Two Stage Supply Chain Enterprises' Production and Reduction Decision-Making Mechanism Research Considering Emission Trading

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***Abstract*—Economic activities should reflect scarce and efficient allocation of environmental resources after carbon emission quota has become a kind of resource. These low-carbon economy characteristics profoundly change the cost structure, profit model and market risk compared with the traditional supply chain. This paper puts forward the topic 'the research of two stage supply chain enterprises' production and reduction decision-making mechanism considering emission trading'. The paper compares performance of the different decision modes in supply chain on carbon emission. Analyze the members profit and the whole supply chain profit by different two modes. Through investigating how upstream and downstream enterprises in the supply chain choose cooperation reduction strategy while they are facing environmental regulation, we can get their profits and reduction efficiencies in two different decision-making models. It can be obtained that in the centralized decision-making case, both their profit and reduction efficiency are optimal. The result shows that in the process of low carbonization of manufacturing enterprises, government should aim at the enterprises which emit larger carbon emission and grab from the source of supply chain firstly. And also enterprises must reduce their optimal output in order to reduce their total carbon emissions.**

***Index Terms*—supply chain management, carbon emission permit, cap and trade, emission reduction level, carbon price.**

I. Introduction

Although the economic development various between countries and the protection of environment is also different, but the carbon cap and trade system has become an important mechanism to reduce the carbon emission. To establish a global carbon emission limitation and emission trading mechanism, the carbon emission rights has gradually become a new commodity. As the goal of pursuit the maximum profit for enterprises, it is important to make a wise decision about how to deal with the opportunities and challenges and to seek a long-term profit maximization at the same time. What kind of incentive can make enterprises to reduction the emission while in risk of increasing the costs, and also the enterprises need to take into consideration about the interaction among enterprises in the reduction of supply chain. And then enterprises should take reasonable ways to increase the efforts of upstream and downstream enterprises' emission reduction and finally get the satisfactory earnings.

Manuscript received January 31, 2015; revised May 20, 2015.

II. Literature Review

Under the background of low carbon economy, some scholars have already introduced the low carbon issues into the production of the entity such as the decisions of inventory and operation management. Zhang (2011) [1] established optimization decision model of production and storage rely on the carbon emissions quota mechanism using the newsvendor model, which based on the stochastic demand. Benjaafar (2013) [2] introduced carbon footprint parameters into all kinds of optimization model, and studied the affection on reducing costs and carbon emissions through the cooperation between the enterprises in the supply chain. Cachon (2011) [3] studied how supply chain retailers network layout in meeting the carbon emission quota while minimizing operating costs under considering the impact on consumers. Consumers gradually pay more attention to the enterprises' performance of environmental protection. (Li, 2011 [4]) Under the background of low carbon economy, carbon emission quota becomes a new type of resource that can be traded. Carbon emissions quota trading and consumer preferences change will have tremendous impact on the enterprises' traditional production mode, operational strategy, enterprises' competition and cooperation strategy. This new mechanism will put forward lots of new issues to be studied for the management of the enterprise in the future.

Researches on the allocation right of carbon emission have gradually been carried out. Stern (2008) [5] thought that carbon emission trading system has been considered as a quite effective strategy to govern the climate change in the future. Kevin A. Baumert (2005) [6] analyzed the statistic data of the recent years' greenhouse gas

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doi: 10.12720/jiii.4.1.46-50

emissions and put forward a reasonable Global Climate Governance Policy. For quota allocation policy of carbon emission rights, most scholars believe that the allocation of carbon emission quota mainly has the way of free distribution, public auction and sale in public. The former two ways are the most common ways, and this paper is based on the thesis of free allocation.

In recent years, it has begun to taking carbon emissions quota into consideration on the literature of supply chain. Linton (2007) [7] introduced the sustainable supply chain, which established a good theoretical foundation of the operations management model of the supply chain. Amin Chaabane (2010) [8] thought that the management of sustainable supply chain relates to balance conflict among economic, environmental and social issues. By using multi-standard way, he designed and evaluated the sustainable supply chain system. Hoen *et al*. (2009) [9] analyzed the actual data which show that the adjustment of transport mode can significantly reduce the carbon emissions. Obviously, carbon emissions quota has become a very important topic whether from the national level or the micro enterprise level. However, there are quite little researches taking into consideration of carbon emissions trading when they make production and operation decision and supply chain integration and coordination optimization problem.

The previous researches are mainly focused on the enterprises' behavior change under different environmental policy, or on operation optimization strategy of individual enterprises, or on transport choice, or on designing supply chain network. And the researches that pay attention to the emission reduction strategies of supply chain's upstream and downstream enterprises are quite few, in addition the researches to study how carbon cap mechanism and carbon trading prices affect the behavior of enterprises and the affection of reduction is rarely. This paper is trying to fulfill the research gap, and to have an in-depth study and discussion about relevant problems of upstream and downstream enterprises' optimal decision-making and different integration decision mode under the carbon emissions trading.

On the basis of previous studies, this paper extends the simple model into a complex one which consider the government's quotas on carbon emissions rights and also consider the downstream retailer's carbon emissions which makes the model more complete.

III. Low-Carbon Game Model Considering Carbon Trade

A. Problem Description

When carbon emission permit as a new recourse is brought into the manufacturing process of the enterprises and influences the enterprises' cost, driven by pursuing maximum profit, the enterprises are figuring out the problem of facing both opportunities and challenges that brought by low-carbon and of making a wise decision to seek the maximization of long-term earnings power. What kind of motivation can make the enterprises reduce emission at the risk of increasing the cost, consider both the interactivities of the enterprises at each point of the supply chain in the changing process and the influences from emission reduction investment spillover and self-learning, etc.

In the structure of two-stage supply chain, except the manufacturer can utilize low-carbon technology R&D to reduce carbon emission, the retailer can reduce carbon emission through reform invest of low-carbon technology optimizing the circulation link (storage-transportation-sale). Therefore, this chapter will analyze the problem of investment on emission reduction technology of the manufacturers and the retailers at upstream and downstream under the condition of the policy of free carbon allowance distributed by the government. To realize the maximization of profits, two enterprises must take the strategy of emission reduction as their decision variable. The enterprises shall make a choice between self-propelling emission reduction and cooperative emission reduction. In addition, the emission reduction of one enterprise will affect the other enterprise. In the meantime, the current carbon trading price will also exert an influence on the effects of emission reduction of supply chain. The enterprise makes different decisions according to different carbon trading prices. Furthermore, the distribution policy of carbon allowance in different forms will have different effects of emission reduction. This chapter will compare these different conditions and draw a conclusion.

There is no comparability between different products when using the reduction quantity of carbon emission as the measuring standard. However, the reduction rate can be compared. Therefore, this chapter will choose reduction rate as a decision variable for the enterprises in the supply chain.

B. Model Assumption

(1) In regard to the function of the enterprise's cost, this paper quotes the classic cost function of cost and R&D investment that proposed by D' Aspemont C (1988) [10], [11]. In hypothesis, the enterprise's cost in the supply chain contains two parts: one is the daily production cost, excluding the activities of the carbon emission reduction; and the other is the extra R&D cost βr^2 resulted from reducing the carbon emission by the enterprise. In which, β is the cost occurred because the enterprise adopts low-carbon chain management measures to promote reduction of carbon emission, such as redesign of product structures, choosing raw material of low carbon emission and environmental co-operation with suppliers, etc. Assuming that it is quadratic relation between the R&D cost and the reduction level of carbon emission of per unit product, which is,

$$c + \beta r^2$$

(2) The upstream manufacturer and the downstream retailer both have the pressure to reduce the carbon emission.

(3) The produced products are necessities. Therefore, the market of the products is imperfect competition market.

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(4) Product demand is only the linear function of its price. For the convenience of calculation, the demand is set as only influenced by product price.

(5) To seek the maximum profits, the enterprise will sell their excess carbon emission quota to obtain profit. Therefore, the enterprise can make the utmost of its owned resource of carbon allowance.

C. Model Structure and Variables

The model structure is illustrated in Fig. 1.

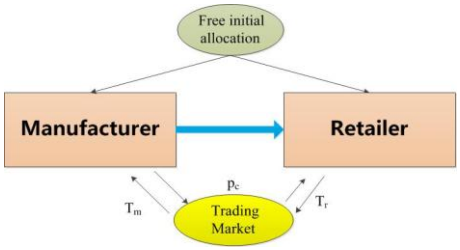

Figure 1. The supply chain structure and decision process considering the carbon emission trading

The decision variables and model parameters are descript in Table I.

TABLE I. DECISION VARIABLES AND MODEL PARAMETER

Decision variables	
ω	Manufacturer's wholesale price
r_m	Manufacturer's reduction rate of emission per product
p	Retailer's sale price
r_d	Retailer's reduction rate of emission per product
V_m	Profit function of the manufacturer
V_d	Profit function of the retailer
V_{SC}	Profit function of the whole supply chain
Parameters	
a	Initial market potential
q	The market demand of the product
β	Enterprise's cost parameter of carbon emission improvement
e_1	The initial carbon emissions of the manufacturer
e_2	The initial carbon emissions of the retailer
c_1	Unit production cost of the manufacturer
c_2	Unit production cost of the retailer

IV. ANALYSIS OF THE MODEL

For the enterprises considering carbon emission and carbon trading, the profit function consists of three parts: sales revenue, R & D investment of carbon emission reduction, profit and loss on the carbon emissions trading. Hence, the profit function for manufacturer is defined as:

$$V_m = (\omega - c_m) \cdot q - \frac{1}{2}\beta r_m^2 - T_m \cdot p_c \tag{1}$$

According to assumption 4, for manufacturer:

$$e_m \cdot q = S_m + r_m \cdot e_m \cdot q + T_m \tag{2}$$

After the transform, we can get (3):

$$T_m = e_m \cdot q - S_m - r_m \cdot e_m \cdot q \tag{3}$$

Putting (3) into (1):

$$V_m = [\omega - c_m - e_m \cdot p_c(1 - r_m)]q - \frac{1}{2}\beta r_m^2 + S_m \cdot p_c \tag{4}$$

According to assumption 3, the linear demand function is defined as:

$$q = a - p \tag{5}$$

So the profit function of the upstream manufacturer can be eventually written as:

$$V_m = [\omega - c_m - e_m \cdot p_c(1 - r_m)] \cdot (a - p) - \frac{1}{2}\beta r_m^2 + S_m \cdot p_c \tag{6}$$

The profit function of the downstream retailer can be written as:

$$V_r = [p - \omega - c_d - e_d \cdot p_c(1 - r_d)] \cdot (a - p) - \frac{1}{2}\beta r_d^2 + S_d \cdot p_c \tag{7}$$

Case 1: Decentralized decision making

In decentralized decision situation, manufacturer and retailer respectively make decision about price and reduction rate of emission based on profit maximization.

Theorem 1 Considering the carbon trading situation, decentralized decision-making model of the two stage low carbon supply chain exists a unique optimal solution. We can use the subscript A to represent the optimal decision for decentralized decision-making model:

$$\begin{cases} \omega_A^* = \dfrac{2e_m e_d p_c^3(e_m - e_d) - p_c^2(2ae_m^2 - c_m e_d^2 + 2c_d e_m^2) + 4\beta p_c(e_m - e_d) + 4\beta(a + c_m - c_d)}{8\beta - p_c^2[2e_m^2 + e_d^2]} \\ p_A^* = \dfrac{-ap_c^2(2e_m^2 + e_d^2) + 2\beta p_c(e_m + e_d) + 2\beta(3a + c_d + c_m)}{8\beta - p_c^2[2e_m^2 + e_d^2]} \\ r_{mA}^* = \dfrac{2e_m p_c[a - c_m - c_d - p_c(e_m + e_d)]}{8\beta - p_c^2[2e_m^2 + e_d^2]} \\ r_{dA}^* = \dfrac{e_d p_c[a - c_m - c_d - p_c(e_m + e_d)]}{8\beta - p_c^2[2e_m^2 + e_d^2]} \end{cases} \tag{8}$$

Case 2: Centralized decision-making

In the centralized decision mode, the upstream and downstream enterprises have fully established cooperative relations. In the first stage, they can be combined to make decision on reduction rate of carbon emission. In the second stage, the upstream and downstream enterprises will decide the sale price of the product together.

$$V_{SC} = (p - c_d - c_m) \cdot q - \frac{1}{2}\beta(r_m^2 + r_d^2) - (T_m + T_d) \cdot p_c$$

$$(e_m + e_d) \cdot q = S_m + S_d + e_m r_m q + e_d r_d q + T_m + T_d$$

The profit function for the supply chain can be defined as:

$$V_{SC} = [p - c_m - c_d - e_m p_c(1 - r_m) - e_d p_c(1 - r_d)]q + (S_m + S_d)p_c - \frac{1}{2}\beta(r_m^2 + r_d^2) \tag{9}$$

Theorem 2 Considering the carbon trading situation, centralized decision-making model of the two stage low carbon supply chain exists a unique optimal solution when $\beta > \frac{1}{2}p_c^2(e_m^2 + e_d^2)$. We can use the subscript B to represent the optimal decision for centralized decision-making model:

$$\begin{cases} p_B^* = \dfrac{-ap_c^2(e_m^2 + e_d^2) + \beta p_c(e_m + e_d) + \beta(a + c_m + c_d)}{2\beta - e_m^2 p_c^2 - e_d^2 p_c^2} \\ r_{mB}^* = \dfrac{p_c e_m(a - e_m p_c - e_d p_c - c_d - c_m)}{2\beta - e_m^2 p_c^2 - e_d^2 p_c^2} \\ r_{dB}^* = \dfrac{p_c e_d(a - e_m p_c - e_d p_c - c_d - c_m)}{2\beta - e_m^2 p_c^2 - e_d^2 p_c^2} \end{cases} \tag{10}$$

Proposition 1 Comparison the reduction rate of carbon emission between two decision models

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(1) Under the condition that all other things remaining same, it is much easier for the manufacturer to realize emission reduction than the retailer in the decentralized decision model, when they have same reduction rate in the centralized decision model.

It can be seen that in the decentralized decision model, when the other conditions remaining same, the retailer at the downstream have more difficulties in emission reduction than the manufacturer at the upstream. The reason for this situation is, if the investment coefficient β of emission reduction is same, the manufacturer at the upstream will obtain higher reduction rate then the retailer at the downstream. In other words, to obtain same reduction rate, the manufacturer has to put more investment in it. Therefore, if we want to reduce carbon emission, when the carbon emission of per unit product remains same, same investment on emission reduction can achieve better efforts of reduction at upstream. In the centralized decision model, when all other things remain same, the reduction rate of the enterprise at upstream and downstream is same, for which the reason is that centralized decision makes that there is no actual upstream or downstream of the supply chain, and that the manufacturer and the retailer become an entity, who put same efforts on emission reduction.

(2) In centralized decision model, the reduction rates of the enterprises at upstream and downstream are rather high. Therefore, it can be concluded that the supply chain enterprises that cooperate and integrate with each other have higher reduction rate than the enterprises using decentralized decision. Therefore, the cooperation of emission reduction between supply chain enterprises shall be strengthened, and then they can make decisions from the view of entire supply chain.

Proposition 2 The relation between the carbon reduction rate of low-carbon supply chain and carbon trading price

Under conditions of two decision models, when $\Delta < 0$, the change of carbon reduction rate is positive, and it first decreases and then increases; when $\Delta > 0$, the change of carbon reduction rate is negative. At the initial stage of promoting carbon trading system, the carbon trading price may be unstable or may be quite low because of relative subsidies of the government. In this circumstance, using decentralized decision can achieve higher carbon reduction rate than using centralized decision. However, along with the stabilization of carbon trading system, when the carbon trading price improves, no matter what the value of Δ is, using centralized decision can achieve higher carbon reduction rate than using decentralized decision.

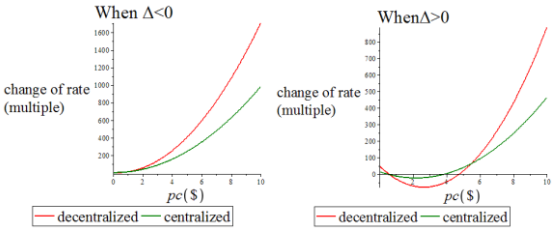

Figure 2. Relationship chart between reduction change rate of carbon emission and carbon trading price under two decision model

Fig. 2 and Fig. 3 show the area of negative correlation is gradually decreasing from decentralized decision to centralized decision. While, the corresponding carbon price along with the optimal emission reduction rate under centralized decision model is smaller than the price under decentralized decision model. Fig. 2 and Fig. 3 can also be concluded that the enterprises using centralized decision are more inclined to adapt lower carbon price. In another word, when the carbon price is relatively low and it is centralized decision between upstream and downstream enterprises, the emission reduction rate can obtain higher value. On the contrary, when the carbon price is relatively high and the enterprises adopt decentralized decision individually, the reduction rate can achieve higher value. The situation, that the emission reduction rate of centralized decision enterprises decreases when it of decentralized enterprises increases, or that the rate of centralized enterprises increases when it of decentralized enterprises decreases, happens often under circumstances of same carbon trading price.

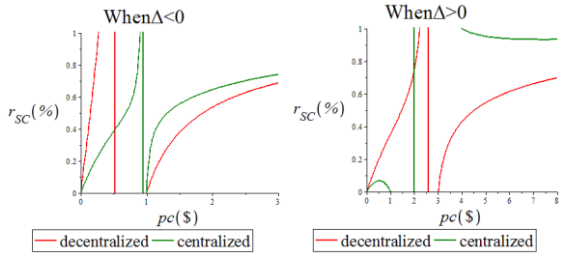

Figure 3. Relationship chart between reduction rate of carbon emission and carbon trading price under two decision model

We can make a conclusion from Fig. 2 and Fig. 3 that emission reduction rate has high sensitivity coefficient to price and big change of carbon price will not produce slight change of emission reduction rate in centralized decision. In general, at the initial stage of emission reduction, carbon price is quite unstable. Many individual enterprises can adapt to this unstable carbon price and can realize certain reduction rate. However, these enterprises cannot achieve good effects of emission reduction. However, as the carbon trading market gradually grows maturely and carbon price tends towards stabilization, those independent enterprises that cannot adapt to the current carbon price cannot realize good effects of emission reduction. In contrary, those cooperative enterprises that adapt to stable carbon price can realize better effects of carbon emission.

Proposition 3 Comparison of total quantity of carbon emission and profit of supply chain between two decision models

(1) For low-carbon supply chain, centralized decision in enterprises at upstream and downstream can obtain the maximized profit. Therefore, for the whole supply chain, if the integration degree of the enterprises is higher, the profit gained by the supply chain is higher. For the enterprises, the integration and cooperation on emission reduction in the process of emission reduction shall be strengthened.

(2) In the entire supply chain, carbon emission of per unit product will reduce as the integration degree

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improves. However, the total output of supply chain will increase as the integration degree improves. Therefore, in two conditions of decisions, the total quantity of carbon emission of the supply chain cannot be compared simply.

In centralized decision, the quantity of carbon emission of per unit products is minimal. Therefore, in the premise that emission reduction rate remaining stable, if the total quantity of carbon emission should be decreased the best way is to reduce the product output of the enterprise. If the enterprise wants to make the total carbon emission lower than the emission limit that the government regulates, it must give up parts of its profit. If the enterprise wants to pursue the maximization of profit, it would produce more carbon dioxide. The enterprise shall weigh between its profit and carbon emission.

V. Conclusion

When carbon emission permit as a new-type special resource is involved in the operation of enterprises of supply chain, it is a necessary method to decrease carbon emission of entire supply chain by integrating the enterprises of upstream and downstream. This paper designs two cooperation forms of emission reduction by relying on the above hypothesis and considering the traditional integrated pricing. Through constructing and analyzing models, and calculating results, it can be concluded that: totally integrated centralized decision can achieve high emission reduction efficiency, as well as high profit value in the meantime. In decentralized decision, the obtained emission reduction level and profit value are both lowest. For the entire supply chain, the upstream and downstream enterprises will influence each other in the process of emission reduction. The effort of governing carbon emission shall not only be on enterprises with high carbon emission of per unit product, but also on the source of the entire supply chain. Since starting from the source of carbon emission, it can gain high emission reduction degree and the spent cost of emission reduction is lower. However, since the enterprise has to give up a part of profit if it decreases carbon emission, and if the enterprise pursues the maximization of profit as always, it must produce more carbon dioxide. Therefore, the enterprise has to weigh between its profit and carbon emission cost. This is a contradiction that is intricate between economic output and environmental pollution. When considering the sensitivity analysis of carbon trading price and coming out that emission reduction is relatively easy, there is positively correlation between reduction rate and emission cost. When emission reduction is difficult, the enterprise will face an area that reduction rate negatively correlates with carbon price.

Different distribution policies of carbon emission quota allowanced by government will lead to different results of emission reduction effects. There is also different results which taken as the endogenous variable that influences emission reduction. In future studies, carbon emission quota according to the output of the enterprise will be considered. Besides, this paper has not conduct the study in the view of social welfares, which can be a direction for future studies.

Acknowledgment

Gratitude is extended to the National Natural Science Foundation of China (Grant No.: 71390333 & 71171156).

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