Green Inventory Model with the Impact of Investment in Green Technology Based on Cap-and-Trade Policy

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Abstract

This study investigates the effect of carbon policy and green technology in the inventory model, taking into account carbon emissions from the product manufacturing, setup, transportation, storage, and recycling processes. The goal of this study is to help firms determine their optimal order quantity and green investment amount in order to minimize costs under carbon cap and trade policy. This research also has practical implications for the government in terms of developing appropriate policies and regulations to balance the trade-off between environmental protection and economic growth. According to the findings, firms that adopt a carbon tax policy would prefer to invest in a relatively efficient green technology. Finally, the developed model is explained numerically.

Keywords: Green Inventory, investment in green technology, carbon emissions, cap and trade, carbon reduction for green technology.
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1.Introduction

Carbon emissions threaten the livelihood of our planet, animals and humans. Carbon emissions occurs when carbondioxide and other green houses gases enters the air because of the human activities, such as burning of fossil fuel for industrialization, transportation, generating electricity and deforestation for urbanization. The amount of carbon emissions trapped in our atmosphere which causes global warming. Global warming poses severe risk to the nature, animal, human being and other living organism which also causes the rise of sea level, disruption in ecosystems, flood, drought, storm etc. Due to global warming, many countries have made environmental policies and regulations to prevent companies from excessively discharging waste water and air into the environment. These are the big challenges to governments and companies. Government needs to validate and trace the carbon emission of each energy consumers and they can also provide some mechanism of carbon emission trading and incentives of green investment for reducing carbon emission. The companies will pursue their best benefits under the regulations, mechanisms and incentives made from governments.

In cap and trade Policy, companies will be taxed if they limit a higher level of carbon emissions than their permitted allowances. Companies also can reduce their emissions and sell or trade the remaining surplus to other companies. For example, California emissions trading system is one of a collection of major policy which was launched in 2013. It gives critical experience in creating and managing an economy wide cap and trade system. Likewise, companies may also choose to invest in green technology as it becomes cheaper than buying permits today. This policy has been implemented in many developing and developed countries. However, pursuing the regardless reduction of carbon emissions of economic growth is not practical for developing countries. Most of the developing countries would have to tradeoff between environmental protection and economic growth.

2. Literature Review

Recently, a few works have analyzed sustainability issues in EOQ models. Carbon tax, carbon offsets, direct accounting, cap-and-trade and direct cap in a lot sizing model by considering business carbon footprint was introduced by Turkay (2008). Bonney and Jaber (2011) introduced various environmental issues arising from the inventory and demonstrate a EOQ inventory model.Bouchery et al. (2012) suggested a multi-objective EOQ model that minimizes the cost and environmental damages. Chen et al. (2013) explained the effects of parameters of carbon emission in lot sizing models in supply chain management and showed the effect of carbon emissions in their work. Ozlu (2013) explored an EOQ model under cap and trade, carbon cap and carbon tax approaches. He examined a retailer's joint decision on inventory replenishment and investment for carbon emission reduction. He et al. (2015) introduced that firms under cap and trade mechanism receive a free carbon emissions cap during a finite tie period and can trade the cap with other firms in the same carbon market. Juanjuan Qin, Xiaojian Bai and Liangjie Xia (2015) examined the sustainable trade credit and replenishmentpolicies under carbon cap-and-trade and carbon tax regulations. Arindam Ghosh, J.K. Jha and S.P. Sarmah (2016) enhanced a two-echelon supply chain with different carbon policies. W.Ritha and J.C. Eveline (2019) explored the lost sales and full backordering sustainable economic production quantity models under cap and trade policy. Chih-Chiang Fang and Ying-An-Lin (2020) examined an inventory management in supply chains with consideration of Logistics, green investment and different carbon emission policies.

The remainder of the study is structured as follows: Section 3 provides fundamental assumptions and notations. Section 4 describes the Mathematical formulation in detail. Section 5 illustrates a numerical example. Section 6 concludes the paper.

3. Mathematical Model

In order to determine the mathematical models, we use the following notations and assumptions.

3.1 Notations

Decision Variables

Q Order quantity per order
G Green investment amount

Other Parameters

D Demand rate
A Ordering cost
h Inventory holding cost
P_c Production cost
M Manufacturing cost
d Distance travelled
v Average velocity
α Proportion of demand returned $(0 < \alpha < 1)$
β Social cost from vehicle emission
a Fixed cost per trip
b Variable cost per unit transported per distance travelled
P Labor cost for packaging per parcel
L The cost of material used for packaging per parcel
θ Proportion of waste produced per lot Q

W_d Cost to dispose waste to the environment
F_d Fixed cost per waste disposal activity
N Number of parcels
A_c Carbon emission quantity from order per cycle
M_c Carbon emission from manufacturing process
h_c Carbon emission quantity from inventory holding
S_c Screening cost
R Recycling cost per unit
R_e Carbon emission from recycling process
R_m Number of returned materials that are suitable for recycle
μ The carbon reduction efficiency factor
σ The offsetting carbon reduction factor
U The upper limit of carbon emissions
C The carbon trading price of unit carbon emission

3.2 Assumptions

1. The rate of the demand and returned products are constant per cycle.
2. Carbon emissions occur in the processes of production, transportation, storage and recycling process.
3. The company has the opportunity to invest on Green technology in each source of emissions separately to reduce emissions.
4. Waste management focuses on source reduction, pollution control and disposal.
5. The selling price of the carbon is same as that of the buying cost.
6. The carbon emissions allowances are sufficient in the market for purchasing.

4. Mathematical Formulation

Cap and trade Policy

Under cap and trade policy firms are allowed to emit carbon within a specified level over a planning horizon (e.g. one year), which is called cap. If the firm crosses the cap during its operations, then the firm has to buy carbon credits from other firms. If the firm emits less carbon emissions than the required level, it earns carbon credit which will be sold to other firms.

The cap and trade policy control the total amount of carbon emissions from the industry. If carbon emissions do not exceed the upper limit U, the surplus can be sold at C per unit to offset the expected costs. In contrast, if carbon emissions exceed the upper limit, the firm has to purchase allowances from other firms or invest in green cost to comply with regulations of limited carbon emissions. Suppose that the surplus is valid only at the current periods regardless of selling or purchasing and the carbon trading price C, is the average price in the market.

4.1 Formulation of model based on cap and trade policy without green technology

In consider the scenario of the cap and trade, the total cost consists of production cost, manufacturing cost, transportation cost, holding cost, screening cost, disposal cost and carbon trading cost. By subtracting the sum of carbon emissions from the production and transportation from the upper limit of carbon emissions, the surplus can be obtained. The total cost under cap and trade is given by

$$TC(Q) = \frac{D}{Q}(A + F_d + (P+L)N + S_c + M + RR_m + 2a) + \frac{Qh}{2} + D\big(P_c + bd(1+\alpha) + W_d(\theta+\alpha)\big) - CU + \frac{D}{Q}C\left(A_c + M_c + \frac{2\beta d}{v}\right) + \frac{Q}{2}ch_c$$

In order to find the optimal order quantity, the above equation is differentiated with respect to Q and equated to zero. The Optimal order quantity is derived as Q^*.

$$\frac{-D}{Q^2}(A + F_d + (P+L)N + S_c + M + RR_m + 2a) + \frac{h}{2} - \frac{D}{Q^2}C\left(A_c + M_c + \frac{2\beta d}{v}\right) + \frac{ch_c}{2} = 0$$

$$Q^* = \sqrt{\frac{2D\left[A + F_d + (P+L)N + S_c + M + RR_m + 2a + C\left(A_c + M_c + \frac{2\beta d}{v}\right)\right]}{h + ch_c}}$$

4.2 Formulation of model based on cap and trade policy with green technology

Nowadays, the companies are started adopting green technology to reduce carbon emission. In this model, we have assumed that the relationship between the green technology and reduction is as follows.

Carbon reduction for green technology = $\mu G - \sigma G^2$
Here G is the amount of capital invested on green technology, μ denotes the carbon reduction efficiency factor and σ denotes the decreasing return parameter.

In this model, the total cost under cap and trade consists of production cost, manufacturing cost, transportation cost, holding cost, screening cost, disposal cost, carbon trading cost and the amount of investment in green technologies. By subtracting the sum of carbon emissions from the production and transportation from the upper limit of carbon emissions and then subtracting the carbon emissions reduction effectiveness from the investment in green technology, the surplus can be obtained. The total cost under cap and trade is given by

$$TC(Q,G) = \frac{D}{Q}(A + F_d + (P+L)N + S_c + M + RR_m + 2a) + \frac{Qh}{2} + D\big(P_c + bd(1+\alpha) + W_d(\theta+\alpha)\big) - CU + G + \frac{D}{Q}C\left(A_c + M_c + \frac{2\beta d}{v}\right) + \frac{Q}{2}ch_c - C(\mu G - \sigma G^2)$$

In order to find the optimal order quantity, the above equation is differentiated with respect to Q and equated to zero. The Optimal order quantity is derived as Q^*.

$$\frac{-D}{Q^2}(A + F_d + (P+L)N + S_c + M + RR_m + 2a) + \frac{h}{2} - \frac{D}{Q^2}C\left(A_c + M_c + \frac{2\beta d}{v}\right) + \frac{ch_c}{2} = 0$$

$$Q^* = \sqrt{\frac{2D\left[A + F_d + (P+L)N + S_c + M + RR_m + 2a + C\left(A_c + M_c + \frac{2\beta d}{v}\right)\right]}{h + ch_c}}$$

In order to find the optimal amount of green investment, the TC equation is differentiated with respect to G and equated to zero. The Optimal order quantity is derived as G^*.

$$G^* = \frac{C\mu - 1}{2C\sigma}$$

5. Numerical Example

Consider the following data to illustrate the proposed model.

D	5000	F_d	\$ 1
A	\$ 120	N	15
h	\$ 20	R	\$ 120
P_c	\$ 200	M	\$ 150
d	250 km	A_c	\$ 130
v	50 km/h	M_c	\$ 160
α	0.2	h_c	\$ 55
β	\$ 20	S_c	\$ 0.2
a	\$ 30	R_e	\$ 130
b	\$ 3	R_m	50
P	\$ 6	U	6000
L	\$ 8	C	\$ 1.8
θ	0.5	μ	4
W_d	\$ 0.8	σ	0.01

The Optimal Solutions are given in the table

Investment Status	Q^*	G^*	TC
Without Green Technology	789.809	-	\$ 5,590,454.178

With Green Technology	789.809	$ 172.222	$ 5,589,920.289

From this result, the investment in green technology gives the optimal solution.

6. Conclusion

In this study, an inventory model is to optimize the total cost with and without investment on green technology under cap and trade policy have been discussed vividly. Carbon cap and trade encourage organization to emit less carbonand also gives the flexible to trade carbon in the market. Therefore, cap and trade is an impressive method to reduce emissions from various sources and thereby minimize the total cost of the system. Hence, the government should fix the limit of carbon emissions within a reasonable range under the cap and trade policy to avoid suppliers overly trading their allotted quantity of carbon emissions.

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9519

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