Profit Distribution Strategy of Cooperation Construction Supply Chain under Carbon Tax Policy

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Abstract. Based on the background of carbon tax policy, this paper studies the optimal emission reduction decision and profit distribution strategy of the secondary construction supply chain composed of a general contractor and a subcontractor. By establishing the profit distribution model of the construction supply chain, the optimal emission reduction, the construction supply chain and the maximum profits of enterprises under the two conditions of decentralization and centralization are obtained, and then the comparative analysis of the two is conducted to obtain the reasonable range of the profit distribution proportion of the construction supply chain under the centralized situation. The results show that the full partnership has a positive effect on enterprises to take action to reduce emissions, and the reasonable profit distribution proportion is helpful to the construction of supply chain profit and the improvement of enterprises' profit.

1. Introduction
In recent years, human society and economy have developed rapidly, but global warming, environmental pollution and other problems have brought huge losses to human beings. IPCC points out that the atmospheric concentration of carbon dioxide has risen to at least the unprecedented level in the past 800,000 years and has increased by 40% since industrialization in its fifth assessment report. How to reduce carbon emissions has become an important issue in the international community. The global community needs to reduce man-made greenhouse gas emissions to avoid worsening climate impacts and to reduce the risks of climate change beyond our means. Policies are needed to reduce energy use, limit greenhouse gas ecosystems[1].

To reduce carbon emissions, countries around the world have carbon policies in order to realize the coordinated development of economy and environment. As an economic means, carbon tax can effectively prevent the high or low carbon price and allow the government to respond quickly to market changes[2,3], which has been recognized as one of the most cost-effective emission reduction policies and advocated by many economists and organizations in the international community[4]. Colombia, Mexico and South Africa have introduced or plan to introduce a carbon tax[5]. Sweden, Denmark, the United Kingdom, the United States and other countries have established a carbon tax system and achieved good environmental benefits.

Construction industry is one of the main sources of carbon emissions, and it is particularly important to control its emission reduction. Many scholars have also studied and discussed supply chain enterprises and their profit distribution strategies from multiple perspectives. Fahimnia et al. took the Australian carbon tax policy as an example and analyzed the change of cost under the carbon tax policy and its impact on emission reduction[6]. Baker and Shittu analyzed the impact factors of
enterprise r&d investment changes and emission reduction decisions under the carbon tax policy[7]. Li et al. used the chromatographic analysis and price transfer method to calculate the optimal fair solution, so as to achieve the goal of equitable distribution of profits between enterprises[8]. Raaid et al. explored the relationship between product sales price, degree of differentiation and total profit of secondary supply chain[9]. Li and Jiang et al. studied the carbon emission reduction and profit distribution of the construction supply chain in the carbon trading market[10,11]. However, the research on the operational decision-making of the secondary construction supply chain enterprises which take the carbon tax policy as an exogenous variable is not very perfect.

In this paper, carbon tax policy as the background, based on the secondary supply chain composed of the general contractor and subcontractor, research in the centralized situation of enterprises emission reduction decisions and profit distribution, to ensure and consolidate the stable development of the supply chain.

2. Problems and models
In project construction, the owner signs a construction contract and submits the construction work of several stages or all stages of the project to the general contractor for completion. A contractor usually does not have the ability to complete the whole construction work independently, so the contractor will hand over the links it is not good at to several subcontractors to complete. In the general contract signed by the proprietor and the contractor, it is assumed that the proprietor, in order to motivate the enterprises to achieve emission reduction goals, signs a contract with the contractor for the fixed total price $P_1$ plus reduction bonus $B$, and then the total contract price is $P = P_1 + B$. The reduction bonus $B$ is in direct proportion to the sum of the reduction emissions of the contractor and subcontractor, $\alpha$ is the bonus coefficient, and then the reduction bonus is expressed as $B(e_1, e_2) = \alpha(e_1 + e_2)$. The carbon tax rate is $r$ and the total carbon emission of the contractor and subcontractor without any investment in emission reduction is $e_0$, and then the carbon tax imposed by the government on the whole supply chain is $t(e_1, e_2) = r(e_0 - e_1 - e_2)$. Due to the dominant role, the reduction bonus after deducting the carbon tax shall be distributed by the contractor. If the profit distribution ratio of the contractor is $\lambda (\lambda \in (0,1))$, and the fixed general contract price given by the contractor to the subcontractor is $P_2$, then the total contract price of the subcontractor is $P_0 = P_2 + (1 - \lambda)(B - t)$. To achieve emission reduction targets, reduce the carbon tax cost, obtain more profits, enterprises will adopt technical renovation, equipment upgrades and other measures to increase investment in emissions reduction. $\beta_1$ and $\beta_2$ are the emission reduction cost coefficients of the contractor and subcontractor respectively, then the investment cost reduction is expressed as: $I_i(e_i) = \frac{1}{2}\beta_i e_i^2$, $i = 1, 2$. $C_1$ and $C_2$ are the fixed normal costs of the contractor and the subcontractor, $\pi, \pi_1$ and $\pi_2$ respectively represent the profits of the supply chain, the contractor and the subcontractor, and then the profit distribution model of the supply chain can be expressed as:

$$
\pi(e_1, e_2) = P_1 + (\alpha + r)(e_1 + e_2) - C_1 - C_2 - re_0 - \frac{1}{2}(\beta_1 e_1^2 + \beta_2 e_2^2) \tag{1}
$$

$$
\pi_1(\lambda) = P_1 - P_2 + \lambda(\alpha + r)(e_1 + e_2) - \lambda re_0 - C_1 - \frac{1}{2}\beta_1 e_1^2 \tag{2}
$$

$$
\pi_2(\lambda) = P_2 + (1 - \lambda)(\alpha + r)(e_1 + e_2) - (1 - \lambda)re_0 - C_2 - \frac{1}{2}\beta_2 e_2^2 \tag{3}
$$

3. Model solution

3.1 Pure Competitive Model
In the pure competitive model, the companies are in the Stackelberg game, and they make emission reduction decisions with the goal of maximizing their own profits. The proportion of profit distribution is determined by the general contractor according to the enterprises’ emission reduction.

**Proposition 1** In the pure competitive model, the optimal emission reduction decisions of the
contractor and the subcontractor are as:

\[ e^N_2 = \frac{(1 - \lambda)(\alpha + r)}{\beta_2} \]  
\[ e^N_1 = \frac{\lambda(\alpha + r)}{\beta_1} \]  

**Proof** Equation (3) deduces \( e_2 \) on both sides, set \( \frac{\partial \pi_2(\lambda)}{\partial e_2} = 0 \). When the subcontractor's profit is the largest, the optimal emission reduction decision of the subcontractor is: \( e^N_2 = \frac{(1 - \lambda)(\alpha + r)}{\beta_2} \).

The contractor makes a decision based on its own profit maximization after knowing the subcontractor's emission reduction decision. Substitute equation (4) into equation (2) and take the derivative of both sides of \( e_1 \), set \( \frac{\partial \pi_1(\lambda)}{\partial e_1} = 0 \), and obtain the optimal emission reduction decision of the contractor when the contractor's profit is the largest as follows: \( e^N_1 = \frac{\lambda(\alpha + r)}{\beta_1} \). This has been proven.

In the pure competitive model, enterprises' optimal emission reduction decisions are related to their respective cost coefficient of emission reduction investment and profit distribution ratio. When the cost coefficient of enterprise emission reduction investment is determined, the larger the profit distribution proportion of the contractor is, the larger the profit of the contractor will be, and the smaller the subcontractor's profit will be.

By substituting equation (4) and (5) into equation (1), (2) and (3), the maximum profit of the supply chain under the optimal emission reduction decision can be obtained as follows: \( \pi^N(\lambda) = P_1 + (\alpha + r)^2 \left( \frac{\lambda}{\beta_1} + \frac{1 - \lambda}{\beta_2} \right) - r e_0 - C_1 - C_2 - \frac{\lambda^2(\alpha + r)^2}{2\beta_1} - \frac{(1 - \lambda)^2(\alpha + r)^2}{2\beta_2} \), the biggest profits for the contractor: \( \pi^N_1(\lambda) = P_1 - P_2 + \lambda(\alpha + r)^2 \left( \frac{\lambda}{\beta_1} + \frac{1 - \lambda}{\beta_2} \right) - \lambda r e_0 - C_1 - \frac{\lambda^2(\alpha + r)^2}{2\beta_1} \), maximum profits for the subcontractor: \( \pi^N_2(\lambda) = P_2 + (1 - \lambda)(\alpha + r)^2 \left( \frac{\lambda}{\beta_1} + \frac{1 - \lambda}{\beta_2} \right) - (1 - \lambda) r e_0 - C_2 - \frac{(1 - \lambda)^2(\alpha + r)^2}{2\beta_2} \).

Under this decision, the profit of the supply chain, the contractor and the subcontractor has the maximum value and is affected by the profit distribution proportion of the supply chain.

**Proposition 2** Under the optimal reduction decision, contractor's biggest profit allocation proportion is \( \lambda_{\text{Max}} = \frac{r e_0 \beta_1 \beta_2}{(\alpha + r)^2 (\beta_2 - \beta_1)} \).

**Proof** \( \pi^N_1(\lambda) \) on both sides of \( \lambda \) derivation, set \( \frac{\partial \pi^N_1(\lambda)}{\partial \lambda} = 0 \), get the biggest profit distribution proportion of the contractor: \( \lambda_{\text{Max}} = \frac{r e_0 \beta_1 \beta_2}{(\alpha + r)^2 (\beta_2 - \beta_1)} \). This completes the proof.

The contractor decides the profit distribution proportion according to the subcontractor's emission reduction investment degree, and its maximum profit distribution proportion is restricted by the enterprises' emission reduction investment cost coefficient, and in this case, the subcontractor's emission reduction investment degree is always greater than the contractor's.

### 3.2 Pure Cooperation Model

In the pure cooperation model, the contractor and subcontractor who establish a complete trust relationship form a consortium, and they coordinate with each other to make decisions with the goal of maximizing the profit of the supply chain.

**Proposition 3** In the pure cooperation model, the optimal emission reduction decisions of the contractor and the subcontractor are as:

\[ e^C_1 = \frac{\alpha + r}{\beta_1} \]  
\[ e^C_2 = \frac{\alpha + r}{\beta_2} \]  

**Proof** Enterprises make decisions with the goal of maximizing the profit of the supply chain. Take
the derivatives of $e_1$ and $e_2$ on both sides of equation (1), set $\frac{\partial \pi(e_1,e_2)}{\partial e_1} = 0$, $\frac{\partial \pi(e_1,e_2)}{\partial e_2} = 0$, and obtain the optimal emission reduction decision of the contractor and subcontractor when the profit of the supply chain is the largest as follows: $e_1^C = \frac{\alpha+r}{\beta_1}$, $e_2^C = \frac{\alpha+r}{\beta_2}$. This completes the proof.

In this case, the optimal emission reduction decision of enterprises is only related to their respective cost coefficient of emission reduction investment and is inversely proportional.

By substituting equation (6) and (7) into equation (1), (2) and (3), we have $\pi^C = P_1 + (\alpha + r)^2 \left( \frac{1}{\beta_1} + \frac{1}{\beta_2} \right) - re_0 - C_1 - C_2 - \frac{(\alpha+r)^2}{2\beta_1} - \frac{(\alpha+r)^2}{2\beta_2}$, $\pi^C(\lambda) = P_1 - P_2 + \lambda(\alpha + r)^2 \left( \frac{1}{\beta_1} + \frac{1}{\beta_2} \right) - \lambda re_0 - C_1 - \frac{(\alpha+r)^2}{2\beta_1}$, $\pi^C_2(\lambda) = P_2 + (1 - \lambda)(\alpha + r)^2 \left( \frac{1}{\beta_1} + \frac{1}{\beta_2} \right) - (1 - \lambda)re_0 - C_2 - \frac{(\alpha+r)^2}{2\beta_2}$.

**Proposition 4** Under the optimal emission reduction decision, the profit of the supply chain is a constant value. The profit distribution proportion of the total contractor has no maximum value.

**Proof** Under this decision, the cost coefficient of enterprises emission reduction remains unchanged, so the supply chain profit is a constant value. There is a linear relationship between corporate profit and profit distribution ratio. The larger the contractor's profit distribution ratio is, the larger the contractor's profit will be, and the smaller the subcontractor's profit will be. Therefore, there is no maximum value for the contractor's profit distribution ratio. This completes the proof.

Since the contractor has no optimal choice, in order to achieve the goal of undiminished profit and the principle of fair distribution, the centralized situation and the decentralized situation are compared to obtain the reasonable profit distribution proportion under the centralized situation.

**Proposition 5** Full partnership has a positive effect on enterprises' emission reduction actions, and can improve the profit of construction supply chain and subcontractors. The reasonable range of profit distribution proportion that the general contractor can choose is: $\sqrt{\frac{P_2}{2\beta_1+\beta_2}} < \lambda < 1$.

**Proof** Compare the two situations: $e_1^C > e_1^N$, $e_2^C > e_2^N$, explain fully cooperation relationship to the enterprises take mitigation action has a positive role. $\pi^C > \pi^N$, illustrate the centralized situation can improve production efficiency and profit of the supply chain. $\pi^C_2 > \pi^N_2$, centralize situation can improve the profits of subcontractor. However, under the centralized situation, whether the profit of the contractor is improved or not depends on the size of profit distribution proportion. Make $\pi^C_1 - \pi^N_1 > 0$, and then the reasonable profit distribution proportion range of the contractor under the centralized situation is: $\sqrt{\frac{P_2}{2\beta_1+\beta_2}} < \lambda < 1$. This completes the proof.

The minimum value of reasonable profit distribution ratio is only related to the enterprises' emission reduction investment cost coefficient. The larger the total contractor's investment cost coefficient is, the smaller the subcontractor's investment cost coefficient is, the smaller the profit distribution ratio will be. When the profit distribution ratio is within this reasonable range, the optimal emission reduction, supply chain and the maximum profit of the enterprise are improved. This shows that under the background of carbon tax policy, it is profitable for enterprises in the construction supply chain of full partnership to make reasonable investment in emission reduction.

### 4. Conclusion and prospect
Carbon tax policy is one of the effective means to realize "low carbon" ideal, energy saving and emission reduction. This paper establishes a profit distribution model based on the classic working mode of a contractor and a subcontractor, and studies the optimal emission reduction decisions and profit distribution problems of enterprises. Through the above theoretical analysis, we can derive the optimal emission reduction decision of enterprises under the centralized situation, the maximum profit of supply chain and enterprises and the reasonable proportion of the profit distribution ratio. The study has found that government implementation of carbon tax policy, the proprietor to reduce emissions incentives and enterprises to establish cooperative relations can effectively promote enterprises to
carry out emission reduction behavior. The cooperative relationship can effectively promote the emission reduction behavior of enterprises and increase the profit of the supply chain. Compared with the decentralized situation, the proportion of profit distribution within a reasonable range can simultaneously achieve greater emission reductions and more profit, and the benefits are considerable.

In addition, the model constructed in this paper is a secondary supply chain. But in practice, different process involves different professional subcontractors, and different working relationship between enterprises has different effects on the supply chain. In future research, we can establish a more realistic multi-level supply chain model, explore the impact of more variable factors on the supply chain, and provide practical guidance for the coordinated development of the supply chain.

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