

# Study on the Coordination of Supply Chain Based on Carbon Emissions Trading Considering the Retailers' Competition

Daoping Wang<sup>1</sup>, Xiaoyan Li<sup>1,\*</sup> and Kun Ding<sup>1</sup>

<sup>1</sup> Donlinks School of Economics and Management, University of Science and Technology Beijing, Beijing 10083, China

Corresponding author: lixiaoyan.24@163.com

**Abstract.** This paper studies the coordination of supply chain in the context of carbon emissions trading mechanism, which considering the competition between retailers. Centralized and decentralized supply chain models were constructed to discuss the price of product, to avoid the losses of profit from the decentralized decision-making, the revenue-sharing contract was introduced to coordinate the supply chain. Research shows that the carbon emissions trading reduce emissions effectively, but the higher price of carbon emissions trading cut down the total profit of supply chain; The competition between retailers upgrades the supply chain members' profit; Coordination was achieved by introducing the revenue-sharing contract. Finally, numerical example was given to illustrate the validity of the revenue-sharing contract, and the sensitivity analysis of parameters such as the price of the emissions trading and the retailers' competition were presented.

## 1 Introduction

The emissions of greenhouse-gases is deemed as the main causes of global warming, with people gradually in-depth understanding of environmental protection and sustainable development, the government and the corporate attaches great importance to the carbon emissions. To achieve the target of emission reduction and implement the growth of carbon economic, the government need to establish the market mechanism gradually, encourage enterprises to reduce carbon emissions. the carbon emission trading is widely promoted as a kind of effective mechanism to control carbon emissions. The manufacturers are starting to pay attention to their carbon emissions to achieve low carbon development. At present, the research on the carbon trading mechanism has got some achievements, however, many studies consider one retailer most of the time, but in actual the retailers show competition for the market. Therefore, study the coordination of supply chain under the carbon trading mechanism and considering retailers' competition has more theoretical value.

## 2 Literature review

Carbon trading refers to the department considering the economic growth and the energy structure comprehensive to determine the enterprise' free carbon quotas, under this background, the enterprise adjust the production plan to mitigation and makes carbon emissions trading to maximize their benefit 1. In recent years, domestic and foreign scholars take research on carbon trading mechanism, Such as Zakeri analysis the reduction mechanism of carbon trading and carbon tax' influence on the supply chain, studies have shown that the carbon trading shows better reduction effect 2. Du put forward a new type of supply chain in the case of considering carbon trading, study the two sides game

process based on the newsboy model 3, on the basis, he see the quotas of the government' carbon emission as a variable parameter, research the carbon emission's impact on the profit of the supplier 4. Abdallah studies how to maximize the enterprises' interests with the economic and environment influence that under the carbon trading mechanism 5. Li solves the logistics distribution routing problem under the carbon emission trading mechanism, introducing a calculation method that consider the vehicle load and speed, make some interesting observation about how to control cost and reduce carbon emissions 6. Ma assuming that a local government has launched a regional carbon trading market in the purpose of maximizing the profit of whole system, the result shows some valuable managerial insights on the decision making of the company and the government 7.

Researchers have further study on supply chain which considering the competition between retailers. Bernstein on the basis of competitive relationship between multiple retailers, studies the decentralized supply chain when faced with uncertain demand equilibrium strategies 8. Yao in the perspective of retailers provide competitive services, study the operation strategy of supply chain which is composed of one manufacturer and two competitive retailers 9. Fan presents a channel pricing strategy which is combated of the quantity discount pricing and slotting fees, on the basis of considering the retailers' competition 10. Gao in the case of two competitive retailers face random demand, to decide the product price, quantity and the responsive to price 11. Cao study the pricing and coordination problems of closed-loop supply chain under stochastic demand, where the two retailers face the different market demand and the product recycled affected by competition price 12.

The literature on carbon trading mechanism has achieved fruitful results, but there are little literature considering the effects of competition between retailers at the same time. Therefore, this article researches the coordination of supply chain that considering retailers' competition under carbon trading mechanism, the optimal decision of the manufacturer and retailers in the mode of centralized and decentralized are concluded, and by introducing the revenue-sharing contract to coordinate the supply chain.

### 3 Model establishment and analysis

#### 3.1 Description of problem and hypothesis

This paper studies the supply chain that composed of one manufacturer and two competitive retailers. In carbon trading mechanism, the government gives carbon emission quota of  $E$  to manufacturer for free, the manufacturer response the government mechanism to reduce emission, and the manufacturer has the carbon trading with price of  $p_c$  to maximize its profit.  $e_H$  and  $e_L$  are the carbon emission of manufacturer that before and after the reduction respectively, where  $\lambda(0 \leq \lambda < 1)$  is the purification rate, and the cost of reduction is  $c_L = \mathcal{E}(\lambda e_H)^2 / 2$ ,  $\mathcal{E}(\mathcal{E} > 0)$  is the parameter for reduction investment. The unit producing cost of product is  $c$ . The manufacturer sales the products to two competitive retailers with wholesale price  $w$ , the sale price of two retailers are  $p_1, p_2$ , which are the decision variables for retailers. The market demand of two competitive retailers are expressed as:  $q_1 = \varphi_1 - p_1 + \beta p_2$ ,  $q_2 = \varphi_2 - p_2 + \beta p_1$ , where  $\varphi_1, \varphi_2$  are the market demand size of two retailers respectively,  $\beta(0 \leq \beta \leq 1)$  is the degree of competition between retailers.

#### 3.2 Decision of supply chain based on the carbon emissions trading considering the retailers' competition

The centralized and decentralized decisions were made which based on the carbon emissions trading considering the retailers' competition, and the revenue-sharing contract was introduced to coordinate the supply chain.

##### 3.2.1 Centralized Decision-making

The centralized decision-making is a kind of ideal system structure, the decision target of the supply chain members is to maximize the total profit of supply chain. The profit of supply chain under centralized decision-making is:

$$\begin{aligned} \Pi_{sc} = & (p_{1c} - c)q_{1c} + (p_{2c} - c)q_{2c} \\ & - p_c(e_L(q_{1c} + q_{2c}) - E) - \frac{1}{2}\varepsilon(\lambda e_H)^2 \end{aligned} \tag{1}$$

By formula (1), take partial derivative of  $p_{1c}$  and  $p_{2c}$  is :

$$\frac{\partial \Pi_{sc}}{\partial p_{1c}} = \varphi_1 + (1 - \beta)(c + p_c e_L) - 2p_{1c} + 2\beta p_{2c}, \quad \frac{\partial \Pi_{sc}}{\partial p_{2c}} = \varphi_2 + (1 - \beta)(c + p_c e_L) - 2p_{2c} + 2\beta p_{1c},$$

the second order

derivative is  $\frac{\partial^2 \Pi_{sc}}{\partial p_{1c}^2} = -2, \frac{\partial^2 \Pi_{sc}}{\partial p_{2c}^2} = -2, \frac{\partial^2 \Pi_{sc}}{\partial p_{2c} \partial p_{1c}} = \frac{\partial^2 \Pi_{sc}}{\partial p_{1c} \partial p_{2c}} = 2\beta$ , considering that  $0 \leq \beta \leq 1$ , so the Hessian matrix of  $\Pi_{sc}(p_{1c},$

$p_{2c})$  is negative, therefore the optimal solution is exist, let  $\frac{\partial \Pi_{sc}}{\partial p_{1c}} = 0$  and  $\frac{\partial \Pi_{sc}}{\partial p_{2c}} = 0$ , the sales price of two retailers in centralized decision-making is:

$$p_{1c}^* = \frac{(1 - \beta^2)(c + p_c e_L) + \beta \varphi_2 + \varphi_1}{2(1 - \beta^2)} \tag{2}$$

$$p_{2c}^* = \frac{(1 - \beta^2)(c + p_c e_L) + \beta \varphi_1 + \varphi_2}{2(1 - \beta^2)} \tag{3}$$

Then take  $p_{1c}^*$  and  $p_{2c}^*$  into the demand function of market, generate the optimal order quantity of two retailers is:

$$q_{1c}^* = \frac{\varphi_1 + (\beta - 1)(c + p_c e_L)}{2} \tag{4}$$

$$q_{2c}^* = \frac{\varphi_2 + (\beta - 1)(c + p_c e_L)}{2} \tag{5}$$

Take  $p_{1c}^*, p_{2c}^*, q_{1c}^*, q_{2c}^*$  into formula (1), the total profit of the supply chain under centralized decision-making is:

$$\begin{aligned} \Pi_{sc}^* = & \frac{(\beta \varphi_2 + \varphi_1 - (1 - \beta^2)(c + p_c e_L))(\varphi_1 - (1 - \beta)(c + p_c e_L))}{4(1 - \beta^2)} \\ & + \frac{(\beta \varphi_1 + \varphi_2 - (1 - \beta^2)(c + p_c e_L))(\varphi_2 - (1 - \beta)(c + p_c e_L))}{4(1 - \beta^2)} \\ & + p_c E - \frac{1}{2}\varepsilon(\lambda e_H)^2 \end{aligned} \tag{6}$$

### 3.2.2 Decentralized Decision-making

In this section assume that the manufacturer and retailers have a Stackelberg game, the manufacturer is in the dominant position, and the retailers in follow status, and Nash game was carried on between two competitive retailers. In decentralized decision-making model, the manufacturer determines the wholesale price firstly to maximize its own profit, then the two retailers decide the sales price to maximize their own profit respectively. The profit of the manufacturer and the two retailers are expressed as:

$$\begin{aligned} \Pi_{Md} = & (w_d - c)(q_{1d} + q_{2d}) - p_c(e_L(q_{1d} + q_{2d}) - E) \\ & - \frac{1}{2}\varepsilon(\lambda e_H)^2 \end{aligned} \tag{7}$$

$$\Pi_{R1d} = (p_{1d} - w_d)q_{1d} \tag{8}$$

$$\Pi_{R2d} = (p_{2d} - w_d)q_{2d} \tag{9}$$

Reverse induction method is used to solve the problem. By formula (8) and

(9), take partial derivative of sales price is:  $\frac{\partial \Pi_{R1d}}{\partial p_{1d}} = \varphi_1 - 2p_{1d} + \beta p_{2d} + w_d, \frac{\partial \Pi_{R2d}}{\partial p_{2d}} = \varphi_2 - 2p_{2d} + \beta p_{1d} + w_d,$

considering  $\frac{\partial^2 \Pi_{R1d}}{\partial p_{1d}^2} = -2$ ,  $\frac{\partial^2 \Pi_{R2d}}{\partial p_{2d}^2} = -2$ , therefore the optimal solution is exist. Let  $\frac{\partial \Pi_{R1d}}{\partial p_{1d}} = 0, \frac{\partial \Pi_{R2d}}{\partial p_{2d}} = 0$ ,

deduce  $p_{1d} = \frac{2\varphi_1 + \beta\varphi_2 + (2 + \beta)w_d}{4 - \beta^2}, p_{2d} = \frac{2\varphi_2 + \beta\varphi_1 + (2 + \beta)w_d}{4 - \beta^2}$  Take  $p_{1d}, p_{2d}$  into formula

(7), let  $\frac{\partial \Pi_{Md}}{\partial w_d} = 0$ , obtain the optimal wholesale price of manufacturer under decentralized decision-making is:

$$w_d^* = \frac{\varphi_1 + \varphi_2 + 2(1 - \beta)(c + p_c e_L)}{4(1 - \beta)} \tag{10}$$

Take  $w_d^*$  into  $p_{1d}, p_{2d}$ , the optimal sales price of retailers under decentralized decision-making is:

$$p_{1d}^* = \frac{4(1 - \beta)(2\varphi_1 + \beta\varphi_2) + (2 + \beta)(\varphi_1 + \varphi_2 + 2(1 - \beta)(c + p_c e_L))}{4(1 - \beta)(4 - \beta^2)} \tag{11}$$

$$p_{2d}^* = \frac{4(1 - \beta)(2\varphi_2 + \beta\varphi_1) + (2 + \beta)(\varphi_1 + \varphi_2 + 2(1 - \beta)(c + p_c e_L))}{4(1 - \beta)(4 - \beta^2)} \tag{12}$$

Then take (11) and (12) into the demand function of market, generate the optimal order quantity of two retailers is:

$$q_{1d}^* = \frac{(6 - \beta)\varphi_1 + (3\beta - 2)\varphi_2 - 2(2 + \beta)(1 - \beta)(c + p_c e_L)}{4(4 - \beta^2)} \tag{13}$$

$$q_{2d}^* = \frac{(6 - \beta)\varphi_2 + (3\beta - 2)\varphi_1 - 2(2 + \beta)(1 - \beta)(c + p_c e_L)}{4(4 - \beta^2)} \tag{14}$$

Take  $p_{1d}^*, p_{2d}^*, q_{1d}^*, q_{2d}^*$  into formula (7), (8) and (9), the profit of manufacture and the two retailers that under the decentralized decision-making is:

$$\Pi_{Md}^* = \frac{(\varphi_1 + \varphi_2 - 2(1 - \beta)(c + p_c e_L))^2}{8(1 - \beta)(2 - \beta)} + p_c E - \frac{1}{2} \varepsilon (\lambda e_H)^2 \tag{15}$$

$$\Pi_{R1d}^* = \left( \frac{(6 - \beta)\varphi_1 + (3\beta - 2)\varphi_2 + 2(\beta^2 + \beta - 2)(c + p_c e_L)}{4(4 - \beta^2)} \right)^2 \tag{16}$$

$$\Pi_{R2d}^* = \left( \frac{(6 - \beta)\varphi_2 + (3\beta - 2)\varphi_1 + 2(\beta^2 + \beta - 2)(c + p_c e_L)}{4(4 - \beta^2)} \right)^2 \tag{17}$$

### 3.2.3 The Coordination of Supply Chain with Revenue-sharing Contract

Here we introduce the revenue-sharing contract to coordinate the decentralized decision-making. The revenue-sharing contract  $(w_1, w_2, \eta_1, \eta_2)$  means: manufacture sales products to two retailers with wholesale price  $w_1$  and  $w_2$  respectively, after the two retailers sell products, they give the manufacture  $(1 - \eta_1)p_1 q_1$  and  $(1 - \eta_2)p_2 q_2$  sales revenue separately, where  $0 < \eta_1, \eta_2 < 1$ . The profit of manufacture and two retailers that with the coordination of revenue-sharing contract is:

$$\begin{aligned} \Pi_M &= (w_1 - c)q_1 + (w_2 - c)q_2 - p_c(e_L(q_1 + q_2) - E) \\ &\quad - \frac{1}{2} \varepsilon (\lambda e_H)^2 + (1 - \eta_1)p_1 q_1 + (1 - \eta_2)p_2 q_2 \end{aligned} \tag{18}$$

$$\Pi_{R1} = (\eta_1 p_1 - w_1)q_1 \tag{19}$$

$$\Pi_{R2} = (\eta_2 p_2 - w_2)q_2 \tag{20}$$

Reverse induction method is used to solve the problem. By formula (19) and (20), take partial derivative of sales price with the retailers' profit is:

$$\frac{\partial \Pi_{R1}}{\partial p_1} = \eta_1(\varphi_1 - 2p_1 + \beta p_2) + w_1, \frac{\partial \Pi_{R2}}{\partial p_2} = \eta_2(\varphi_2 - 2p_2 + \beta p_1) + w_2, \text{ the two order derivative is } \frac{\partial^2 \Pi_{R1}}{\partial p_1^2} = -2\eta_1, \frac{\partial^2 \Pi_{R2}}{\partial p_2^2} = -2\eta_2,$$

considering that  $0 \leq \eta_1, \eta_2 \leq 1$ , therefore there is optimal solution, let  $\frac{\partial \Pi_{R1}}{\partial p_1} = 0, \frac{\partial \Pi_{R2}}{\partial p_2} = 0$ , obtain the optimal sales price:

$$p_1^* = \frac{\eta_1(2\varphi_1 + \beta\varphi_2) + (2 + \beta)w_1}{\eta_1(4 - \beta^2)} \tag{21}$$

$$p_2^* = \frac{\eta_2(2\varphi_2 + \beta\varphi_1) + (2 + \beta)w_2}{\eta_2(4 - \beta^2)} \tag{22}$$

When the optimal decision behavior of the decentralized decision-making is equal to the centralized decision-making, the supply chain achieves coordination, in this model means  $p_1^* = p_{1c}^*, p_2^* = p_{2c}^*$ , we obtained:

$$w_1^* = \frac{3\eta_1\beta^2\varphi_1 + \beta\eta_1\varphi_2(2 - \beta^2) + \eta_1(4 - \beta^2)(1 - \beta^2)(c + p_c e_L)}{2(1 - \beta^2)(2 + \beta)} \tag{23}$$

$$w_2^* = \frac{3\eta_2\beta^2\varphi_2 + \beta\eta_2\varphi_1(2 - \beta^2) + \eta_2(4 - \beta^2)(1 - \beta^2)(c + p_c e_L)}{2(1 - \beta^2)(2 + \beta)} \tag{24}$$

Then take  $w_1^*, w_2^*, p_1^*$  and  $p_2^*$  into formula (20), the profit of manufacture and retailers that after introducing of the revenue-sharing contract is:

$$\Pi_M^* = \left( \frac{3\eta_1\beta^2\varphi_1 + \beta\eta_1(2 - \beta^2)\varphi_2 + (1 - \eta_1)(2 + \beta)(\beta\varphi_2 + \varphi_1)}{2(1 - \beta^2)(2 + \beta)} + \frac{(\eta_1 - 1 - \beta\eta_1)(c + p_c e_L)}{2} \right) * \left( \frac{\varphi_1 + (\beta - 1)(c + p_c e_L)}{2} \right) \tag{25}$$

$$\Pi_{R1}^* = \left( \frac{3\eta_2\beta^2\varphi_2 + \beta\eta_2(2 - \beta^2)\varphi_1 + (1 - \eta_2)(2 + \beta)(\beta\varphi_1 + \varphi_2)}{2(1 - \beta^2)(2 + \beta)} + \frac{(\eta_2 - 1 - \beta\eta_2)(c + p_c e_L)}{2} \right) * \left( \frac{\varphi_2 + (\beta - 1)(c + p_c e_L)}{2} \right) + p_c E - \frac{1}{2} \varepsilon (\lambda e_H)^2 \tag{26}$$

$$\Pi_{R2}^* = \left( \frac{\eta_1(6 + \beta - \beta^2)(1 + \beta)(c + p_c e_L) + \eta_1(3\beta + 2)\varphi_1 + \eta_1\beta^2\varphi_2}{2(1 + \beta)(2 + \beta)} \right) * \left( \frac{\varphi_1 + (\beta - 1)(c + p_c e_L)}{2} \right) \tag{27}$$

### 4 Numerical example

For more in-depth research, the model is analyzed by using Matlab software, to investigate the influence of the revenue-sharing contract on the profit of the supply chain. The parameters in the model are assigned as follows:  $E=1000, \varphi_1=1000, \varphi_2=800, \eta_1=0.6, \eta_2=0.5, \beta=0.4, c=100, e_H=10, \varepsilon=1000, \gamma=0.5, \lambda=0.4, m=3, p_c=50$ .

The result of Centralized decision-making, Decentralized decision-making and decision-making with the revenue-sharing contract follows in table1.

**Table 1.** The profit of supply chain members in different decision-making model.

Decision-making model	Centralized decision-making	Decentralized decision-making	The decision-making with revenue-sharing

The sales price of retailer1	985.7	1197.9	985.7
The sales price of retailer2	914.3	1114.6	914.3
The profit of manufacturer	—	268875.0	272915.6
The profit of retailer1	—	61462.7	91344.8
The profit of retailer2	—	27087.7	44311.1
The total profit of supply chain	408571.4	357425.3	408571.4

Table1 shows after introducing of the revenue-sharing contract, the manufacturer and the retailers' profit are higher than the decentralized decision-making that without the contract. The manufacturer's profit relatively increased 1.5%, the profit of the two retailers grow 48.6% and 63.6% respectively. At the same time, the total profit of supply chain rises 14.3%, that is equal to the profit of the supply chain under the centralized decision-making, that means the revenue-sharing contract coordinate the supply chain effectively.

Table 2 shows the influence of carbon emissions trading' price on the total carbon emissions, the profit of supply chain members and the total profit of supply chain.

**Table 2.** The influence of carbon emissions trading price on the total carbon emissions and profit in decentralized decision-making.

The price of carbon emissions trading	Total carbon	The profit of manufacture	The profit of retailer1	The profit of retailer2	The total profit of
10	3015.0	338675.0	85800.2	43925.2	468400.3
20	2880.0	319200.0	79336.1	39336.1	437872.2
30	2745.0	301075.0	73125.2	35000.2	409200.3
40	2610.0	284300.0	67167.4	30917.4	382384.7
50	2475.0	268875.0	61462.7	27087.7	357425.3

Table 2 shows: (1) With the risen in the price of trading, the total carbon emissions has been controlled effectively, the carbon trading mechanism plays positive role in the process of low carbon economy; (2) With the risen in the price of trading, the profit of manufacturer, retailers and the overall supply chain are both on decline, so the government needs to control the price reasonably, neither too low nor too high. The low carbon trading price can't stimulate the manufacture to reduce the carbon emissions, on the contrary, the high carbon trading price will aggravate the burden on supply chain members.

**Table 3.** The influence of retailers' competing degree on the profit that after coordination.

The degree of retailers'	The profit of manufacturer	The profit of retailer1	The profit of retailer2	The total profit of supply chain
0.1	122814.2	61430.8	24300.5	208545.5
0.2	157311.2	69669.1	29436.4	256416.7
0.3	205210.2	79338.9	35868.3	320417.6
0.4	272915.6	91344.8	44311.1	408571.4

0.5	372133.3	107200.0	56000.0	535333.3
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The Table3 analyzes the influence of the retailers' competing degree on the profit of supply chain members and the total profit of supply chain after introducing of the contract. Table3 shows: with the increase of retailers' competition, the profit of manufacturer, two retailers and the total profit of the supply chain were both promoted, it means the existence of the competition of retailers making the retailers have motivation to promote for more profit, and the effective market competition also increases the profit of manufacturer.

## 5 Conclusion

Under the background of carbon trading mechanism, this paper studies the coordination problem of supply chain. By building the centralized and decentralized decision-making model of supply chain, the optimal pricing strategy of manufacturer and retailers were obtained, and in order to solve the problem of profit losses which resulting from the decentralized decision-making, the revenue-sharing contract was introduced to coordinate the supply chain. Research shows that: (1)With the revenue-sharing contract, the supply chain members' profit and the gross profit of supply chain both run up to the centralized decision-making level; (2)The implementation of the carbon trading mechanism reduces carbon emissions in the process of production effectively; (3)With the risen in the price of carbon trading, the profit of the manufacturer, the retailers and the overall supply is on the decline, so the government need to control the price of carbon trading; (4)With the increase of retailers' competition ,the profit of manufacturer, two retailers and the total profit of the supply chain were both promoted.

But we have not considered the competition between manufacturers, it will be the main content of further research.

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