Supply chain coordination contract with carbon emissions sensitive demand and green technology investments

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Abstract
In this paper, coordination problems of a two-stage supply chain, which is formed by one manufacturer who can invest in emission reduction and one retailer, were discussed under 'cap-and-trade' policy. Firstly, by analysis, we got the optimal retail price, carbon emission reduction degree and production. Second, we found that the traditional revenue sharing contract could not coordinate the supply chain, because the manufacturer undertook emission reduction investment costs completely, so that manufacturer's investment enthusiasm was reduced. Then we designed a 'revenue and carbon reduction cost sharing' contract, and realized the coordination of the supply chain. At last, the influence to supply chain decisions and profit from carbon price and carbon quota were discussed, and got some management implications which benefited the enterprise's decision-making and coordination of the supply chain.
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1. Introduction

In June 2014, enterprise, such as Guangdong Fenglv.Co. Ltd and Zhonglian Group, received the first national Certification of Low Carbon Products. This policy is an important initiative, which controls the emission of greenhouse gas from the consumers, implements China's emission target in 2020, and boosts the development of low-carbon products. The implementation of this policy results in a transfer of customers' focus of attention from traditional price to aspects such as service, flexibility, and environment. Companies are also seeking a profitable and low-carbon operating model from production, logistics or other segments of operation to reduce carbon emission, and meet customers' carbon sensitive demand, so that customers are more willing to purchase green, environmentally friendly, and sustainable products [1-2]. As pointed out in Nielsen's 2013 "Global, Socially Conscious Consumer" report, about 66% of customers think that companies should protect the environment, and they are willing to bear more costs for green emission reduction. Customers' environmental awareness is gradually awaking and they are paying more attention to green and environmental protection when they are purchasing products. This has created green consumer demand which will become the powerful pushing hands to force companies carrying out green production.

Implementation of the carbon cap-and-trade policy has brought new opportunity and challenge to company operation and supply chain management, and it has also affected customers to pay higher price than the original price for carbon footprint labelled products [3]. In recent years, research on coordinated optimization of supply chain under the carbon cap-and-trade policy has attracted increasing attention. Benjaafar et al [4] brought carbon emission into a supply chain system. They investigated company purchasing, production, inventory and investment decision on green technology under the carbon cap-and-trade policy, and analysed the influence of enterprise cooperation on reduction of operating cost and carbon emission in the supply chain. Subsequently, many researchers have utilized different agreements to coordinate low carbon supply chain. Du et al [5] used two stages supply chain consists of carbon emission permit market suppliers and carbon emission companies under the carbon cap-and-trade policy, adopted non-cooperative game theory to achieve the coordination of the supply chain. Choi [6] studied the influence of two agreements, wholesale price and price subsidy on retailer choose purchasing sources under random market demand,. Swami et al [7] focused on consumers' environmental awareness, they suggested that the efforts that manufacturer and retailer put on the supply chain green operation will affect consumers' demand. They designed a cost sharing contract to achieve the coordination of supply chain. Li et al [8] discussed a supply chain consists of one manufacturer and one retailer in the context of low carbon supply chain, and according to them, option contract could effectively coordinate supply chain, and it was robustness. They also stated risk preference of the subject of decision-making that had significant influence on profit distribution. Xu et al [9] discussed the issue of price discrimination of green production and ordinary products in the context of low carbon. In regards to the efficiency loss of supply chain caused by decentralized decision-making, they employed Shapley value to coordinate the supply chain and designed a coordination mechanism. In consideration of the influence of carbon emission reduction in the production process on demand, Xia et al [10] investigated the emission reduction interactions between supplier and manufacturer, and designed a self-executing and side payment contact to coordinate supply chain.

Different from previous studies, this paper investigates consumers' carbon sensitive demand from the point of view of supply chain. It discusses which contract can achieve coordination of supply chain when the manufacturer is investing in green technology; whether the profits can be divided freely. It also investigates the influence of carbon emission policy on retailer's order quantity, and the influence of the trade price of carbon emission on the production output of supply chain. This article extends the research range of supply chain management of carbon emission, enhances the research on company decision and coordinated optimization of supply chain under carbon cap-and-trade policy. It has considerable theoretical value and practical significance.

2.Problem description and assumptions

This paper focuses on a second-stage supply chain which consists of a dominating manufacturer and a weak retailer. Under the carbon cap-and-trade policy, in order to promote energy conservation and emission reduction in every company member of the supply chain, the government assigned a certain amount of initial carbon quota to both manufacturer and retailer, and they can also buy carbon footprint from outside market. Carbon footprint refers to the total amount of greenhouse gas emission in the production and logistics of manufacturer and the transportation of retailer. This paper investigates supply chain coordination problem of manufacturer's investment in green technology and consumers' carbon sensitive demand in the context of carbon cap-and-trade policy.

Relevant hypotheses of the model are as follows:

(1) There is a linear relationship between customer demand and price of low carbon products and the rate of commission reduction ($q = b - cp + d\rho > 0$, b,c, dare constant). The demand is decreased with the increasing of the price of low carbon products, and it is increased with the increasing of the rate of carbon emission.

(2) Product carbon footprint comes from the production and logistic processes of manufacturing, as well as the transportation of retailer. Also, without investing in green technology, the carbon commission of net product in every segment is constant. Manufacturer can reduce carbon emission in production by investing in green technology. The carbon commission of retailer 's transportation segment is a fixed amount.

(3) Marginal abatement cost is increased with the rise of carbon emission reduction rate. Company controls unit product carbon emission reduction rate by adjusting marginal abatement cost. Therefore, carbon emission reduction rate is one of the decision variables.

(4) Single periodic carbon footprint that the government assigns to the company is determined according to the production output and the emission amount

of unit product last period, and has nothing to do with the output of current period. It is an exogenous variable which cannot be transferred to the next period.

(5) Transaction price is determined by the trading market of carbon emission, and is an exogenous variable.

(6) Members of the supply chain are risk neutral and information sharing. Stock out, residual value of product, and order lead-time are not in consideration. Parameters and variables used in this particle are demonstrated in Figure 1.

Table 1. Symbols and Definitions

Symbols	Definitions
q	Production / order quantity, $q=b-cp+d\rho>0$ b, c and d are constants.
ρ	carbon reduction rate
C_s	production cost
p	price of the product
w	wholesale price
C_e	trade price of each unit of carbon emission
E_M	carbon footprint of each product in manufacturer's production part
e_M	carbon footprint of each product in manufacturer's logistics part
e_R	carbon footprint of each product in retailer's logistics part
A_M / A_R	manufacturer's /retailer's carbon quota
$C(\rho)$	Carbon reduction cost, $C(\rho)=a\rho^2$, 'a' is carbon reduction cost coefficient
φ	retailer's revenue sharing proportion
θ	retailer's carbon reduction cost sharing proportion
$\pi_M / \pi_R / \pi_{SC}$	Profit of the manufacturer/the retailer/ the supply chain

3. Decision-making model of supply chain in context of carbon cap-and-trade policy

3.1. Decentralized decision-making model of supply chain

The government implements carbon cap-and -trade policy on both manufacturer and retailer, which means that both manufacturer and retailer need to consider their own carbon emission amount during the interactions with each other. In this section, the sequence of event is as follows: first of all, manufacturer decides the best wholesales price w_{m1}^* and the optimal emission reduction factor ρ_{m1}^*, for the purpose of profit maximization; secondary, based on the wholesales price and emission reduction factor decided by the manufacturer, the retailer decides the best retail price p_{r1}^*, q_{r1}^*, for the purpose of profit maximization. Next, establish, analyze and resolve the decentralized decision-making model of manufacturer and retailer in context of carbon cap- and-trade policy.

In the decentralized decision-making model of supply chain, retailer's profit function is as follows:

$$\begin{aligned}\pi_R(p_{r1},q_{r1}) &= p_{r1}q_{r1}-wq_{r1}-(e_Rq_{r1}-A_R)C_e \\ &=(p_{r1}-w-e_RC_e)(b-cp_{r1}+d\rho)+A_RC_e\end{aligned} \quad (1)$$

If $q_{r1}=0$, $\pi_R=A_RC_e$, The means that if the retailer does not sale goods, it can also make profit through selling carbon emission rights issued by government. If $e_Rq_{r1}-A_R>0$, the retailer needs to buy extra carbon emission rights from carbon emission trade market to make more productions. On the contrary, If $e_Rq_{r1}-A_R<0$, the retailer must sell out redundant carbon emission rights.

In order to gain a maximum profit, the retailer need to make out the optimal sales price p_{r1}^* and the optimal order quantity q_{r1}^*.

$$\frac{\partial\pi_R}{\partial p_{r1}}=b-cp+d\rho-c(p-w-e_RC_e)$$

$$\frac{\partial^2\pi_R}{\partial^2 p_{r1}}=-2c<0 \quad (2)$$

we can know that the second derivative of π_R is less than 0, then it can be concluded that is a strictly concave function, then the retailer's optimal price function is as formula (3):

$$p_{r1}=\frac{b+d\rho+c(w+e_RC_e)}{2c} \quad (3)$$

The manufacturer's carbon reduction rate are unknown variables. If we want to get the optimal solutions of p_{r1}^* and q_{r1}^*, the manufacturer's optimal carbon reduction rate ρ_{m1}^* and optimal wholesale price w_{m1}^* should be made out first.

In the decentralized decision-making model of supply chain, the profit function for the manufacturer is as formula (4):

$$\begin{aligned}&\pi_M(w_{m1},\rho_{m1})=w_{m1}q_{r1}-C_sq_{r1} \\ &-[E_M(1-\rho_{m1})q_{r1}+e_Mq_{r1}-A_M]C_e-a\rho_{m1}^2\end{aligned} \quad (4)$$

In formula (4), if $E_M(1-\rho)q_{r1}^*+e_Mq_{r1}^*-A_M>0$ there is not enough carbon emission right for the manufacturer. In order to ensure the production, the manufacturer must buy some extra carbon emission right from carbon emissions trading market; While if $E_M(1-\rho)q_{r1}^*+e_Mq_{r1}^*-A_M$ <0, the manufacturer may sell the rest of the carbon emissions to make a profit.

Obviously, formula (4) is a function of two variables, and it has one stationary point $\pi(w_0,\ \rho_0)$.

$$w_0 = \frac{b + d\rho_0 - ce_R C_e + c\left[C_s + E_M(1-\rho_0)C_e + e_M C_e\right]}{2c}$$

$$\rho_0 = \frac{E_M C_e\left[b - c(w_0 + e_R C_e)\right] + d\left[w_0 - C_s - E_M C_e - e_M C_e\right]}{4a - 2dE_M C_e}$$

At the stationary poin, the Hessian Matrixis as follows:

$$d''\left(E(\pi_0)\right) = \begin{bmatrix} \frac{\partial^2 E(\pi_M)}{(\partial w_0)^2} & \frac{\partial^2 E(\pi_M)}{\partial w_0 \partial \rho_0} \\ \frac{\partial^2 E(\pi_M)}{\partial \rho_0 \partial w_0} & \frac{\partial^2 E(\pi_M)}{(\partial \rho_0)^2} \end{bmatrix}$$

$$= \begin{bmatrix} -c & \frac{d - cE_M C_e}{2} \\ \frac{d - cE_M C_e}{2} & dE_M C_e - 2a \end{bmatrix}$$

It is can be figured out that it is a negative definite matrix. So the optimal solution can be made as formula (5):

$$\left(w_{m1}^*, \rho_{m1}^*\right) = \begin{cases} w_{m1}^* = \dfrac{b + d\rho + c\begin{bmatrix} C_s + E_M(1-\rho)C_e + \\ e_M C_e - e_R C_e \end{bmatrix}}{2c} \\ \rho_{m1}^* = \dfrac{(cE_M C_e + d)\left[b - c\begin{pmatrix} C_s + E_M C_e + \\ e_M C_e + e_R C_e \end{pmatrix}\right]}{8ac - d^2 - 2cdE_M C_e - c(E_M C_e)^2} \end{cases} \quad (5)$$

And then the optimal sale price p_{r1}^* can be made out as formula (6):

$$p_{r1}^* = \frac{b}{c} + \frac{\left[b - c(C_s + E_M C_e + e_M C_e + e_R C_e)\right]}{4c\left[8ac - d^2 - 2cdE_M C_e - c(E_M C_e)^2\right]} \begin{bmatrix} 4d(cE_M C_e + d) \\ -8ac - c^2(E_M C_e)^2 + c(E_M C_e)^2 \end{bmatrix} \quad (6)$$

Put the function q=b-cp+dρ , into formula (6), the optimal order quantity q_{r1}^* can be figured out as formula (7):

$$q_{r1}^* = \frac{\left[8ac + c^2(E_M C_e)^2 - c(E_M C_e)^2\right]\left[b - c(C_s + E_M C_e + e_M C_e + e_R C_e)\right]}{4\left[8ac - d^2 - 2cdE_M C_e - c(E_M C_e)^2\right]} \quad (7)$$

3.2. Centralized decision-making model of supply chain

When the cap and trade policy is for both manufacturers and retailers, in centralized decision making pattern, the supply chain's profit is as formula (8):

$$\pi_{SC}(p_{sc},\ \rho_{sc}) = p_{sc}q - C_s q - \begin{bmatrix} E_M(1-\rho_{sc})q + e_M q \\ +e_R q - A_R - A_M \end{bmatrix} C_e - a\rho_{sc}^2 \quad (8)$$

Proposition 1. Under cap and trade policy, the optimal sell price is

$$p_{sc}^* = \frac{b\left[2a - E_M C_e(cE_M C_e + d)\right]}{4ac - (cE_M C_e + d)^2} + \frac{\left[2ac - d(cE_M C_e + d)\right](C_s + E_M C_e + e_M C_e + e_R C_e)}{4ac - (cE_M C_e + d)^2}$$

the optimal carbon reduction rate is

$$\rho_{sc}^* = \frac{(cE_M C_e + d)\left[b - c\begin{pmatrix} C_s + E_M C_e \\ +e_M C_e + e_R C_e \end{pmatrix}\right]}{4ac - (cE_M C_e + d)^2}$$

and the optimal production is

$$q_{sc}^* = \frac{2ac\left[b - c\begin{pmatrix} C_s + E_M C_e \\ +e_M C_e + e_R C_e \end{pmatrix}\right]}{4ac - (cE_M C_e + d)^2}$$

Proof: Put the function $q = b - cp + d\rho$ into formula (8), we can get the supply chain's profit:

$$\pi_{SC}(p_{sc},\ \rho_{sc}) = \begin{bmatrix} p - C_s - E_M(1-\rho)C_e \\ -e_M C_e - e_R C_e \end{bmatrix} (b - cp + d\rho) + (A_R + A_M)C_e - a\rho^2$$

It can be known that the function π_{SC} is a function of two variables, that is q and ρ. So the optimal solution $\left(p_{sc}^*,\ \rho_{sc}^*\right)$ can be made as follows:

$$p_{sc}^* = \frac{b + d\rho_{sc}^* + c\begin{bmatrix} C_s + E_M\left(1 - \rho_{sc}^*\right)C_e \\ +e_M C_e + e_R C_e \end{bmatrix}}{2c}$$

$$= \frac{b\left[2a - E_M C_e\left(cE_M C_e + d\right)\right]}{4ac - \left(cE_M C_e + d\right)^2} + \frac{\left[2ac - d\left(cE_M C_e + d\right)\right]\left(C_s + E_M C_e + e_M C_e + e_R C_e\right)}{4ac - \left(cE_M C_e + d\right)^2}$$

$$\rho_{sc}^* = \frac{\left(cE_M C_e + d\right)\left[b - c\left(\begin{matrix} C_s + E_M C_e \\ + e_M C_e + e_R C_e \end{matrix}\right)\right]}{4ac - \left(cE_M C_e + d\right)^2}$$

For that $q = b - cp + d\rho$, the optimal production of the supply chain q_{sc}^* is :

$$q_{sc}^* = \frac{2ac\left[b - c\left(C_s + E_M C_e + e_M C_e + e_R C_e\right)\right]}{4ac - \left(cE_M C_e + d\right)^2}$$

End.

Comparing the optimal production q_{sc}^* in centralized decision-making model with the optimal order quantity q_{r1}^* in decentralized decision-making model, it can be known that $q_{sc}^* > q_{r1}^*$. This means that when the government adopts cap and trade policy, the optimal production in centralized decision making pattern is always higher than the optimal order quantity in decentralized decision making pattern; The traditional wholesale contract cannot coordinate the supply chain. As the leader of the supply chain, in order to make the retailer accept cooperation, the manufacturer must adopt a cooperation strategy, to increase retailer's order quantity.

4. Strategy of supply chain coordination in the context of carbon cap-and-trade policy

4.1. Coordination strategy of revenue-sharing contract

In the revenue-sharing contract the manufacturer sell product to retailer at a lower wholesales price, after the retailer sold the product, it will pay back to the manufacturer in the proportion of $(1-\varphi)$ as "return".

In the revenue sharing coordination contract, the retailer's profit is as formula (9):

$$\pi_R^1(p,q) = \varphi pq - wq - \left[E_M q - A_R\right]C_e \qquad (9)$$

Take the equation $q = b - cp + d\rho$ to formula (9), the retailer's profit can be expressed as follows:

$$\pi_R^1(p,q) = \varphi pq - wq - \left[E_M q - A_R\right]C_e$$

Then the optimal sale price is:

$$p = \frac{\varphi(b + d\rho) + c\left(w + e_R C_e\right)}{2\varphi c} \qquad (10)$$

Proposition 2. The revenue-sharing contract cannot coordinate the whole supply chain in the context of carbon cap-and-trade policy.

Proof: From formula (3), we can get manufacturer's profit function in the decision-making model:

$$\pi_M^1(\rho) = wq - C_s q - \left[E_M(1-\rho)q + e_M q - A_M\right] C_e - a\rho^2 + (1-\varphi)pq$$

$$= \left[w - C_s - E_M(1-\rho)C_e - e_M C_e + (1-\varphi)p\right] * \frac{\varphi(b + d\rho) - c\left(w + e_R C_e\right)}{2\varphi} + A_M C_e - a\rho^2 \qquad (11)$$

Then we can get the optimal emission reduction rate under the revenue-sharing contract:

$$\rho_1^* = \frac{\left(cE_M C_e + \varphi d\right)\left[\varphi b - c\left(\begin{matrix} C_s + E_M C_e + e_M C_e \\ + e_R C_e - (1-\varphi)p_1 \end{matrix}\right)\right]}{4\varphi ac - \left(cE_M C_e + \varphi d\right)^2}$$

To achieve supply chain coordination, the following conditions should be met at the same time. Firstly, the optimal order quantity of retailer in decentralized decision-making is equal to the optimal order quantity of retailer in supply chain centralized decision-making. Secondly, the optimal carbon emission strategy in decentralized decision-making is the same as the optimal carbon emission strategy in supply chain centralized decision-making. Thirdly, the best product price in decentralized decision-making is equal to the best product price in supply chain centralized decision-making. That is $p_1^* = p_{sc}^*$, $\tilde{n}_1^* = \tilde{n}_{sc}^*$, $q_1^* = q_{sc}^*$. If $p_1^* = p_{sc}^*$, $q_1^* = q_{sc}^*$, it can be concluded that:

$$\tilde{n}_1^* = \frac{c\left(cE_M C_e + d\right)\left[C_s + E_M C_e + e_M C_e + e_R C_e\right]}{\left(cE_M C_e + d\right)^2 - 4ac}$$

$\left(cE_M C_e + d\right)^2 - 4ac > 0$, Compared with

$$\rho_{sc}^* = \frac{\left(cE_M C_e + d\right)\left[b - c\left(\begin{matrix} C_s + E_M C_e + e_M C_e \\ + e_R C_e \end{matrix}\right)\right]}{4ac - \left(cE_M C_e + d\right)^2},$$

$$\rho_{sc}^* = \frac{\left(cE_M C_e + d\right)b}{4ac - \left(cE_M C_e + d\right)^2} + \rho_1^*,$$

that is, $\rho_1^* > \rho_{sc}^*$, this is inconsistent with the formula $\rho_1^* = \rho_{sc}^*$. In the same way, we can know that $q_1^* \neq q_{sc}^*$. So the revenue-sharing contract cannot coordinate the supply chain.

End.

and-trade policy, the traditional revenue-sharing contract cannot eliminate the double marginal effect, so it cannot coordinate the supply chain. If $p_1^* = p_{sc}^*$,

$q_1^* = q_{sc}^*$, $\rho_1^* > \rho_{sc}^*$. This means that if the manufacturer wants the order quantity to achieve the level in centralized decision-making pattern, it must invest more to lower carbon emissions. Because that the carbon emission has an impact on the demand, the retailer does not bear the carbon cost but it can get the benefits of carbon emission reduction. For the manufacturer, it is unfair. The manufacturer will not increase investment without subsidies or incentives. In conclusion, the traditional revenue-sharing contract cannot coordinate the supply chain, and a new contract is needed.

To achieve coordination, the new contract must have the advantages bellow. Firstly, it can stimulate the retailer to order. Secondly, it can also attract the manufacturer to invest the green product technology to lower the carbon emission level. On condition that the carbon reduction cost should not be undertook by the manufacturer, which will reduce the manufacturer's enthusiasm, a new "revenue sharing and carbon cost sharing coordination contract" is adopted in this paper, to eliminate the double marginal effect and to inspire the manufacturer to invest green technology by sharing carbon cost, at last coordinate the supply chain.

4.2. Revenue sharing and carbon cost sharing coordination contract

In the revenue sharing and carbon cost sharing coordination contract, the manufacturer sell product to retailer at a lower wholesales price, after the retailer sold the product, it will pay back to the manufacturer in the proportion of '1-φ' as 'return'. At the same time, both the manufacturer and the retailer will share the carbon reduction cost. That is, the retailer share a proportion of θ, while the manufacturer share a proportion of '1-φ'.

The manufacturer's profit function is as formula (12):

$$\pi_R^2(p_2) = \varphi p_2 q - wq - \theta \begin{bmatrix} E_M(1-\rho)q + e_M q \\ +e_R q - A_R - A_M \end{bmatrix} C_e - \theta a \rho^2 \quad (12)$$

Proposition 3. If $\varphi = \theta$, $w = \varphi C_s$, The revenue sharing and carbon cost sharing coordination contract can coordinate the whole supply chain in the context of carbon cap-and-trade policy.

Proof: The coordination state means that the manufacturer and the retailer's independent optimal decisions must be the same with the centralized optimal decisions.

Put the formula $q = b - cp + d\rho$ into formula (12):

$$\pi_R^2(p_2) = \begin{bmatrix} \varphi p - w - E_M(1-\rho)\theta C_e \\ -e_M \theta C_e - e_R \theta C_e \end{bmatrix} (b - cp + d\rho) + \theta(A_R - A_M)C_e - \theta a \rho^2$$

Then the sales price can be concluded as formula (13):

$$p_2 = \frac{\varphi(b + d\rho) + c\begin{bmatrix} w + E_M(1-\rho)\theta C_e \\ +e_M \theta C_e + e_R \theta C_e \end{bmatrix}}{2\varphi c} \quad (13)$$

From the formula $q = b - cp + d\rho$, the order quantity can be concluded:

$$q_2 = b - p_2^* + d\rho \quad (14)$$

In order to coordinate the supply chain, the condition $p_2^* \equiv p_{cs}^*$ must be met. Assuming that

$$\begin{cases} \varphi = \theta, \\ w = \varphi C_s \end{cases} \quad (15)$$

Now let us verify the condition $p_2^* \equiv p_{cs}^*$.

In the decentralized decision making, the manufacturer's profit function is as follows:

$$\pi_M^2(\rho_2) = (1-\varphi)pq + wq - C_s q - (1-\theta)\left[E_M(1-\rho_2)q + e_M q + e_R q - A_R - A_M\right]C_e - (1-\theta)a\rho_2{}^2$$

Take formula (13), (14), (15) into formula $\pi_M^2(\rho_2)$, the optimal emission reduction rate ρ_2^* can be figured out:

$$\rho_2^* = \frac{(cE_M C_e + d)\left[b - c\begin{pmatrix} C_s + E_M C_e + \\ e_M C_e + e_R C_e \end{pmatrix}\right]}{4ac - (cE_M C_e + d)^2}$$

Comparing ρ_2^* with ρ_{sc}^*, we can know that $\rho_2^* = \rho_{sc}^*$.

End.

Deduction1. In the context of carbon cap-and-trade policy, when the supply chain is be coordinated, $\pi_R^2 = \varphi\pi_{SC}$, $\pi_M^2 = (1-\varphi)\pi_{SC}$.

Proof: In order to coordinate the supply chain, the condition must be met. So the profit of the manufacturer and the retailer is as formula (16) and (17).

$$\pi_R^2 = \varphi\pi_{SC} \quad (16)$$

$$\pi_M^2 = (1-\varphi)\pi_{SC} \quad (17)$$

End

Deduction 1 shows that if the supply chain get the maximum profit, the manufacturer and retailer's profit are decided by the revenue sharing parameter φ or the carbon cost sharing parameter θ, which is decided by the battle between the manufacturer and the retailer.

Now we need to do a feasibility study of the revenue sharing and carbon cost sharing coordination contract. That is, if the coordinate parameter φ or θ is in the range of (0,1).

Obviously, in the context of carbon cap-and-trade policy, in order to attract the manufacturer and the retailer to collaborate, the coordinate profit of them must be more than the profit before coordination, that is $\pi_R^2 > \pi_R$, $\pi_M^2 > \pi_M$. What's more, the supply chain's profit in centralized decision making pattern must be more than the sum of manufacturer and retailer's profit in decentralized decision making pattern. And according to the formula (15), (16) and (17), $\frac{\pi_R}{\pi_{SC}} < 1 - \frac{\pi_M}{\pi_{SC}}$, $\varphi = \theta \subset \left(\frac{\pi_R}{\pi_{SC}}, 1 - \frac{\pi_M}{\pi_{SC}} \right)$, then it must be concluded that $\varphi = \theta < 1$. So in the the context of carbon cap-and-trade policy, if $\varphi = \theta$, $w = \varphi C_s$, the revenue sharing and carbon cost sharing coordination contract can coordinate the whole supply chain.

5. Analysis and Discussion

The research shows that under cap and trade policy, revenue sharing and carbon cost sharing coordination strategy can also make the supply chain coordinate, cap and trade policy does not affect supply chain's coordination state. Cap and trade policy, however, affects the supply chain's strategy and other factors, such as the production, profit, carbon emissions and so on.

Without carbon constraint, the supply chain's profit is as formula (18):

π_{SC} = ùùùù $_s$ = (− $_s$)(−) (18)

So the optimal sale price $p_0^* = \frac{b + cC_s}{2c}$, the optimal order quantity $q_0^* = \frac{b - cC_s}{2}$.

End.

Proposition 4 indicates that under cap and trade policy, the consumers also undertake part of carbon cost when buying the product.

Proposition 5

If $C_e < \frac{(b - cC_s)(cE_M C_e + d)^2}{4ac^2 (E_M + e_M + e_R)}$, $q_{sc}^* > q_0^*$,

If $C_e \geq \frac{(b - cC_s)(cE_M C_e + d)^2}{4ac^2 (E_M + e_M + e_R)}$, $q_{sc}^* \leq q_0^*$.

Proof: Without carbon constraint, the optimal production of the supply chain is $q_0^* = \frac{b - cC_s}{2}$, while it is $q_{sc}^* = \frac{2ac\left[b - c\left(\begin{matrix} C_s + E_M C_e \\ + e_M C_e + e_R C_e \end{matrix} \right) \right]}{4ac - (cE_M C_e + d)^2}$ under cap and trade policy.

If $C_e < \frac{(b - cC_s)(cE_M C_e + d)^2}{4ac^2 (E_M + e_M + e_R)}$, $q_{sc}^* > q_0^*$, else $q_{sc}^* \leq q_0^*$.

Proposition 5 shows that in the context of carbon cap-and-trade policy, the production is not always less than that under no carbon constraint. That is because consumers' demand for low carbon product is sensitive; they tend to buy lower carbon products. This also means that the carbon constraints implemented by the government do not always have disadvantages on production, on the contrary, if the carbon price is less than $\frac{(b - cC_s)(cE_M C_e + d)^2}{4ac^2 (E_M + e_M + e_R)}$, the production can be more than that under no carbon constraint.

Proposition 6. In the context of carbon cap-and-trade policy, the initial quota of the company assigned by the government is irrelevant to the q_{sc}^*、p_{sc}^*、ρ_2^* of supply chain, while is increased proportionally with π_{SC}、π_R^2、π_M^2.

Proof: In the context of carbon cap-and-trade policy,

$$q_{sc}^* = \frac{2ac\left[b - c\left(C_s + E_M C_e + e_M C_e + e_R C_e \right) \right]}{4ac - (cE_M C_e + d)^2}$$

$$\rho_2^* = \frac{(cE_M C_e + d)\left[b - c\left(\begin{matrix} C_s + E_M C_e + \\ e_M C_e + e_R C_e \end{matrix} \right) \right]}{4ac - (cE_M C_e + d)^2}$$

$$p_{sc}^* = \frac{b\left[2a - E_M C_e (cE_M C_e + d) \right]}{4ac - (cE_M C_e + d)^2} + \frac{\left[2ac - d(cE_M C_e + d) \right] (C_s + E_M C_e + e_M C_e + e_R C_e)}{4ac - (cE_M C_e + d)^2}$$

Obviously, q_{sc}^*, ρ_{sc}^* and ρ_{sc}^* are not connected with A_M and A_R .

From formula (8), we can know that

From formula(8), we can know that:

$$\frac{\partial \pi_{SC}}{\partial A_M} = C_e ; \frac{\partial \pi_{SC}}{\partial A_R} = C_e$$

This means that the profit of supply chain is increased proportionally with the sum of A_M and A_R .

According to formula (16) and (17), it can be deduced that in the context of carbon cap-and-trade policy, the profits of manufacturer and retailer chain is increased proportionally with the sum of A_M and A_R .

End.

Proposition 6 indicates that carbon cap-and-trade policy not only can limit carbon emission, but also can make companies get revenue and guarantee their production through carbon emission permit. At the same time, the amount of profit of supply chain, manufacturer, and retailer is determined by the sum of A_M and A_R of the initial quota.

6. Conclusion and future direction

The paper focused on a second-stage supply chain which consists of a dominating manufacturer and a weak retailer, investigated the strategy of supply chain coordination, in consideration of manufacturer's investment in green technology and consumer's carbon sensitive demand, in the context of carbon cap-and-trade policy. The above researches indicate that, in the context of carbon cap-and-trade policy, the traditional revenue sharing contract cannot coordinate the supply chain, therefore revenue sharing and carbon cost sharing contract was designed, And it can coordinate the supply chain, as well as achieve the free distribution of profit. The results prove that: 1. Consumers shared part of the carbon emission reduction cost, and this leads to the result that retailer price of the product is higher than the retailer price that without carbon cap; 2. The purchase price of carbon emission permit is determined by the output of the product; 3. Under the circumstance of high carbon emission permit assigned by the government, the profit of manufacturer and retailer can be both higher than the profit without carbon cap.

This paper put the amount of carbon cap and transaction policy in the point of view of supply chain. It took the carbon footprint in the whole process of product from production to sales into consideration. It considered the influence of consumer's carbon sensitive demand on the decision of retailer ordering products, and built profit functions for manufacturer, retailer, and the whole supply chain on the basis of carbon trade and manufacturer's green emission reduction measures. Ultimately, the coordination of low carbon supply chain is achieved in the context of carbon cap-and-trade policy. This article not only can provide guidance to company supply chain under the carbon cap-and-trade policy, but also can provide theoretical support for the formulation of government carbon emission index. In future research, issues such as multi-product and the coordination of multi-stage supply chain under the carbon cap-and-trade policy are worth to be investigated.

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