' of the product. Further, `b' and ` ' denote the demand sensitivity to price and `greening level' respectively. The above equation captures the phenomenon of increased consumer demand achieved as a result of greening. We further model Government penalisation similar to the one levied under CAFE Standards. Let `K ' denote the penalty levied per unit di erence in greening standards per unit produced. We assume that the Government set environmental standard is given by `$_0$'. Under such a taxation scheme, the pro t function of the rm can be written as :

$$_{SF} = (p \quad c)q \quad I \; ^2 \quad K (\; _0 \quad)q \qquad (2)$$

$$s{:}t{:}$$

^{0}

$$; p \quad 0$$

The index SF denotes a single rm in our case. The above model captures two phenomena. Firstly, the rm incurs a cost of greening given by $I \; ^2$ which is increasing in the level of greening and convex. I is an investment parameter here. Convex costs re ect diminishing returns from R&D expenditures. Convexity of costs are often attributed to diseconomies of scale where investment e orts are involved. To explain further, we estimate that the `low hanging fruit' during greening would be plucked much easily by the rms while subsequent improvements may become progressively more oo8q0tely morephenomenon greening improvement that we model here refers to a product attribute such that once the improvement comes into being, it makes the older product obsolete. Bhaskaran and Krishnan (2009) and Abbott (1953) refer to such improvements as \innovation quality dimensions" which when introduced cost no more to produce thus turning the older quality obsolete. It is to be noted that our model speci cally addresses the problem where the rm falls short of the Government mandated greening standards, a signi cantly widespread problem as illustrated through the case of CAFE nes.

The rm has two decisions to make. How much `price' to charge and the `level of greening' improvements to achieve. The rm's objective is to maximise (2) with respect to these key decision variables under Government penalty and investments in greening. The decision making by the rm follows the following sequence:

(i) The rm selects the `level of greening' and decides on the price of its green product

(ii) Demand is realised based on the price and greening level set by the rm.

The above optimisation problem is solved with respect to the decision variables. However we rst propose here a few results with respect to the nature of the optimisation problem and then proceed to derive the equilibrium values.

Lemma 1. *The deterministic model given by equation 2 is a convex program.*

Proof. The objective function function is concave for $\frac{\partial^2 \, _{SF}}{\partial p^2} = \; 2b < 0; \frac{\partial^2 \, _{SF}}{\partial \, ^2} =$ $2(I \quad K \;) < 0$ and $|H| = 4Ib \quad (\; + Kb)^2 > 0$. The constraint is linear in the decision variable of the model. Hence, the deterministic constrained pro t maximisation problem for the single rm is a convex program.

Since, the deterministic model is a convex program, Karush-Kuhn-Tucker(KKT) optimality conditions are necessary and su cient to obtain optimal solution for the problem. Using the KKT optimality conditions for the constrained optimization problem, the optimal solution for the rm's problem is given as follows

$$a \quad 2bp + bc + \quad + Kb(\;_0 \quad) = 0 \tag{3}$$

$$(p \quad c + K \,)(a \quad bp + \quad) + \quad (p \quad c \quad K (\;_0 \quad)) \quad 2I \qquad = 0 \tag{4}$$

where

$$A_1 = \frac{(\quad + Kb)(a \quad bc + \quad _0)}{4b \quad _0} \qquad (11)$$

For non-negativity of $_{SF}$, we assume $a > b(c + K \quad _0)$. Thus the two assumptions in this model are:

Assumption : $a > b(c + K \quad _0)$

Assumption : $4Ib \quad (\quad + bK)^2 > 0$

It can be inferred from the above proposition that when the cost of greening is quite high, the rm falls short of the Government mandated standards. However, when the cost of `greening' is less than the bound given by $A_1$, the rm would attain the Government decided `level of greening'. Note that the bound given by A_1 is increasing in the penalty levied (K) and decreasing in Government decided environmental standard $_0$. (The partial derivative of A_1 w.r.t K is positive and the partial derivative of A_1 w.r.t $_0$ is given by $\frac{(a \quad bc)(\quad + Kb)}{4b \quad _0^2}$ which is negative).

Lemma 2. $_{SF}$ *i decreaing in the cotof greening(I) and increaing in conmer en-itivityoward greening( ).*

Proof: The derivative of $_{SF}$ w.r.t I gives $\frac{@_{SF}}{@I} = \frac{4b(\quad + Kb)(a \quad b(c + K \quad _0))}{(4Ib \quad (\quad Kb)^2)^2} < 0.$
Also, the derivative of $_{SF}$ w.r.t gives $\frac{@_{SF}}{@} = \frac{(a \quad b(c + K \quad _0))((\quad + Kb)^2 + 4Ib)}{(4Ib \quad (\quad Kb)^2)^2} > 0.$

Thus, $_{SF}$ decreases with cost of greening(I). This is a consequence of the fact that when the cost rises, the rm cannot a ord higher levels of greening. Refer gure 1. Additionally, $_{SF}$ increases with consumer sensitivity towards greening( ). Higher consumer sensitivity to greening provides the required impetus to achieve higher levels of greening as through marginal increase in greening levels, the demand increases manifolds. The plot of level of greening to the ratio = shows that as the ratio increases(by increasing) the level of greening achieved by the rm rises. Refer gure 5. The argument reveals why Governments should make consumers environmentally conscious while simultaneously taxing product manufacturers.

Lemma 3. *Under the given assumption, the corresponding value of price, quantity and profit of the firm are*

$$p_{SF} = \begin{cases} \dfrac{2I(a + b(c + K\ _0)) \quad (\quad + Kb)(aK + \quad (c + K\ _0))}{4Ib \quad (\quad + Kb)^2} & \text{if} \quad I > A_1 \\ \dfrac{a + bc + \quad _0}{2b} & \text{if} \quad I \quad A_1 \end{cases} \tag{12}$$

$$q_{SF} = \begin{cases} \dfrac{2Ib(a \quad b(c + K\ _0))}{4Ib \quad (\quad + Kb)^2} & \text{if} \quad I > A_1 \\ \dfrac{a \quad bc + \quad _0}{2} & \text{if} \quad I \quad A_1 \end{cases} \tag{13}$$

$$_{SF} = \begin{cases} \dfrac{[(a \quad b(c + K\ _0)]^2 I}{4Ib \quad (\quad + Kb)^2} & \text{if} \quad I > A_1 \\ \dfrac{(a \quad bc + \quad _0)^2 \quad 4Ib\ _0^2}{4b} & \text{if} \quad I \quad A_1 \end{cases} \tag{14}$$

The above results are derived by substituting the optimal value of $_{SF}$ into the expressions for prices, quantity and profits.

Lemma 4. *The price of the green product is increasing in the cost of greening(I) while the total quantity and profit of the firm are decreasing in the cost of greening(I).*

Proof: The partial derivatives of the variables with respect to I gives $\frac{@p_{SF}}{@I} = \frac{2(a \quad b(c + K\ _0))(Kb + \quad)(Kb \quad \quad)}{(4Ib \quad (\quad + Kb)^2)^2} > 0$, $\frac{@q_{SF}}{@I} = \frac{2(a \quad b(c + K\ _0))(Kb + \quad)^2 b}{(4Ib \quad (\quad + Kb)^2)^2} < 0$, $\frac{@ \ _{SF}}{@I} = \frac{(a \quad b(c + K\ _0))^2 (Kb + \quad)^2}{(4Ib \quad (\quad + Kb)^2)^2} < 0$.

The impact of increased cost of greening on the various rm level outcomes are expressed in the above result. Our results corroborate the concerns of managers over greening costs. Our results analytically support managerial decision making based on the total costs incurred and other parametric values. Refer gures 2, 3 and 4.

The structural results are followed by numerical analysis in the following section.

3.1 Numerical Analysis

To study the impact of Government levied penalty(K) and consumer sensitivity towards greening( ), we conduct various sensitivity analyses in this section.

Impact of consumer sensitivity towards greening( ) : We conduct numerical analysis where the parametric values are the following based on the model assumptions, $a = 4000; b = 50; c = 6; I = 950; K = 5; {}_0 = 8;$ is varied from 40-94. It is observed that price is decreasing in the consumer sensitivity towards greening( ). Refer Fig 6. With increased sensitivity of consumers towards greening, the quantity demanded rises and the rm subsequently quotes a lower price for its product. Additionally, the quantity demanded for the green product increases with the increase in consumer sensitivity towards green products. Refer Fig 7. The pro t of the rm also increases with increase in ( ), signi cantly in uenced by the increase in demand for the green product. Refer Fig 8.

Impact of penalty(K) : The Government's linear penalization of rms for falling short of the mandated environmental greening standards has interesting implications. To study the impact of Government penalty(K) we assume the following parametric values: $a = 4000; \ = 40; c = 6; b = 50; I = 960; {}_0 = 8; K = 3 \quad 6:8$. It can be inferred that the producer's pro t is decreasing in penalty as with increasing penalization the producer earns less pro ts. Refer Fig 12. Interestingly, *high* government penalty(K) leads to lower

the vehicle manufacturers adhering to the CAFE legislations.

$$\frac{\partial SS}{\partial} = \frac{q}{b} \quad 2l \quad + Eq$$

The second order conditions are

$$\frac{\partial^2 SS}{\partial^2 q} = \frac{1}{b} \tag{19}$$

$$\frac{\partial^2 SS}{\partial^2} = 2l \tag{20}$$

$$\frac{\partial^2 SS}{\partial q \partial} = \frac{}{b} + E \tag{21}$$

The Hessian is positive for $l > \frac{b}{2}(\frac{}{b} + E)^2$. Thus, equating the rst order conditions to zero and solving for the socially optimal , quantity and price gives

$$_{SS} = \frac{(\quad + bE)(a \quad b(c + E \quad _0))}{2lb \quad (\quad + bE)^2} \tag{22}$$

$$q_{SS} = \frac{(a \quad b(c + E \quad _0))2lb}{2lb \quad (}$$

i 0

i ; p_i 0

i 6= j; i; j = 1 ;

From the optimal greening level, the price, quantity and profit function of Firm i, $i \neq j$, $i,j = 1;2$ under competition is derived as:

$$p_i^{NC} = \frac{A_1 + \frac{G_2 G_3 b S_1}{G_1} - \frac{bT G_2 G_4}{G_1}}{W} \qquad (29)$$

$$q_i^{NC} = b\left(\frac{A_2 + \frac{G_2 G_3 b S_2}{G_1} - \frac{bT G_2 G_4}{G_1}}{W}\right) \qquad (30)$$

$$\pi_i^{NC} = \frac{b[A_1 - Wc + G_2 G_3 b S_1 / G_1 - bG_2(G_4 T / G_1)][A_2 + G_2 G_3 b S_2 / G_1 - bG_2(G_4 T / G_1)]}{W^2} - \frac{l_i G_2^2 G_3^2 b^2}{G_1^2}$$

When

$$\text{Condition} \quad : I_i \quad [bG_2(b(S_1 + KW)(2S_2 + T) + bS_2T) \quad _0(b^2T^2(S_1 + S_2 + KW)^2$$

$$4b^2S_2^2KW(2S_1 + KW)) \quad 2bG_2 I_j W^2]W$$

result con rms our understanding of the CAFE legislations where Toyota had not paid any ne over a period of twenty years while its competitors who had signi cantly higher costs of greening had been ned and provided lower levels of greening(fuel economy) in the vehicles they produced.

4.1 When Firms have equal costs of Greening

In this section, we deal with the case when cost of greening for both the rms are equal.

The equilibrium values of prices, quantities and pro ts are derived as:

$$p^N = [\frac{A_1 + (S_1 \quad T)\frac{b[S_2(A_1 \quad W(c + K \ _0)) + A_2(S_1 + KW)]}{2IW^2 \quad 2bS_2(S_1 + KW) + bT(S_1 + S_2 + KW)}}{W}]$$

$$q^N = b[\frac{A_2 + (S_2 \quad T)\frac{b[S_2(A_1 \quad W(c + K \ _0)) + A_2(S_1 + KW)]}{2IW^2 \quad 2bS_2(S_1 + KW) + bT(S_1 + S_2 + KW)}}{W}]$$

$$^N = [(2IW^2(A_1 \quad c) + 2bS_2WK(Wc \quad A_1K) \quad A_1bS_1S_2$$

$$+ (S_1 + KW)(A_1bT + bA_2(S_1 \quad T)) + WbS_1c(S_2 \quad T) \quad W^2bcK(2S_2 \quad T)$$

$$bS_2KW \ _0(S_1 \quad T))(A_2 + (1=2)(\frac{bM(S_2 \quad T)}{N}))b]=[W^2(2IW^2 \quad 2bS_2(S_1 + KW)$$

$$+ bT(S_1 + S_2 + KW))]$$

$$(1=4)(\frac{Ib^2N^2}{M^2}) \quad \frac{K(\ _0 \quad (1=2)(\frac{bN}{M}))b(A_2 + (1=2)(\frac{bN(S_2 \quad T)}{M}))}{W}$$ where;

$$M = IW^2 \quad bS_2(S_1 + KW) + \frac{1}{2}bT(S_1 + S_2 + KW)$$

and

$$N = S_2(A_1 \quad W(c + K \ _0)) + A_2(S_1 + KW)$$

However, for Condition : $I \quad \frac{b}{2 \ _0W^2}[S_2(A_1 \quad W(c \quad K \ _0)) + (S_1 + KW)(A_2 \quad T \ _0) + S_2 \ _0(2S_1 \quad T)]$

$$^N = \ _0$$

$$p^N = \frac{A_1 + \ _0(S_1 \quad T)}{W}$$

$$q^N = b(\frac{A_2 + \ _0(S_2 \quad T))}{W}$$

$$^N = b[\frac{A_1 + \ _0(S_1 \quad T)}{W} \quad c][\frac{A_2 + \ _0(S_2 \quad T)}{W}] \quad I \ _0^2$$

4.2 Contract Analysis and Greening

In the following sections we consider few contracts which impact the decision making of rms under greening and government legislations. Our scope of study limits itself to two competing rms facing government legislations. In that perspective we deal with contracts which help share the burden of development of the greening innovation between both the rms. We study a xed fee contract and revenue sharing contract in this section. In another section we study a cost sharing contract under cooperation. As outlined previously, there are several examples of rms participating in the joint development of the green product or sharing the cost of development of the technology or sharing revenues generated through the development of the green technology with the partner rm. Tsay,Nahmias and Aggarwal(1999) and Cachon(2003) provide a detailed review of and the objective of Firm j is :

$$\max_{p_j} \quad _j = (p_j \quad c \quad K(\; _0 \quad))q_j \quad F$$

The demand realised is :

$q_j = a \quad bp_j + \quad p_i + \quad (\qquad)$ where $i \neq j$ and $i; j = 1; 2$

Solving for the optimum level of greening (^{F}) gives:

$$^F = \frac{N_3 b N_2}{N_1}$$

for

$$\text{Condition} \quad : I > \frac{bN_3[N_2 + \quad _0 N_3]}{_0(4b(b \quad) + \quad ^2)}$$

Substituting the optimum greening level(^{F}) into the pro t function of Firm i gives:

$$^F_i = [N_5 \quad c \quad N_4][a \quad (b \quad)N_5 + \frac{N_3 b N_2(\qquad)}{N_1}] \quad \frac{I_i N_3^2 b^2 N_2^2}{N_1^2} + F$$

Substituting the optimum greening level(^{F}) into the pro t function of Firm j gives:

$$^F_j = [N_5 \quad c \quad N_4][a \quad (b \quad)N_5 + \frac{N_3 b N_2(\qquad)}{N_1}] \quad F$$

where

$N_1 = I(4b(b \quad) + \quad ^2) \quad b((\qquad) + K(b \quad))^2$

$N_2 = a \quad (b \quad)(c + K \; _0)$

$N_3 = \qquad + K(b \quad)$

$N_4 = K(\; _0 \quad \frac{N_3 b N_2}{N_1})$

$$N_5 = \frac{a + \frac{N_3 b N_2(\qquad)}{N_1} + b(c + N_4)}{2b}$$

Both Firm i and j would participate in the xed fee contract when their pro ts through the contract are greater than the pro ts in the non-contractual case . Thus, Firms would participate when

F
i

NC
i

4.2.2 Greening through Revenue Sharing

We discuss another mechanism of greening where one of the rms o ers a revenue sharing contract in return for leasing/usage of green technology/product that the other rm develops. Revenue sharing contracts have been dealt with in detail by Cachon and Lariviere(2005). However the authors discuss the contract in the context of a supply chain whereas we apply the revenue sharing contract in the case of a duopoly with price and greening competition. Decision making under the revenue sharing contract follows the following sequence :

1: Firm j o ers a portion ! of its revenues to Firm i for utilizing the green technology/product that Firm i solely develops.

2: Firm i decides to accept or reject the revenue sharing contract. If Firm i accepts the o er, then based on the portion of revenues shared by Firm j, Firm i decides on the level of greening to achieve. It also incurs the cost of greening.

3: Both the rms compete on prices and demand is realised based on the prices and

The optimal greening levels and pro t functions of each rm is derived as

$$^{RS} = (1=2)(\frac{S_{12}}{S_{11}})$$

Substituting the above value of (^{RS}) into the pro t function of each rm gives

$$_i^{RS} = (\frac{S_{13}}{!S_1} \quad c)S_{10} \quad 1=4(\frac{I_i S_{12}^2}{S_{11}^2}) \quad K(\ _0 \quad 1=2(\frac{S_{12}}{S_{11}}))S_{10} + \frac{(1 \quad !)S_{14}(a \quad \frac{bS_{14}}{!S_1} + \frac{S_{13}}{!S_1} + 1=2\frac{S_{12}(\quad)}{S_{11}})}{!S_1}$$

$$_j^{RS} = \frac{(S_{15}S_{16})}{S_1} \quad cS_{16} \quad K(\ _0 \quad 1=2(\frac{S_{12}}{S_{11}}))S_{16}$$

where $S_1 = 4b^2 \quad ^2(2 \quad !)$

$S_{10} = (a \quad \frac{bS_{13}}{!S_1} + \frac{S_{14}}{!S_1} + 1=2\frac{S_{12}(\quad)}{S_{11}})$

$S_{11} = \%1$

$S_{12} = \%2$

$S_{13} = \%4 = (!a + bc) \ (2 \quad !) + 2!b(a + bc) + \ Kb \ _0(2 \quad !) \quad \frac{KbS_{12}}{S_{11}} + 2!Kb^2 \ _0 + \frac{!S_{12}(\quad)(\ + \ )}{S_{11}} \quad \frac{!Kb^2S_{12}}{S_{11}} \quad (1=2)\frac{!^2 S_{12}(\quad)}{S_{11}} + (1=2)\frac{! \ KbS_{12}}{S_{11}}$

$S_{14} = \%5 = \ ! \ 2ab + 2Kb^2 \ _0 + \frac{!bS_{12}(\quad)}{S_{11}} + 2b^2c + ! \quad (a + b(c + K \ _0)) + (1=2)\frac{! \ S_{12}(\quad)}{S_{11}} \quad (1=2)\frac{! \ KbS_{12}}{S_{11}} \quad \frac{Kb^2S_{12}}{S_{11}}$

$S_{15} = \%4_j = \ ! \ 2ab + 2b^2(c + K \ _0) + \frac{!bS_{12}(\quad)}{S_{11}} \quad (1=2)\frac{! \ KbS_{12}}{S_{11}} \quad \frac{Kb^2S_{12}}{S_{11}} + (1=2)\frac{! \ S_{12}(\quad)}{S_{11}} + ! \quad (a + b(c + K \ _0))$

$S_{16} = \%5_j = a \quad \frac{bS_{15}}{!S_1} + \frac{}{!S_1}[2 \ bc + 2b!(a + bc) \quad (1=2)\frac{!^2 S_{12}}{S_{11}} + \ Kb \ _0(2 \quad !) + 2!(\ a + Kb^2 \ _0) \quad \frac{KbS_{12}}{S_{11}} \quad ! \quad (!a + bc) + \frac{b!S_{12}(\quad)}{S_{11}} \quad \frac{!Kb^2S_{12}}{S_{11}} + \frac{! \ S_{12}(\quad)}{S_{11}} + (1=2)(\frac{! \ S_{12}}{S_{11}})(! \quad + Kb)] + (1=2)\frac{S_{12}(\quad)}{S_{11}}$

4.2.3 Greening through cost sharing contract

We address the question of what happens to the choice of greening level when rms decide to co-operate. Subsequently we nd the impact of greening levels on the price of the product. One of the reasons cited in literature for co-operation is the reduced cost of development (Banker,Khosla and Sinha, 1998). We model the reduced cost of development in the following way. The reduced cost of development is given by I_c where the index c stands for co-operation.

$$I_c = 2 I \quad \text{where} \quad 0 \quad 1$$

The above model of cost under co-operation indicates that the cost of greening under co-operation is certain fraction of the total cost of greening when rms work individually. The decision making between the two rms follows the following sequence in our model:

1. The two rms jointly select their greening levels.
2. The rms then compete on their prices.
3. Demand is realised based on the choice of prices and greening levels.

We assume that the total cost of greening under co-operation given by I_c is shared between the two rms such that rm i incurs portion of the cost while rm j incurs (1). The parameter is assumed to be decided exogenously. In another model we discuss the implications of being decided endogenously by one of the rms. For our model, given greening levels, we nd that the equilibrium prices of each rm are . We assume the two rms cooperate in choosing the greening levels and hence $_i = _j = ^C$. On substituting the same, the two rms jointly maximise their pro ts given by:

$$^C(\ ) = {}^C_1(\ ) + {}^C_2(\ )$$

$$= \frac{b(A_1 \quad Wc + \quad (S_1 \quad T))(A_2 + \quad (S_2 \quad T))}{W^2} \quad I_c{}^2 \quad bK(=2 \text{ eir prices.}$$

$$= \frac{2b(A_1 \quad Wc + \quad (S_1 \quad T))(A_2 + \quad (S_2 \quad T))}{W^2} \quad I_c \, ^2 \quad \frac{2bK(\,_0 \quad)(A_2 + \quad (S_2 \quad T))}{W}$$

Finding the rst order condition and equating it to zero we get,

$$^C = \frac{b[(S_1 \quad T)A_2 \quad KW(S_2 \quad T)\,_0 + KWA_2 + (S_2 \quad T)(A_1 \quad Wc)]}{[I_c W^2 \quad 2b(S_1 \quad T)(S_2 \quad T) \quad 2bKW(S_2 \quad T)]}$$

$$= \frac{b[(S_2 \quad T)(A_1 \quad W(c + K\,_0)) + A_2(KW + (S_1 \quad T))]}{[I_c W^2 \quad 2b(S_2 \quad T)((S_1 \quad T) + KW)]}$$

for

$$\text{Condition} \quad : I_c > \frac{b}{W^2\,_0}[(S_2 \quad T)(A_1 \quad W(c + K\,_0))$$

$$+ KWA_2 + (S_1 \quad T)A_2 + 2\,_0(S_1 \quad T + KW)(S_2 \quad T)]$$

Substituting the above value of ^{C} into the prices and quantities of each rm we get,

$$p^C(\;) = \frac{(A_1 + (S_1 \quad T)\,^C)}{W}$$

$$= [I_c A_1 W^2 \quad b(S_1 \quad T)(S_2 \quad T)W(K\,_0 + c)$$

$$bA_1(S_2 \quad T)(S_1 \quad T + 2KW) + bA_2(S_1 \quad T)(S_1 \quad T + KW)]$$

$$=[W(I_C W^2 \quad 2b(S_1 \quad T)(S_2 \quad T) \quad 2bKW(S_2 \quad T))]$$

$$q^C(\;) = b\frac{(A_2 + (S_2 \quad T)\,^C)}{W}$$

$$= [I_c A_2 W^2 \quad bA_2(S_1 \quad T)(S_2 \quad T) \quad bKWA_2(S_2 \quad T)$$

$$+ b(S_2 \quad T)^2(A_1 \quad W(c + K\,_0))]$$

$$=[W(I_C W^2 \quad 2b(S_1 \quad T)(S_2 \quad T) \quad 2bKW(S_2 \quad T))]$$

The pro t of each rm is given as:

$$^{C}_{i}(\ ) = \frac{b(A_1 \quad Wc + \quad (S_1 \quad T))(A_2 + \quad (S_2 \quad T))}{W^2} \quad I_c{}^2 \quad \frac{bK(\ _0 \quad)(A_2 + \quad (S_2 \quad T))}{W}$$

and

$$^{C}_{j}(\ ) = \frac{b(A_1 \quad Wc + \quad (S_1 \quad T))(A_2 + \quad (S_2 \quad T))}{W^2} \quad (1 \quad)I_c{}^2 \quad \frac{bK(\ _0 \quad)(A_2 + \quad (S_2 \quad T))}{W}$$

where,   is given by equilibrium value of ^{c}.

When

$$\text{Condition} \quad : I_c \quad \frac{b}{W^2\ _0}[(S_2 \quad T)(A_1 \quad W(c + K \ _0))$$
$$+ KWA_2 + (S_1 \quad T)A_2 + 2\ _0(S_1 \quad T + KW)(S_2 \quad T)]$$

$$^{C} = \ _0$$
$$p^C = \frac{A_1 + \ _0(S_1 \quad T)}{W}$$
$$q^C = b\frac{A_2 + \ _0(S_2 \quad T)}{W}$$
$$^{C}_{i} = b[\frac{A_1 + \ _0(S_1 \quad T)}{W} \quad c][\frac{A_2 + \ _0(S_2 \quad T)}{W}] \quad I_c\ {}^2_0$$

of greening issues. Lastly, the issues arising out of greening initiatives need an analytical approach to understanding and simplify them. We believe that our research lays down such a platform for researchers and practitioners alike.

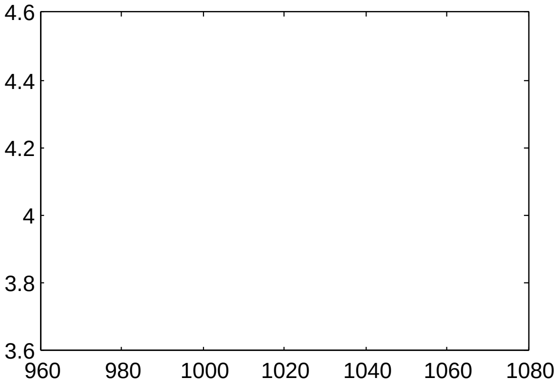

Figure 1: $_{SF}$ vs I

Figure 2: p_{SF} vs I

Figure 3: q_{SF} vs I

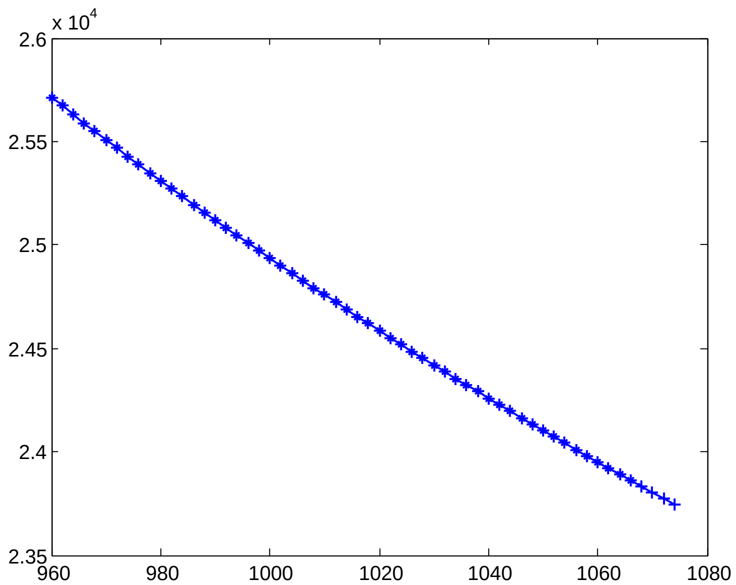

Figure 4: $_{SF}$ vs I

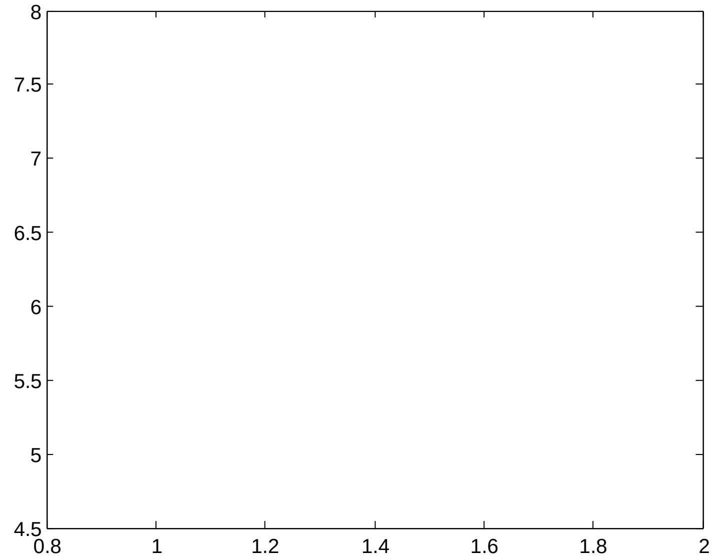

Figure 5: $_{SF}$ vs

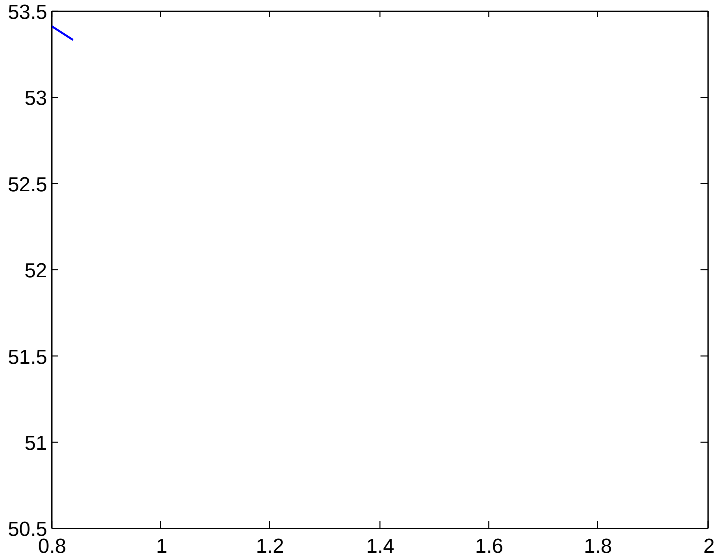

Figure 6: p_{SF} vs

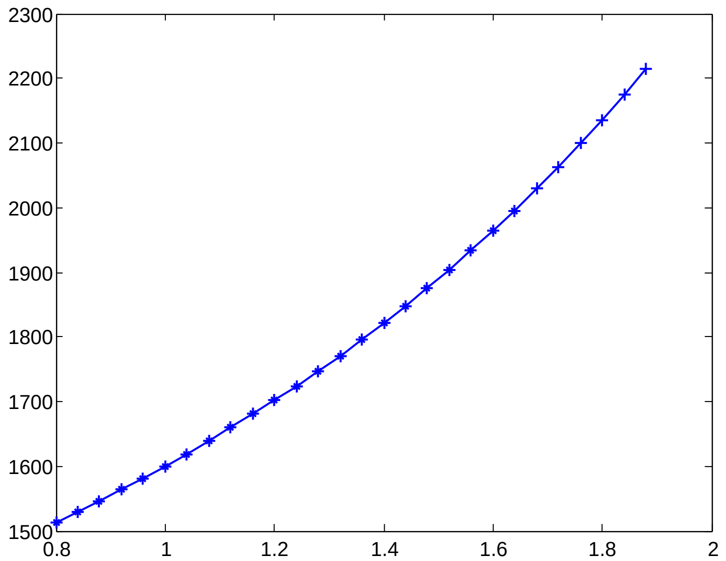

Figure 7: q_{SF} vs

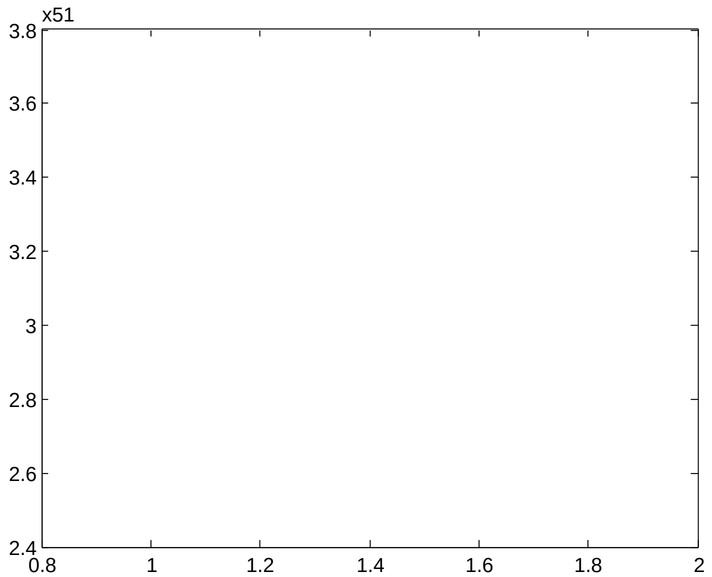

Figure 8: $_k$ vs

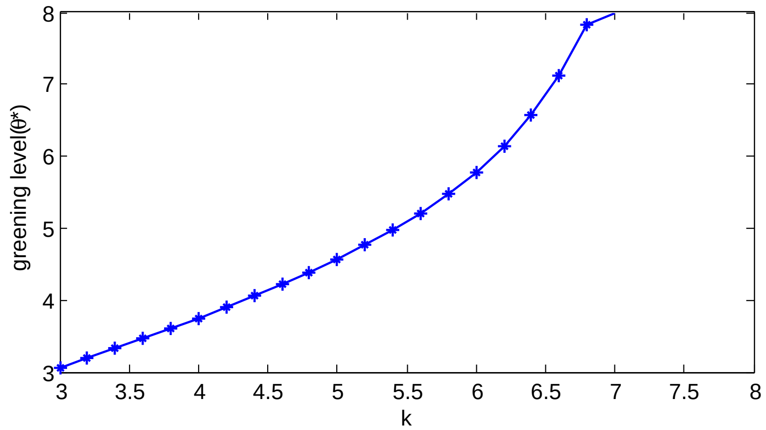

Figure 9: $_{SF}$ vs k

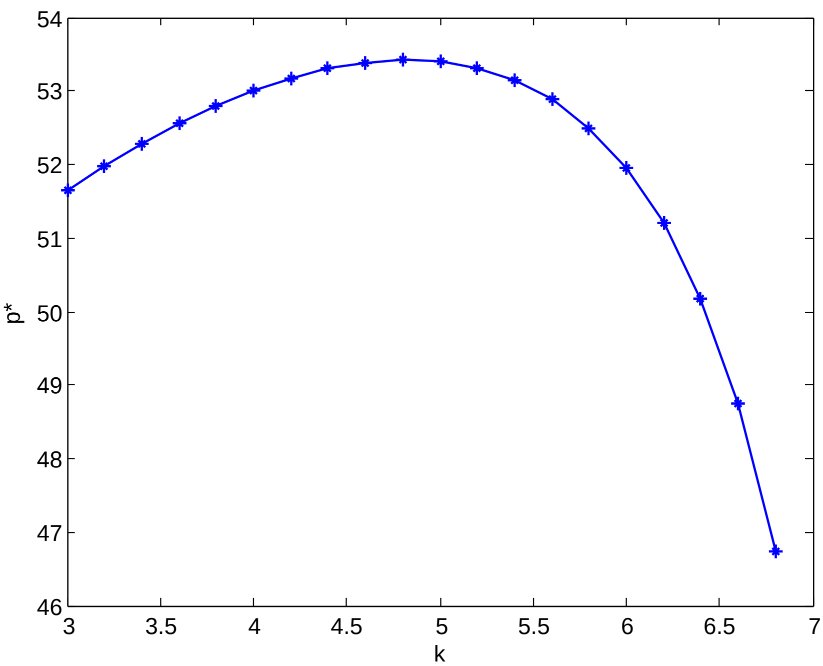

Figure 10: p_{SF} vs k

Figure 11: q_{SF} vs k

Figure 12: $_{SF}$ vs k

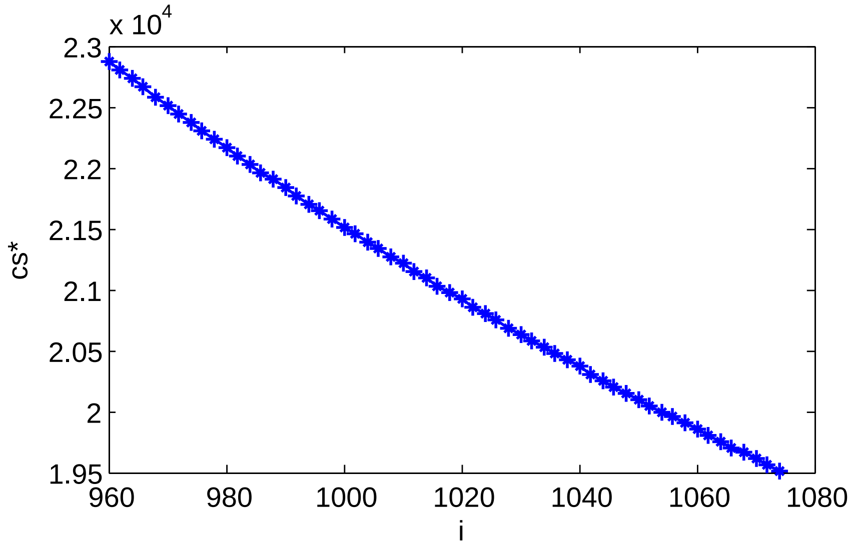

Figure 13: CS_k vs I

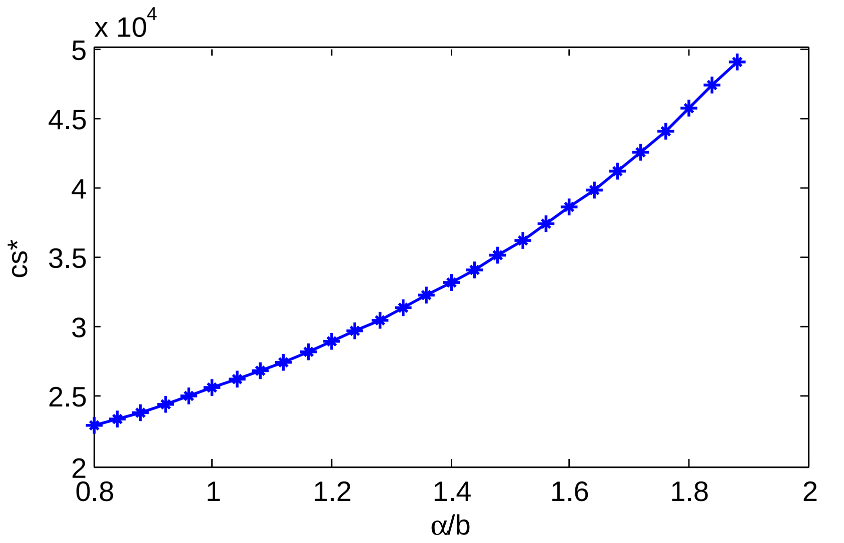

Figure 14: CS_k vs

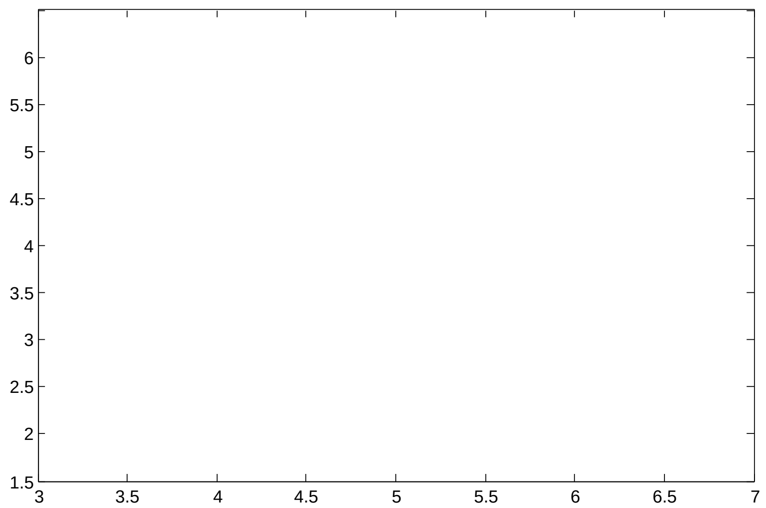

Figure 15: $_k$; CS_k; SS_k vs k

Appendix

The case of a Duopoly

We employ backward induction method to solve the second problem. We rst nd out the equilibrium prices given greening levels $_i; \; _j$. We derive,

$$_i(\; _i; \; _j) = (p_i \quad c \quad K(\; _0 \quad _i))(a \quad bp_i + \; p_j + \quad _i \quad _j) \quad I_i \; _i^2$$

The rst order condition is

$$\frac{@}{@p} \; _i(\; _i; \; _j) = \quad 2bp_i + a + \; p_j + \quad _i \quad _j + bc + Kb(\; _0 \quad)$$

$$= a \quad 2bp_i + \; p_j + \; _i(\quad Kb) \quad _j + b(c + K \; _0)$$

The second order condition is

$$\frac{@^2}{}$$

To simplify the expression for the equilibrium value of $\;_i$ further, let

$$X = S_2(A_1 \quad W(c + K \;_0)) + A_2(S_1 + KW)$$
$$Y = T(S_1 + S_2 + KW)$$
$$B = b{=}2$$
$$Z = bS_2(S_1 + KW)$$

Thus,

$$\;_i = \frac{B[X \quad \;_j Y]}{I_i W^2 \quad Z} \qquad i \not= j; i; j = 1; 2$$

Now, solving the two simultaneous equations in $\;_i$ and $\;_j$, we get the equilibrium `levels of greening' as:

$$\;_i^{NC} = \frac{BX[(I_j W^2 \quad Z) \quad BY]}{(I_i W^2 \quad Z)(I_j W^2 \quad Z) \quad B^2 Y^2}$$
$$= b[(S_2(A_1 \quad W(c + K \;_0)) + A_2(S_1 + KW))(b(S_1 + KW)(2S_2 + T) + bS_2 T \quad 2I_j W^2)]{=}[b^2 T^2 (S_1 + S_2 + KW)^2$$
$$+ 4bS_2 KW^3 (I_i + I_j) \quad 4(I_j W^2 \quad bS_1 S_2)(I_i W^2 \quad bS_1 S_2) \quad 4b^2 S_2^2 KW(2S_1 \quad KW)]$$

where NC denotes the Nash Equilibrium under competition. To ensure $\;_i^{NC} > 0$ we need,

$$\text{Condition} \quad : I_j > \frac{BY + Z}{W^2}$$
$$) \quad I_j > \frac{b[TS_2 + (2S_2 + T)(S_1 + KW)]}{2W^2}$$

Now, $\;_i^{NC} < \;_0$ which gives the condition

$$\text{Condition} \quad : I_i > [bG_2(b(S_1 + KW)(2S_2 + T) + bS_2 T) \quad \;_0(b^2 T^2 (S_1 + S_2 + KW)^2 \quad 4b^2 S_2^2 KW(2S_1 + KW))$$
$$2bG_2 I_j W^2 \quad \;_0 4bS_2 KW^3 I_j \quad 4\;_0 bS_1 S_2 (I_j W^2 \quad bS_1 S_2)]{=}[\;_0(4bS_2 KW^3 \quad 4W^2(I_j W^2 \quad bS_1 S_2))]$$

Greening through Fixed Fee Contract

b2 20 stams2 Td [0[2227 TfTd [TJ/F19 5.9776 Tf 12.89 -1.107776 77 Td [(2)]TJ/F18 7
S2
NC
We 4.1 2.813 Td [(N)-108(C)]TJ/F18 7.1088.19 5.9776 Tf 8.773 -1.107 Td [(2)]TJ/F21 7.9701 Tf 4.151 1.107 Td [(K)-71(W)]TJ/F19 5.9776 Tf4648.3 1

The rst order condition gives :

$$\frac{@}{@} = (\frac{\quad bK}{2b} + K)(a \quad \frac{(b \quad)\%1}{2b} + \quad (\quad)) + (\frac{\%1}{2b} \quad c \quad K(_0 \quad))((\quad) \quad \frac{(b \quad)(\quad bK)}{2b}) \quad 2I$$

where $\%1 = a + \quad (\quad) + b(c + K(_0 \quad))$

The second order condition gives :

$$2b\frac{(\quad + K(b \quad))^2}{(2b \quad)^2} \quad 2I$$

which is strictly less than zero when $I > \frac{b(\quad + K(b \quad))^2}{(2b \quad)^2}$. Thus equating the rst order condition to zero and solving for gives

$$^F = \frac{[(\quad) + K(\quad)]b[a \quad (b \quad)(c + K _0)]}{bK^2 \; (2b \quad) + (b \quad)(4Ib \quad (\quad)2bK) \quad b((\quad)^2 + (bK)^2) + I \quad ^2}$$

This is written as:

$$^F = \frac{N_3 bN_2}{N_1}$$

Substituting the optimum greening level(^{F}) into the pro t function of Firm i gives:

$$^F_i = [N_5 \; c + K$$

Thus pro t function of Firm j is concave in p_j. Thus equating the rst order conditions to zero and solving the two simultaneous equations we get

$$p_i = \frac{!\ 2b(a + bc) + (\quad)!\ (2b + (2\ !)) + (!a + bc)(2\ !) + (_0\ )Kb((2\ !) + !\ 2b)}{!\ (4b^2\ ^2(2\ !))}$$

$$p_j = \frac{2b(!a + bc) + !\ (a + bc) + (_0\ )Kb(2b + !\ ) + (\quad)!\ (2b + \ )}{!\ (4b^2\ ^2(2\ !))}$$

We substitute the prices, quantities as a function of level of greening ( ) into the pro t function of $_i$ and get

$$^{RS}_i = [\frac{S_2}{!S_1}\ (c + K(_0\ ))]S_4\ \ I_i\ ^2 + \frac{(1\ !)S_3S_5}{!S_1}$$

where $S_1 = 4b^2\ ^2(2\ !)$
$S_2 = 2b!(a + bc) + (2\ !)(!a + bc) + (_0\ )Kb(2!b + (2\ !)) + (\quad)!\ (2b + (2\ !))$
$S_3 = 2b(!a + bc) + (_0\ )Kb(! + 2b) + (\quad)!\ (+ 2b) + !\ (a + bc)$
$S_4 = (a\ \ \frac{bS_2}{!S_1} + \frac{S_3}{!S_1} + (\quad))$
$S_5 = (a\ \ \frac{bS_3}{!S_1} + \frac{S_2}{!S_1} + (\quad))$
The pro t function is concave in (derived from second order condition w.r.t) when

$$I > \frac{(S_8S_6 + (1\ !)S_9S_7)}{!S_1} + KS_6$$

where $S_6 = (\quad \frac{(bS_8\ \ S_9)}{!S_1})$
$S_7 = (\quad \frac{(bS_9\ \ S_8)}{!S_1})$
$S_8 = (\quad)!\ (2b + (2\ !))\ \ Kb(2b! + (2\ !))$
$S_9 = 2b!(\quad)\ \ 2Kb^2\ \ !\ (Kb\ \ )$
Equating the rst order condition w.r.t , we derive the optimal greening level (^{RS}) as

$$^{RS} = (1=2)(\frac{S_{12}}{S_{11}})$$

Substituting the above value of (^{RS}) into the pro t function of each rm gives

$$^{RS}_i = (\frac{S_{13}}{!S_1}\ \ c)S_{10}\ \ 1=4(\frac{I_iS^2_{12}}{S^2_{11}})\ \ K(_0\ \ 1=2(\frac{S_{12}}{S_{11}}))S_{10} + \frac{(1\ !)S_{14}(a\ \ \frac{bS_{14}}{!S_1} + \frac{S_{13}}{!S_1} + 1=2\frac{S_{12}(\quad)}{S_{11}})}{!S_1}$$

$$^{RS}_j = \frac{(S_{15}S_{16})}{S_1}\ \ cS_{16}\ \ K(_0\ \ 1=2(\frac{S_{12}}{S_{11}}))S_{16}$$

where $S_{10} = (a\ \ \frac{bS_{13}}{!S_1} + \frac{S_{14}}{!S_1} + 1=2\frac{S_{12}(\quad)}{S_{11}})$
$S_{11} = \%1$
$S_{12} = \%2$
$S_{13} = \%4 = (!a + bc)(2\ !) + 2!b(a + bc) + Kb\ _0(2\ !)\ \ \frac{KbS_{12}}{S_{11}} + 2!Kb^2\ _0 + \frac{!S_{12}(\quad)(+\ )}{S_{11}}\ \ \frac{!Kb^2S_{12}}{S_{11}}$ $(1=2)\frac{!^2S_{12}(\quad)}{S_{11}} + (1=2)\frac{!KbS_{12}}{S_{11}}$
$S_{14} = \%5 = !\ 2ab + 2Kb^2\ _0 + \frac{!bS_{12}(\quad)}{S_{11}} + 2b^2c + !\ (a + b(c + K\ _0)) + (1=2)\frac{!S_{12}(\quad)}{S_{11}}\ \ (1=2)\frac{!KbS_{12}}{S_{11}}\ \ \frac{Kb^2S_{12}}{S_{11}}$
$S_{15} = \%4_j = !\ 2ab + 2b^2(c + K\ _0) + \frac{!bS_{12}(\quad)}{S_{11}}\ \ (1=2)\frac{!KbS_{12}}{S_{11}}\ \ \frac{Kb^2S_{12}}{S_{11}} + (1=2)\frac{!S_{12}(\quad)}{S_{11}} + !\ (a + b(c + K\ _0))$
$S_{16} = \%5_j = a\ \ \frac{bS_{15}}{!S_1} + \frac{}{!S_1}[2bc + 2b!(a + bc)\ \ (1=2)\frac{!^2S_{12}}{S_{11}} + Kb\ _0(2\ !) + 2!(a + Kb^2\ _0)\ \ \frac{KbS_{12}}{S_{11}}\ \ !\ (!a + bc) + \frac{b!S_{12}(\quad)}{S_{11}}\ \ \frac{!Kb^2S_{12}}{S_{11}} + \frac{!S_{12}(\quad)}{S_{11}} + (1=2)(\frac{!S_{12}}{S_{11}})(! + Kb)] + (1=2)\frac{S_{12}(\quad)}{S_{11}}$

Greening through cost sharing contract

The second order condition gives

$$\frac{@^2}{@^2}(\quad) = \frac{4b(S_1\ \ T)(S_2\ \ T)\ \ 2I_cW^2 + 4BKW(S_2\ \ T)}{W^2}$$

which when subjected to the condition of being negative for a global maximum gives the condition

$$\text{Condition} \quad : I_c > \frac{2b(S_2 \quad T)(S_1 \quad T + KW\ )}{W^2}$$

When, $\quad < \ _0$, we get the condition:

$$\text{Condition} \quad : I_c > \frac{b}{W^2 \ _0}[(S_2 \quad T)(A_1 \quad W(c + K \ _0)) + KWA\ _2 + (S_1 \quad T)A_2 + 2\ _0(S_1 \quad T + KW\ )(S_2 \quad T)]$$

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