Strategy of Emission Reduction and Profit Distribution of Co-opetition Construction Supply Chain with Carbon Tax

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Abstract. Under the carbon tax policy, the profit distribution study and emission reduction strategy study exist in construction supply chain of co-opetition. This paper establishes a profit distribution model of co-opetition composed by a general contractor and a subcontractor. The effects of the carbon tax rate on the decision-making variables and profits are analysed. And the decision-making variables involve the emission reduction of enterprises and incentive payment’s proportion. It is shown that the tax rate has a positive impact on emission reduction. Meanwhile, the profits of supply chain and enterprises are inversely proportional to the carbon tax rate. This paper provides a reference for enterprises of construction supply chain to make the emission reduction decision.

1. Introduction
Environmental pollution and climate warming have become international concerns. Supply chain activities are closely related to carbon emissions which are generated in production, transportation, materials and other process[1]. The pollution and sustainable problems caused by carbon emission affect the development of supply chain and hinder the economic development of countries[2]. In order to reduce the carbon emission of enterprises and achieve the coordinated development of economy and environment, carbon emission policies have been formulated by various countries around the world[3]. Among them, the carbon tax policy is based on the principle of "who consumes, who pays", directly charging enterprises that emit carbon dioxide. As a special tax, the carbon tax has a direct impact on enterprises' carbon dioxide emissions, product pricing, production decisions and profit distribution.

The current research on the supply chain under the carbon tax policy can be divided into the following two aspects. One part of the research is to analyze the effect of carbon tax policy on enterprise’s emission reduction and production decision under decentralized decision. Baker and Shittu analyzed new technology investment and the influencing factors of emission reduction decisions under the carbon tax policy[4]. Li analyzed the pricing and green technology investment of suppliers with carbon tax[5]. Wang made use of Stackelberg game to investigate the relationship between business decision and the tax policy[6]. The other part is to analyze the effect of the carbon tax policy on the whole supply chain. Jiang researched the profit distribution and emission reduction decisions with cap-and-trade policy[7]. Cheng studied the optimal carbon dioxide emission reduction and pricing strategies of manufacturers and retailers under the tax policy from the perspective of supply chain[8]. Zhou made a pricing decision based on the optimal tax rate and maximum social welfare[9]. The above researches provide reference opinions for green emission reduction and production decisions of supply chain enterprises under the carbon tax policy. However, the working relationship between the general contractor and subcontractor is not discussed in detail. Different working relations among enterprises in supply chain will influence
enterprises to make different production decisions and profit distribution schemes. Co-opetition model is a common relationship in supply chain enterprise.

In view of the above research status, this paper establishes the emission reduction and profit distribution model based on the widely used co-opetition model among enterprises in the secondary supply chain. This paper mainly studies the decision making of enterprises on emission reduction and analyzes the profit distribution of the general contractor and subcontractor.

2. Model descriptions and assumption

We consider the system of a two-stage construction supply chain composed by a general contractor and a subcontractor in co-opetition. In order to motivate the contractor to make great efforts to reduce carbon emission, the proprietor sets up the incentive payment which is positively related to emission reduction. A part of the incentive payment is paid to the subcontractor by the contractor. In addition, they agree on the proportion of incentive payment distribution in contract as the basis for determining the level of reduction efforts.

The following assumptions are made to develop the proposed model. The proprietor and the general contractor agree that the total contract price $P$ is the sum of the fixed contract price $P_1$ and the incentive payment $b$, that is $P = P_1 + b$. We assume that the coefficient of the incentive payment is $g$. There is a relationship between the incentive payment $b$ and the emission reduction of enterprise $e_i (i = 1, 2)$, that is $b = g e_i (i = 1, 2)$. The cost of carbon tax $t_i (i = 1, 2)$ produced by the contractor or subcontractor is proportional to the carbon tax rate and the real emission. We assume the initial emission without any reduction effort is $e_{0i}$. So the real emission with reduction efforts is $(e_{0i} - e_i)$. While the carbon tax cost can be expressed as $t_i(e_i) = r(e_{0i} - e_i)$, $(i = 1, 2)$. Here, $r$ represents the tax rate. For the general contractor, the amount of incentive payment at its disposal is the difference between the emission reduction incentive payment $b$ and the overall carbon tax cost produced by the supply chain, that is $b - \sum_{i=1}^{i=2} t_i$. The general contractor gives the subcontractor a proportional amount of the incentive payment. We assume the subcontractor gets a proportion of incentive payment, that is $1 - \lambda$ ($0 \leq \lambda \leq 1$). On this basis, the fixed contract price given by the general contractor to the subcontractor is $P_2$. It is easy to see that the total contract price of subcontract $P_0 = P_2 + (1 - \lambda)(b - \sum_{i=1}^{i=2} t_i)$. For the purpose of emission reduction, enterprises increase investment in emission reduction and carry out technological upgrading, but it brings additional costs, namely investment costs. With the increase of input, the amount of investment cost will be greater and greater. We assume that the cost of enterprises to reduce emission is $I_i (i = 1, 2)$ and the emission reduction cost coefficient of enterprise is $\beta_i (i = 1, 2)$. So, it is easy to see $I_i = \frac{1}{2} \beta_i e_i^2$, $(i = 1, 2)$. In co-opetition model, the fixed normal costs for the completion of the project undertaken by the general contractor and subcontractor are $C_1$ and $C_2$, respectively, without any emission reduction effort. Then the fixed normal cost of the construction supply chain is $C = C_1 + C_2$. Based on the above assumptions, the profit of the general contractor, denoted $\pi_1$, is

$$
\pi_1(e_1, \lambda) = P_1 + \lambda b - \sum_{i=1}^{i=2} t_i - P_2 - C_1 - I_1
= P_1 - P_2 - C_1 + \lambda(g + r)(e_1 + e_2) - \lambda r(e_{01} + e_{02}) - \frac{1}{2} \beta_1 e_1^2
$$

(1)

The profit of the subcontractor, denoted $\pi_2$, is

$$
\pi_2(e_2, \lambda) = P_2 + (1 - \lambda) b - \sum_{i=1}^{i=2} t_i - C_2 - I_2
= P_2 - C_2 + (1 - \lambda)(g + r)(e_1 + e_2) - (1 - \lambda)r(e_{01} + e_{02}) - \frac{1}{2} \beta_2 e_2^2
$$

(2)

The profit of the supply chain, denoted $\pi$, is

$$
\pi(e_1, e_2, \lambda) = \pi_1 + \pi_2
= P_1 - C_1 - C_2 + (g + r)(e_1 + e_2) - r(e_{01} + e_{02}) - \frac{1}{2}(\beta_1 e_1^2 + \beta_2 e_2^2)
$$

(3)
3. Model analysis
In the co-opetition model, the general contractor and subcontractor cooperate to improve the overall profit of the supply chain, and pursue their own profit maximization at the same time. The variables to be decided in this paper are the proportion of incentive payment and emission reduction of the enterprise.

**Proposition 1** In the co-opetition model, the emission reduction of the general contractor and subcontractor willing to make are

\[ e_1 = \frac{\lambda (g + r)}{\beta_1} \]  
\[ e_2 = \frac{(1-\lambda)(g + r)}{\beta_2} \]

**Proof** Since the general contractor determines its reduction effort level according to its profit maximization, we take the derivative of Equation (1) with respect to \( e_1 \) as follows \( \frac{\partial \pi_1(e_1, \lambda)}{\partial e_1} = \lambda (g + r) - \beta_1 e_1 \). In the same way, the subcontractor determines its reduction effort level according to its profit maximization, so we take the derivative of Equation (2) with respect to \( e_2 \) as follows \( \frac{\partial \pi_2(e_2, \lambda)}{\partial e_2} = (1-\lambda)(g + r) - \beta_2 e_2 \). Here we make \( \frac{\partial \pi_1(e_1, \lambda)}{\partial e_1} = 0, \frac{\partial \pi_2(e_2, \lambda)}{\partial e_2} = 0 \), then we can easily get the emission reduction of the general contractor is \( e_1 = \frac{\lambda (g + r)}{\beta_1} \) and the emission reduction of the subcontractor is \( e_2 = \frac{(1-\lambda)(g + r)}{\beta_2} \).

From proposition 1, we can observe that the emission reduction made by the enterprise is directly proportional to the proportion of incentive payment distribution. That is to say, the higher the proportion of incentive payment received by enterprise, the more emission reduction of the enterprise is willing to make.

Then, we substitute \( e_1, e_2 \) of Equations (4) and (5) to Equations (1)-(3), we obtain the optimal profits of the general contractor, subcontractor and the supply chain as follows

\[ \pi_1^*(\lambda) = P_1 - P_2 - C_1 + \lambda (g + r)^2 \left( \frac{\lambda (2-\beta_2 \beta_1)}{2 \beta_1 \beta_2} + \frac{\alpha}{\beta_1} \right) - (1-\lambda)\alpha r (e_{01} + e_{02}) \]  
\[ \pi_2^*(\lambda) = P_2 - C_2 + (1-\lambda) (g + r)^2 \left( \frac{\alpha (2-\beta_2 \beta_1)}{2 \beta_1 \beta_2} + \frac{\alpha}{\beta_2} \right) - (1-\lambda)\alpha r (e_{01} + e_{02}) \]  
\[ \pi^*(\lambda) = P_1 - C_1 - C_2 + (g + r)^2 \left( \frac{\alpha}{\beta_1} + \frac{(1-\lambda)}{\beta_2} \right) - (g + r)\alpha r (e_{01} + e_{02}) - \frac{1}{2} \left[ \left( \frac{g + r}{\beta_1} \right)^2 + \left( \frac{g + r}{\beta_2} \right)^2 \right] \]

**Proposition 2** In the co-opetition model, the optimal proportion of the general contractor's incentive payment is

\[ \lambda^* = \frac{\beta_2}{\beta_1 + \beta_2} \]

**Proof** Both the general contractor and the subcontractor take the profit maximization of the supply chain as the common goal, and they cooperate to determine the proportions of incentive payment. So, we take the derivative of Equation (8) with respect to \( \lambda \), and we make \( \frac{\partial \pi^*(\lambda)}{\partial \lambda} = 0 \). Easily, we obtain the optimal proportion of general contractor’s incentive payment as proposition 2. This completes the proof.

From proposition 2, we can easily get the optimal proportion of the subcontractor’s incentive payment is \( 1 - \lambda^* = \frac{\beta_1}{\beta_1 + \beta_2} \). In the co-opetition model, the lower the emission reduction cost coefficient is, the higher the proportion of incentive payment distribution is. This will prompt the general contractor and subcontractor to upgrade emission reduction technologies and reduce the cost coefficient, so as to obtain more benefits.

4. Influence of the tax rate on strategy of emission reduction and profit
**Proposition 3** Under the condition of realizing the optimal profit of the supply chain, we obtain the relationships between the emission reduction and the tax rate, they are \( e_1^* = \frac{(g + r)\beta_2}{(\beta_1 + \beta_2)\beta_1}, e_2^* = \frac{(g + r)\beta_1}{(\beta_1 + \beta_2)\beta_2} \).

**Proof** Substituting \( \lambda^* \) and \( 1 - \lambda^* \) of proposition 2 to Equations (4) and (5), we get the expressions in proposition 3. The relationship between the tax rate and the emission reduction is obviously as
From Proposition 3, we obtain that the tax rate is positively correlated with the emission reduction. For general contractor and subcontractor, the higher the tax rate is, the higher emission reductions of the general contractor and subcontractor should make.

Then we examine the effect of tax rate on the maximum profits of contractor, subcontractor and total supply chain.

We make a numerical example to examine it. We assume that the fixed contract price of general contractor is $P_1 = 89000$ yuan, the fixed contract price of subcontractor is $P_2 = 31800$ yuan, the coefficient of the incentive payment is $g = 10$ yuan/tCO$_2$, initial emission of general contractor without any reduction effort $e_{01} = 260$ tCO$_2$, initial emission of subcontractor without any reduction effort $e_{02} = 170$ tCO$_2$. If the fixed normal cost of general contractor is $C_1 = 41120$ yuan, the fixed normal cost of subcontractor is $C_2 = 25000$ yuan, the emission reduction cost coefficient of general contractor is 0.75, the emission reduction cost coefficient of subcontractor is 0.65. The proportion of general contractor's incentive payment is given 0.46. Above assumptions, we acquire the different profits of the general contractor, subcontractor and supply chain with the varies of the tax rate. Through the changes of profits, we aim to analysis the effect of tax rate on profits of contractor, subcontractor and supply chain.

| $r$ | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $\pi_1^*$ | 15017 | 14835 | 14644 | 14473 | 14294 | 14116 | 13939 | 13763 | 13588 |
| $\pi_2^*$ | 5559 | 5374 | 5136 | 4926 | 4717 | 4510 | 4303 | 4098 | 3893 |
| $\pi^*$ | 20576 | 20182 | 19780 | 19399 | 19012 | 18626 | 18242 | 17861 | 17481 |

Table 1 shows the carbon tax rate has a negative impact on profits of general contractor, subcontractor and supply chain. If the other variables are the same, the profits are limited in areas with high tax rate. Therefore, when setting the carbon tax policy, the government should take full account of the actual situation of local supply chain enterprises and determine the reasonable carbon tax rate.

5. Conclusion

Under the carbon tax policy, this paper studies the emission reduction strategy and profit distribution of co-opetition enterprises in supply chain. We establish the emission reduction and profit distribution model. Through the model, we analyze the strategy of emission reduction and profit distribution in view of the general contractor, subcontractor and supply chain. The profits of the general contractor, subcontractor and supply chain are calculated. Also, the influence of the tax rate on emission reduction and profit are analyzed. This provides the reference opinion for the enterprise's production strategy.

In the process of production and construction, enterprises who stand in the perspective of their own profits determine the emission reduction. At the same time, they cooperate to determine the proportions of incentive payment in order to maximize the profit of the supply chain. Through the analysis, we find the tax rate has a positive impact on emission reduction. It is found that in co-opetition, the profits of supply chain and enterprises are inversely proportional to the tax rate, which is the reference for enterprises to determine the production decision and the government to set the tax rate.

In this paper, a two-level supply chain system consisting of a general contractor and a subcontractor is selected as the research object, which is for the purpose of building a clear and concise model and focusing on analyzing the main influencing factors and action paths of profit. However, in actual production, there may be more than one subcontractor. The supply chain system with multiple subcontractors can be taken as the research object in the subsequent research to establish a more practical theoretical model and solve practical problems.

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