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Product Pricing in a Two-echelon Supply Chain with Stochastic Demand Under Carbon Cap & Trade Regulations

Rajib Chakrabarty[1], Vaskar Sarkar[2,*] and Narayan Chandra Majee[1]

1 Department of Mathematics, Jadavpur University, Kolkata, India.

2 Department of Mathematics, School of Science, Adamas University, Barrackpore Barasat Road, Kolkata, India.

Abstract: In this paper we have considered a two echelon supply chain (SC) under aspect of carbon cap and trade, where the two players of the SC are manufacturer, distributors. We have considered price and carbon emission dependent stochastic demand for single manufacturer and many distributors. First we formulates integrated SC model that allows Stackelberg game policy for optimizing profits of manufacturer and distributors for two scenarios centralized and decentralized. The decentralized scenario is subdivided depending upon the power of the manufacturer and distributors. We find the optimal values of distributor's base selling price, carbon foot print (emission) after carbon emission mitigation and manufacturer's wholesale price for unit product. Here we have used Mathematica 7.0 for solution of numerical example.

MSC: 90B06.

Keywords: Supply chain, Stackelberg game policy, Carbon foot print, Carbon cap-and-trade mechanism, Carbon emission mitigation.

1. Introduction

In recent years global warming is a foremost hazard to our planet. It's having severe threat to the human health, and well-being and nature. It has many disastrous effects, such as rise of sea level, flood, drought, storm [1], disruption in ecosystems and increased clear-air turbulence [7]. The world ecosystem, environment and human society facing the most severe problems of eco-environment deterioration and imbalance. The main reason behind this crisis is excessive emission of greenhouse gases. To control and reduce the emission of greenhouse gases effectively, many countries and regions [1, 2] have been proposed some legislations and regulations. By cap-and-trade mechanisms [3, 4] i.e., the emission trading scheme is one of the widely accepted mechanisms to make possible the enterprises for conservation of energy and reduction of emission of the greenhouse gases. Some countries already have taken remarkable measures to reduce the emission of green house gases. The Kyoto Protocol, in 1997, have issued by United Nations (UN), which get on a scheme to involved enterprises members' production process under the regulation of cap-and-trade [5]. In 2005, European Union Trading Systems (EU-ETS) was initiated the biggest international scheme for the trading of greenhouse gasses. European Union, covering more than 31 counties which contribute almost half of the carbon emission, controls the emission of greenhouse gases through the implementation of a series of financial policies which includes CCA (Climate Change Agreements), CCT (Climate Change

* *E-mail: vaskar.dgp@gmail.com*

Tax) and CPS (Carbon Price Support) [6]. Being a large scale manufacturing country China has taken continuous drives to reduce emission of greenhouse gases. At some provinces and cities like Beijing, Tianjin, the trading market of carbon emission was framed, in 2013. The emission reduction and efficiency of energy saving is promoted by the carbon emission trading scheme. It is evident that, irrespective of developed or developing country, adapting the measures for reduction of carbon emission. Therefore, with the low-carbon economy becoming a global trend and national strategic behaviour. Use of the cap-and trade regulation encourage enterprises to raise the environmental performance which has the characteristics of external public interests. Therefore, being the primary carrier of greenhouse gases, enterprises have been faced a challenge, due to carbon emission limit and also put in many restrictions in the operations. Due to consumer awareness, they are inclined to the choice to purchase a low-carbon and environment friendly products. Under this situation, the enterprises focus on the technological up-gradation and improved operational management of enterprises to comply with cap-and-trade regulation [8]. Also profit disagreement among the players (upstream and downstream) in supply chain is increasing seriously, since the technological up-gradation in the carbon emission mitigation incurred huge investment. Here we consider that the market demand is stochastic and also affected by selling price and carbon footprint with linear relationship.

2. Literature review

In the field of production–inventory literature, articles considering carbon policies are few but increasing rapidly. Dobos [26] introduced limit of carbon trading permits in the well-known Arrow–Karlin production–inventory model. Also, Dobos [27] further extended his earlier work considering the aspects of time-dependent unit tradable permit and calculated the immediate procurement cost of environmental licenses. The basic EOQ model with carbon emission mitigation investment, has extended by Toptal [14], under carbon cap, carbon tax and cap-and-trade policies. An optimal model for an SC to minimize opportunity cost considering carbon cap developed by Diabat and Simchi-Levi [15]. A model for a green SC, developed by Abdallah [16], to determine lot sizes of production and shipment for raw materials and finished products assuming the constraints over carbon emission. Benjaafar [17] considered carbon tax, strict cap on emission, cap-and-trade and carbon-offset policies to determine optimal production, inventory, backorder quantity and amount of carbon traded to minimize the total SC cost for a single firm and also extended their models for multiple firms with or without coordination. Chen [18] depicted how with operational adjustments emissions can be reduced without significant increase in cost under different carbon policies. Wahab [19] incorporated screening and holding cost of defective items in their model taking the fixed and variable carbon costs in their model. Du [20] developed a model using game theoretical approach for centralized and decentralized decisions of the manufacturer and the retailer in an SC where both the parties induce low-carbon efforts. Mostly the papers in the field of production-inventory and supply chain management with carbon policies have considered deterministic demand. But in real life scenario, enterprises regularly experience stochastic demand due to shrinking product life cycles, seasonality, buying patterns of customers, and other relevant issues [21]. Few research articles recently considered random or stochastic demand to reflect realistic aspects while considering different carbon policies. Rosic and Jammernegg [22] optimized a dual sourcing problem with carbon tax and carbon cap-and-trade policies considering stochastic demand in the newsboy environment. Dong [25] suggested a profit maximization multi-stage SC model considering carbon-cap-and-trade policy and stochastic demand in single-period planning horizon. Zhang and Xu [23] also considered stochastic demand at the time of developing a multi-item production planning model to maximize profit with carbon trading cost, and assumed newsvendor-type products while developed the model. Arikan and Jammernegg [24] suggested a single-period inventory model considering carbon footprint constraint and demand as a positive random variable.

The literature review reveals that the authors have considered stochastic demand with different carbon policies either in single-period or multi-period time horizon. To our knowledge, only a few authors in the literature considered carbon policies with random/stochastic demand in infinite planning horizon.

3. Problem Definition

In this paper, we considered infinite planning horizon, stochastic demand in a two-echelon supply chain under cap-and-trade regulation, which consists of single manufacturer and many distributors. The manufacturer uses raw materials to produce product with a wholesale price and adopts emission reduction technologies to reduce carbon footprint. Meanwhile, the distributors buy the single type of product. The relationship between the manufacturer and distributors in supply chain can be considered as two-stage Stackelberg game, where the manufacturer and the distributors having same power or someone is leader and someone is follower. Under cap-and-trade mechanism, the government or regulatory body directs the related laws and regulations to impose on manufacturer during production process. Further, the manufacturer trades with other firms in carbon emission market, which has surplus or insufficient carbon emission quotas. Also we have considered that consumers have an environmental awareness to pay more buying interest for products with lower carbon footprint.

4. Notations and Assumptions

4.1. Notations

In this paper we have used following notations to develop the model:

Parameters

d_i- Potential market demand for i^{th} distributor

M_C- Manufacturer's production cost for unit product

e_0- Initial amount of carbon emission for unit product

$\mu-$ Cost coefficient in carbon emission mitigation

$E-$ Total carbon emission quota allowed (carbon cap) by government

P_e- Unit trading price for carbon credit (carbon quota)

ξ_i- Sensitivity coefficient of consumer's awareness to carbon emission mitigation for i^{th} distributor

a_i- Sensitivity coefficient of consumer's preference to selling price for i^{th} distributor

$\prod_j^i-$ Profit in different scenarios, $i \in C, D$ refers to centralize and decentralize models, $j \in m, d, sc$ refers to manufacturer, distributor and supply chain.

$n-$ Number of distributor

x_d- Percentage of minimal ensured or restricted profit of the distributors (for the existence of the business process), in decentralized model where manufacturer is leader

x_m- Percentage of minimal ensured or restricted profit of the manufacturer (for the existence of the business process), in decentralized model where distributor is leader

Decision variables

P_d- Distributors' base selling price for unit product

$e-$ Carbon foot print (emission) for unit product after carbon emission mitigation

$w-$ Manufacturer's wholesale price for unit product

4.2. Assumptions

(1). In this supply chain we have two players, namely, manufacturer, distributers. Here first we consider different competitive scenario of profit maximizing between manufacturer and distributors.

(2). Here we assume that d_i is a random variable following some distribution function with known mean and standard deviation (s.d.). Also referring to the related literature, such as, [8, 9] we assume that the market demand is affected by selling price and carbon foot print, which indicates the consumer's preference for selling price and carbon foot print (emission level) will generate a negative contribution effect on market demand. With out loss of generality the demand function for i^{th} distributor can be modelled as $D_i = d_i - a_i P_d - \xi_i e$.

(3). As in the existing literature [10, 11] the initial amount of carbon emission for unit product is e_0, is a known constant. After technological upgradation adopted by manufacturer the carbon foot print reduced from e_0 to e, where $0 < e \leq e_0$, for unit product. The cost function for such technological up-gradation is given by $C(e) = \frac{1}{2}\mu(e_0 - e)^2$.

(4). The carbon credit under the cap and trade mechanism i.e., the total cap of carbon emission E during production process is allowed by the government, which is called carbon credit [12, 13]. Here we have assumed that after adopting carbon emission mitigation the carbon foot print is e. So, the total carbon emission is $e\sum\limits_{i=1}^{n} D_i$. Thus the cost of surplus or deficit carbon credit is $P_e\left[E - e\sum\limits_{i=1}^{n}(d_i - a_i P_d - \xi_i e)\right]$.

(5). In the real life scenario, the carbon emission mitigation investment results in diseconomy of scale. That is through the changes in products design and manufacturing process the mitigation of carbon emission will come easily and the mitigation of carbon emission is more difficult with diminishing profit. Therefor we assume that the coefficient for carbon emission mitigation μ should be large enough and the conditions

(a). $\dfrac{1}{2\sum\limits_{i=1}^{n} a_i}\left(\sum\limits_{i=1}^{n}(\xi_i + P_e a_i)\right)^2 - \mu < 0.$

(b). $\dfrac{1}{4\sum\limits_{i=1}^{n} a_i}\left(\sum\limits_{i=1}^{n}(\xi_i + P_e a_i)\right)^2 - \mu < 0.$

(c). $2P_e\sum\limits_{i=1}^{n}\xi_i - \mu < 0.$

(d). $\left(\mu - P_e\sum\limits_{i=1}^{n}\xi_i\right)\left(\sum\limits_{i=1}^{n}\xi_i - \mu\sum\limits_{i=1}^{n}a_i\right) > 0.$

5. Mathematical Modelling of the System Considering Manufacturer and Distributors

Here depending up on the dominating scenario of the manufacturer and the distributors, we derived two types of models namely centralized model and decentralized model.

5.1. Centralized Model

In the centralized scenario, the model consider the manufacturer and the distributors of entire supply chain as one system, where the manufacturer and distributors jointly make the optimal decision with selling price P_d of distributors and carbon emission e to maximize the total profit $\prod\limits_{sc}^{C}$. Here we consider that on mutual understanding basis the total profit $\prod\limits_{sc}^{C}$ is equally shared among the manufacturer and distributors. So, the model of the supply chain system under centralized scenario can be expressed as follows:

$$\max \prod_{sc}^{C}(P_d, e) = (P_d - M_C)\sum_{i=1}^{n} D_i + P_e(E - e\sum_{i=1}^{n} D_i) - C(e),$$
$$i.e., \max \prod_{sc}^{C}(P_d, e) = (P_d - M_C)\sum_{i=1}^{n}(d_i - a_iP_d - \xi_i e) + P_e\left[E - e\sum_{i=1}^{n}(d_i - a_iP_d - \xi_i e)\right] - \frac{1}{2}\mu(e_0 - e)^2 \tag{1}$$

Proposition 5.1. *In the model under centralized scenario the optimal selling price P_r and carbon emission e are as follows:*

$$P_d^C = \frac{1}{2\sum_{i=1}^{n} a_i}\left[\sum_{i=1}^{n}(d_i + M_C a_i) - e\sum_{i=1}^{n}(\xi_i + P_e a_i)\right] \tag{2}$$
$$e^C = \frac{\sum_{i=1}^{n}(\xi_i - P_e a_i)\sum_{i=1}^{n}(d_i - M_C a_i) - 2\mu e_0\sum_{i=1}^{n} a_i}{\left(\sum_{i=1}^{n}(\xi_i - P_e a_i)\right)^2 - 2\mu\sum_{i=1}^{n} a_i} \tag{3}$$

with the condition

$$\frac{1}{2\sum_{i=1}^{n} a_i}\left(\sum_{i=1}^{n}(\xi_i + P_e a_i)\right)^2 - \mu < 0 \tag{4}$$

Proof. Here first we find the optimal value of P_d and put that value in $\prod_{sc}^{C}$ and then find the optimal value of e as follows:

$$\frac{\delta}{\delta P_d}\prod_{sc}^{c} = \sum_{i=1}^{n}(d_i - a_iP_d - \xi_i e) + (P_d - M_C)\left(-\sum_{i=1}^{n} a_i\right) + eP_e\sum_{i=1}^{n} a_i$$

and $\frac{\delta^2}{\delta P_d^2}\prod_{sc}^{c} = -2\sum_{i=1}^{n} a_i < 0$. Now, $\frac{\delta}{\delta P_d}\prod_{sc}^{c} = 0$ gives, $P_d = \frac{1}{2\sum_{i=1}^{n} a_i}\left[\sum_{i=1}^{n}(d_i + M_C a_i) - e\sum_{i=1}^{n}(\xi_i - P_e a_i)\right]$. Now putting P_d in $\prod_{sc}^{c}$ we get, $\pi_{sc}^{c} = \frac{1}{4\sum_{i=1}^{n} a_i}\left[\left(\sum_{i=1}^{n}(d_i - e\xi_i - M_C a_i)\right)^2 - \left(eP_e\sum_{i=1}^{n} a_i\right)^2\right] + P_e\left[E - \frac{1}{2}\sum_{i=1}^{n}(ed_i - e^2\xi_i - eM_C a_i - e^2 P_e a_i)\right] - \frac{1}{2}\mu(e_0 - e)^2$ and $\frac{\delta}{\delta e}\prod_{sc}^{c} = 0$ gives, $e = \frac{\sum_{i=1}^{n}(\xi_i - P_e a_i)\sum_{i=1}^{n}(d_i - M_C a_i) - 2\mu e_0\sum_{i=1}^{n} a_i}{\left(\sum_{i=1}^{n}(\xi_i - P_e a_i)\right)^2 - 2\mu\sum_{i=1}^{n} a_i}$. Also, $\frac{\delta^2}{\delta e^2}\prod_{sc}^{c} = \frac{1}{2\sum_{i=1}^{n} a_i}\left(\sum_{i=1}^{n}(\xi_i + P_e a_i)\right)^2 - \mu < 0$ provided, $\mu > \left(\sum_{i=1}^{n}(\xi_i + P_e a_i)\right)^2$. □

5.2. Decentralized model

In a supply chain it is not always possible to take centralized decision. Thus the decentralized scenario is unavoidable. Within the supply chain it is not always possible that manufacturer and distributors are of equal power. Some times, distributors (retailers) are more power full, like different shopping malls, some times manufacturer is more power full, like Microsoft. Then under decentralized scenarios, it is required to assume some one as leader and some one as follower based on the dominating nature of the players. So for the decentralized model each one is considered as leader and each one is considered as follower and optimize the supply chain cost to determine the best possible combination. Also we consider all distributors (retailers) are independent and have same power, i.e., either they together act as leader or as follower. So we classify the decentralized model as following two cases:

Case 1: Manufacturer is leader and distributors are follower

While manufacturer is leader and distributors are follower in the Stackelberg game of supply chain which maximize their own profits as the goal. Thus the game between members is as follows:

First the manufacture determines the wholesale price w and emission level e for unit product and then the distributors decides the optimal strategy of selling price P_d accordingly to the best response of manufacturer. We can easily find the dynamic game under complete information where subgame should be perfect Nash equilibrium. Also to protect the minimal profit of the distributors (for the existence of the business process) a minimum x_d percentage of profit is ensured or restricted. So the decision models of manufacturer and distributors can be expresses as follows:

$$\begin{aligned} &\max \prod_m^D(w,e) = (w-M_C)\sum_{i=1}^n D_i + P_e(E - e\sum_{i=1}^n D_i) - C(e), \\ i.e.,\ &\max \prod_m^D(w,e) = (w-M_C)\sum_{i=1}^n (d_i - P_d a_i - e\xi_i) + P_e\left[E - e\sum_{i=1}^n (d_i - P_d a_i - e\xi_i)\right] - \frac{1}{2}\mu(e_0-e)^2 \end{aligned} \tag{5}$$

and

$$\begin{aligned} &\max \prod_d^D(P_d) = (P_d - w)\sum_{i=1}^n D_i \\ i.e.,\ &\max \prod_d^D(P_d) = (P_d - w)\sum_{i=1}^n (d_i - P_d a_i - e\xi_i), \end{aligned} \tag{6}$$

subject to the constraint, $P_d \geq (1 + \frac{x_d}{100})w$.

Proposition 5.2. *In the model under decentralized scenario, where manufacturer is leader and distributors are follower, the optimal selling price P_d, wholesale price w and carbon emission e are as follows:*

$$\begin{aligned} P_d^D &= \frac{1}{2\sum_{i=1}^n a_i}\sum_{i=1}^n (d_i + w a_i - e\xi_i) \\ w^D &= \frac{1}{2\sum_{i=1}^n a_i}\sum_{i=1}^n [d_i + M_C a_i - e(\xi_i - P_e a_i)] \\ e^D &= \frac{\sum_{i=1}^n (d_i - M_C a_i)\sum_{i=1}^n (\xi_i + P_e a_i) - 4\mu e_0 \sum_{i=1}^n a_i}{\left(\sum_{i=1}^n (P_e + \xi_i)\right)^2 - 4\mu\sum_{i=1}^n a_i} \end{aligned}$$

with the condition $\frac{1}{4\sum_{i=1}^n a_i}\left(\sum_{i=1}^n (\xi_i + P_e a_i)\right)^2 - \mu < 0.$

Proof. Here first we find the optimal value of P_d for the maximum value of $\prod_d^D(P_d)$ and we substitute P_d in $\prod_m^D(w,e)$. For maximum value of $\prod_m^D(w,e)$ we find the optimal value of w and substitute it in $\prod_m^D(w,e)$ and derive the reduced function $\prod_m^D(e)$ to find the optimal value of e for maximum $\prod_m^D(e)$ as follows:

Here, $\frac{\delta}{\delta P_d}\prod_d^D = \sum_{i=1}^n (d_i - P_d a_i - e\xi_i) - (P_d - w)\sum_{i=1}^n a_i$ and $\frac{\delta}{\delta P_d}\prod_d^D = -2\sum_{i=1}^n a_i < 0$. Now $\frac{\delta}{\delta P_d}\prod_d^D = 0$ gives, $P_d = \frac{1}{2\sum_{i=1}^n a_i}\sum_{i=1}^n (d_i + w a_i - e\xi_i)$. □

Case 2: Distributors are leaders and Manufacturer is follower

While distributors are leaders and manufacturer is follower in the Stackelberg game of supply chain which maximizes their own profits as the goal. Thus the game between members is as follows:

First the distributors determine the base selling price P_d and wholesale price w for unit product and then the manufacturer decides the emission level e for unit product. As before we can easily find dynamic game under complete information where subgame should be perfect Nash equilibrium and also to protect the minimal profit of the manufacturer (for the existence of the business process) a minimum x_m percentage of profit is ensured or restricted. So the decision models of manufacturer and retailers can be expresses as follows:

$$\begin{aligned} \max \prod_d^D(P_d, w) &= (P_d - w)\sum_{i=1}^n D_i \\ i.e., \ \max \prod_d^D(P_d, w) &= (P_d - w)\sum_{i=1}^n (d_i - P_d a_i - e\xi_i) \end{aligned} \tag{7}$$

and

$$\begin{aligned} \max \prod_m^D(e) &= (w - M_C)\sum_{i=1}^n D_i + P_e(E - e\sum_{i=1}^n D_i) - C(e), \\ i.e., \ \max \prod_m^D(e) &= (w - M_C)\sum_{i=1}^n (d_i - P_d a_i - e\xi_i) + P_e\left[E - e\sum_{i=1}^n (d_i - P_d a_i - e\xi_i)\right] - \frac{1}{2}\mu(e_0 - e)^2, \end{aligned} \tag{8}$$

subject to the constraint, $w \geq (1 + \frac{x_m}{100})M_C$.

Proposition 5.3. *In the model under decentralized scenario, where retailers are leaders and manufacturer is follower, the optimal selling price P_r, wholesale price w and carbon emission e are as follows:*

$$\begin{aligned} e^D &= \frac{(w - M_C)\sum\limits_{i=1}^n \xi_i - P_e\sum\limits_{i=1}^n (P_r a_i - d_i) - \mu e_0}{2P_e\sum\limits_{i=1}^n \xi_i - \mu} \\ w^D &= \frac{\sum\limits_{i=1}^n (d_i - a_i P_r)\sum\limits_{i=1}^n (2P_e\xi_i - \mu) + (M_C + P_r)(\sum\limits_{i=1}^n \xi_i)^2 + e_0\mu\sum\limits_{i=1}^n \xi_i}{2(\sum\limits_{i=1}^n \xi_i)^2} \\ P_d^D &= \left(-\mu\sum_{i=1}^n a_i\sum_{i=1}^n d_i(\mu - P_e\sum_{i=1}^n \xi_i)\right) + \sum_{i=1}^n a_i\sum_{i=1}^n \xi_i\left(e_0\mu + \sum_{i=1}^n d_i P_e + M_C\sum_{i=1}^n \xi\right)\left(\mu - P_e\sum_{i=1}^n \xi_i\right) \\ &\quad + \mu\sum_{i=1}^n d_i\left(-\mu\sum_{i=1}^n a_i + \sum_{i=1}^n \xi_i\right)\left(\sum_{i=1}^n a_i P_e + \sum_{i=1}^n \xi_i\right) - \sum_{i=1}^n \xi_i\left(e_0\mu + \sum_{i=1}^n d_i P_e - \sum_{i=1}^n \xi_i(w + M_C)\right) \\ &\quad - \frac{-\mu\sum\limits_{i=1}^n a_i + \sum\limits_{i=1}^n \xi_i\left(\sum\limits_{i=1}^n a_i P_e + \sum\limits_{i=1}^n \xi_i\right)}{2\sum\limits_{i=1}^n a_i(\mu - P_e\sum\limits_{i=}^n \xi_i)\left(-\mu\sum\limits_{i=1}^n a_i + \sum\limits_{i=1}^n \xi_i\left(\sum\limits_{i=1}^n a_i P_e + \sum\limits_{i=1}^n \xi_i\right)\right)} \end{aligned}$$

with the condition, $2P_e\sum_{i=1}^n \xi_i - \mu < 0$ *and* $(\mu - P_e\sum_{i=1}^n \xi_i)(\sum_{i=1}^n \xi_i - \mu\sum_{i=1}^n a_i) > 0$.

Proof. Here first we find the optimal value of P_d and w taking $\frac{\delta}{\delta P_d}\prod_d^D = 0$ and $\frac{\delta}{\delta w}\prod_d^D = 0$ for the maximum value of $\prod_d^D(P_d, w)$. We put the optimal values of P_d and w in $\prod_m^D$, which will become a function of e only. Then we find the optimal value of e taking $\frac{\delta}{\delta e}\prod_m^D(e) = 0$ for which $\prod_m^D(e)$ is minimum. □

6. Numerical example

In this section, we present some numerical examples to demonstrate the impact of consumers' awareness and initial carbon emission on the performance and social welfare, as well as present the performances of coordination contract under centralized scenario. Also we consider the both decentralized scenarios with the same input data and compare all the evaluated results. We consider that d_i follows uniform distribution with known parameters and consider the specific values for different parameters as follows (all data are with usual unit):

$n = 3$, $M_C = 2$, $e_0 = 2.5$, $\mu = 5$, $E = 5$, $P_e = 0.5$, $\xi_1 = 0.2$, $\xi_2 = 0.2$, $\xi_3 = 0.1$, $a_1 = 0.2$, $a_2 = 0.3$, $a_3 = 0.1$, $d_i \sim Uniform(m_i, n_i)$, $m_1 = 5$, $n_1 = 3$, $m_2 = 5$, $n_2 = 2$, $m_3 = 4$, $n_3 = 3$ and for decentralized models $x_m = 30$ and $x_d = 30$. We replace d_i by the mean of d_i i.e., by $E[d_i] = \frac{m_i+n_i}{2}$. We have solved the models using Mathematica 7.0, using the above input data. In Table 1, the obtained results are given.

Case Type	Manufacturer's total profit	Distributors' total profit	Manufacturer's Wholesale Price /unit	Distributors' base selling price/ unit	Emission level/unit after mitigation
Centralized (Manufacturer and distributors having same power)	15.44	15.44	NA	9.94	1.34
Decentralized (Manufacturer is leader and distributors are follower)	15.89	7.07	9.84	13.27	1.95
Decentralized (Distributors are leaders and Manufacturer is follower)	2.58	29.26	2.60	9.40	2.12

Table 1. **Result analysis**

7. Result Analysis and Conclusion

In the centralized model, when manufacturer and distributors having same power, the total profit is distributed equally within manufacturer and distributors, where distributers directly sell the products. We can observe in Figure 1, that the selling price of distributors increases as the carbon emission level decreases, which results in over all maximum profit shared among manufacturer and distributors.

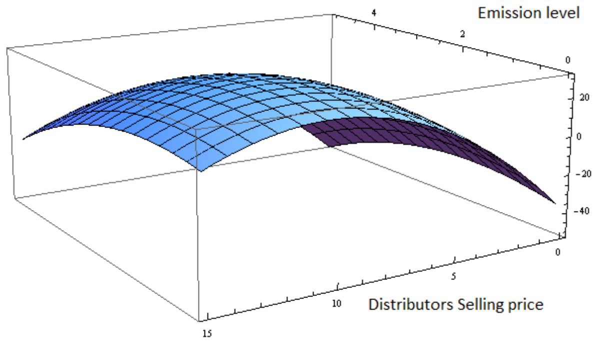

Figure 1. **Distributors Selling price Vs Emission level in Centralized Model**

In the decentralized model, when manufacturer is leader and distributors are follower, the emission level after mitigation is higher than that of centralized model. Also, as the distributors base selling price increases and affect the total sell, which results in remarkably less profit of the distributors. In the Figure 2, we also observed that,as the emission level decreases the manufacturer's wholesale price decreases.

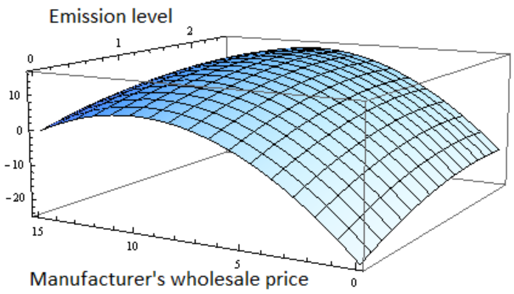

Figure 2. Manufacturer's wholesale price Vs Emission level in Decentralized Model(when manufacturer is leader and distributors are follower)

Again, in the decentralized model, when distributors are leaders and manufacturer is follower, the emission level after mitigation is highest than that of all the models. It indicates that being the leader under decentralized scenario, the distributors have not taken care of about carbon emission mitigation. Also the manufacturer's profit decreased remarkably and the distributors profit increased unnaturally. In the Figure 3, the distributors dominated the manufacturer by keeping the manufacturer's wholesale Price as less as possible and hiking the distributors base selling price for more profit making, ignoring the carbon emission effects.

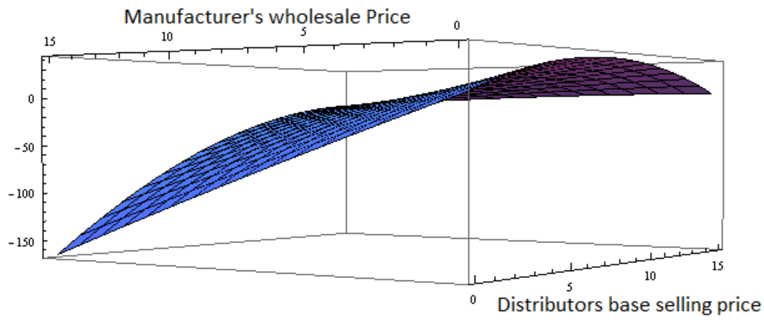

Figure 3. Distributors base selling price Vs manufacturer's wholesale Price in Decentralized Model(when distributors are leaders and manufacturer is follower)

Thus, it has been found that the centralized model worked best under the coordination system. In centralized model the distributors selling price is under control and also the emission level after mitigation is the least due to joint contribution of both manufacturer and distributors.

This model can be further be extended to three-echelon supply chain model by introducing the retailers with auction concept as buyers of the distributors.

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