Emission Reduction Policy for Construction Supply Chain with Mix Financing and Cap-and-trade

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Abstract: Under the cap-and-trade and the incentive of emission reduction bonus, we investigated a two-stage construction supply chain consisting of a subcontractor with capital constraints and a general contractor. Firstly, this paper constructed a decision model of emission reduction considering both internal financing and external financing (i.e. mix financing). Secondly, the optimal decisions and maximum profit of both parties are obtained. In addition, this study also showed that the total amount of emission reduction of the general contractor increases in carbon trading price; the total amount of emission reduction of the subcontractor increases in carbon trading price and decreases in external financing interest rate; the optimal proportion of internal financing increases in internal financing interest rate while decreases in external financing interest rate.

1. Introduction
Global warming is one of the most serious challenges faced by the human in the 21st century, which has attracted the high attention of all countries in the world. The 19th National Congress of the Communist Party of China explicitly set green development as a long-term goal for China [1]. To achieve the goal, carbon emissions must be controlled first. In particular, the construction industry, as a major carbon emitter in China, often has the problems in low efficiency and high cost of emission reduction due to the lack of scientific and effective management [2]. Therefore, how to study the emission reduction of construction supply chain enterprises from the perspective of supply chain management has become a hot issue in academic research.

In order to control carbon emissions, governments are attempting to find scientific and effective countermeasures. Cap-and-trade policy has become a priority for governments because of its dual advantages of government regulation and market regulation. With the increasingly serious global warming problem, the concept of low-carbon products has been accepted by more and more consumers, who are willing to pay higher prices for low-carbon products [3]. In order to response the cap-and-trade policy and cater the low-carbon demand of consumers, construction supply chain owners often adopt incentive bonus to encourage contractors to make more efforts to reduce the carbon emissions [4], so as to improve the competitiveness of construction and development.

Capital constraint is the normal state of construction supply chain enterprises and a hot issue in academic research [5-7]. As a member of small and medium-sized enterprises, due to the low repayment ability and credit rating, the subcontractor often faces financing difficulties when emission reduction funds are constrained. In order to ensure the smooth and orderly progress of the construction project, the general contractor considers to give the subcontractor some financial support for emission reduction and as a guarantor of the external financing charged by the subcontractor, i.e. internal financing. The
general contractor's repayment capacity and credit rating are often higher than that of the subcontractor. With the general contractor as the guarantee, the subcontractor's remaining emission reduction funds gap can be financed from external financial institutions, that is, external financing. Although mix financing effectively alleviates the problem of capital constraint on emission reduction faced by the subcontractor, but also makes the operational decisions of the general contractor and the subcontractor more complicated.

Rest of this paper is organized as follows. Related literature is presented in Section 2. The model description and assumption are presented in Section 3. In Section 4, we established the decision-making model considering mix financing. Sensitive analysis is presented in Section 5. Finally, Section 6 concludes this paper and presents area for future investigation.

2. Literature review

Introducing the carbon emission into all steps of the supply chain can not only achieve emission reduction, but also create new value for supply chain enterprises. Hua et al. studied the influence of the cap-and-trade mechanism on order, emission reduction and total cost with comprehensive consideration of carbon emissions generated in transportation and storage [8]. Toptal et al. studied the joint decision-making of stock replenishment and emission reduction investment under the three mechanisms of carbon caps, cap-and-trade and carbon tax [9]. With a two-echelon supply chain consisting of one supplier constrained by cap-and-trade policy and one retailer, Jiang et al. studied the supply chain decision-making and coordination, and obtained the optimal decisions and maximum expected profit of centralized supply chain including two scenarios of rational expectation equilibrium and quantity commitment [10]. With a two-stage supply chain composed of an upstream manufacturer and a downstream retailer regulated by cap-and-trade policy, Xu et al. studied the production and pricing of the supply chain, and obtained that the cap-and-trade policy will not only affect the decisions of retailers, but also affect the production decisions of manufacturers [11]. Most of the above researches focus on traditional supply chain. On the one hand, they fail to focus on the construction supply chain; on the other hand, there is no consideration of the financial constraints.

Capital constraints not only affect the decision-making of supply chain members, but also adversely affect the optimization and coordination of the supply chain. Jing and Hao studied the role of prepayment strategy in alleviating financial constraints on suppliers and found that the value of prepayment depends on the bargaining power of the supply chain members [12]. Under the capital constraint, Dada and Hu designed the nonlinear loan contract based on the newsvendor model and pointed out that the order quantity of retailers after financing was lower than that of the traditional newsvendor model [13]. Kouvelis and Zhao considered a two-echelon supply chain consisting of a supplier and a retailer with capital constraints, and studied the design of supply chain coordination contract considering bankruptcy cost under the bank financing [14]. Yang and Birge examined the impact of trade credit contracts on supply chain performance and risk sharing, and showed that trade credit contracts can enable suppliers to increase inventory levels, and increase the profits of suppliers and retailers [15]. Most of the above studies use financing funds for production and order, lacking of financing funds for emission reduction. In addition, there is no research on enterprise operation decision-making considering mix financing.

3. Model description and assumption

Under the cap-and-trade and the incentive of emission reduction bonus, this paper conducted the emission reduction decision-making model considering mix financing. The subcontractor is difficult in financing due to the low repayment capacity and credit rating. The general contractor provides the subcontractor with part of the financial support for emission reduction under the contract. For the remaining funds gap, the subcontractor will seek financial support from external financial institutions. When the general contractor provides a high proportion of internal financing in order to obtain the high financing interest, while the subcontractor will reduce the emission reduction efforts to avoid paying higher financing interest; when the proportion of internal financing is low, the subcontractor may reduce the emission reduction efforts due to lack of funds. At this time, the financing interest charged by the
The internal financing paid by the general contractor; the subcontractor's financing interest, emission reduction cost and bonus also reduce, but the excessive carbon emission will generate additional carbon trading cost. In contrast, if effort level is too high, the bonus and carbon trading income will increase, but the general contractor will pay higher emission reduction cost, and the subcontractor will pay higher emission reduction cost and financing interest.

In addition, this paper assumes that the parameters satisfy the following conditions:

1. To simplify the model, this paper assumes that the total amount of initial carbon emissions of the general contractor is equal with the subcontractor.
2. $e_0 > e_1, e_0 > e_2$. That is, the total amount of carbon emitted by the contractors after emission reduction input is less than the initial carbon emission amount.
3. $\beta < r < 2\beta$. As the general contractor provides financial support for the subcontractor and takes the financing risks. Therefore, the internal financing rate set by the general contractor is higher than but not more than twice the external financing rate.

Throughout this paper, we use the parameters and variables as the following notations in Table 1.

| Notation | Description |
|----------|-------------|
| $P_1$ | The fixed total amount of money paid by the owner to the general contractor |
| $P_2$ | The total fixed price paid by the general contractor to the subcontractor |
| $C_1, C_2$ | The construction costs of the general contractor and the subcontractor, respectively |
| $e_0$ | The total initial carbon emissions of the general contractor and the subcontractor |
| $e_1, e_2$ | The total carbon emissions after emission reduction input of the general contractor and subcontractor respectively |
| $\varepsilon_0$ | Emission reduction incentive coefficient awarded by the owner to the general contractor |
| $l$ | The ratio coefficient of internal financing |
| $r$ | Internal financing rate set by the general contractor |
| $\beta$ | External financing rate |
| $K_1, K_2$ | The initial carbon quotas for the general contractor and the subcontractor respectively |
| $\mu$ | Cost coefficient of carbon emission reduction |
| $k$ | External market carbon trading price |

4. The model

In this paper, under the fixed price plus bonus contract, the general contractor decides emission reduction effort level and internal financing ratio with the profit maximization according to carbon trading price, incentive intensity and emission reduction cost etc; and the subcontractor also determines the emission reduction effort level with the profit maximization according to the financing rate, carbon trading price, incentive intensity and emission reduction cost etc. Therefore, this part is a two-stage Stackelberg game with the general contractor as the lead party and the subcontractor as the subordinate party, so the optimal emission reduction strategy of the subcontractor is first found. At this time, the profit function of the general contractor is:

$$\pi(e_1, l) = P_1 + \varepsilon_0[(e_0 - e_1) + (e_0 - e_2)] - \frac{1}{2}\mu(e_0 - e_1)^2 - \frac{1}{2}\mu(e_0 - e_2)^2 l + \frac{1}{2}\mu(e_0 - e_2)^2 l(1 + r) - C_1 - P_2 - e_0(e_0 - e_2) - (e_1 - K_1)k$$

In the above formula, $\varepsilon_0[(e_0 - e_1) + (e_0 - e_2)]$ represents the emission reduction bonus paid by owners; $\frac{1}{2}\mu(e_0 - e_1)^2$ means emission reduction cost of the general contractor; $\frac{1}{2}\mu(e_0 - e_2)^2 l$ means the internal financing paid by the general contractor; $\frac{1}{2}\mu(e_0 - e_1)^2 l r$ represent the internal financing interest paid by the subcontractor; $(e_1 - K_1)k$ means the carbon trading with the external market. When
$e^*_1 > K_1$, it represents buying from external markets; On the contrary, it means selling to the external market. Please refer to table 1 for the meanings of other parameters.

Simplify the above formula to get:

$$
\pi(e_1, l) = P_1 + e_0 (e_0 - e_1) - \frac{1}{2} \mu(e_0 - e_1)^2 + \frac{1}{2} \mu(e_0 - e_2)^2 l r - C_1 - P_2
- (e_1 - K_1)k
$$

(1)

The profit function of the subcontractor is:

$$
\pi(e_2) = P_2 + e_0 e_0 - e_2 - \frac{1}{2} \mu(e_0 - e_2)^2 l r - \frac{1}{2} \mu(e_0 - e_2)^2 (1-l) \beta - C_2 - (e_2 - K_2)k
$$

(2)

In the above formula, $e_0 (e_0 - e_2)$ represents the emission reduction bonus of the subcontractor; \( \frac{1}{2} \mu(e_0 - e_2)^2 l r \) and \( \frac{1}{2} \mu(e_0 - e_2)^2 (1-l) \beta \) represent the internal and external financing interest paid by the subcontractor, respectively; \( (e_2 - K_2)k \) also means the carbon trading with the external market.

Proposition 1 The optimal decisions of the general contractor are $e^*_1 = e_0 - \frac{e_0 + k}{\mu}$ and $l^* = \frac{\beta}{r-\beta}$.

the optimal decision of the subcontractor is $e^*_2 = e_0 - \frac{e_0 + k}{2 \mu \beta}$.

Proof. Due to \( \frac{d^2 \pi(e_2)}{d e_2^2} = - \mu l r - \mu (1-l) \beta < 0 \), $\pi(e_2)$ is a concave function of $e_2$, and there is a unique optimum value $e_2$ to maximize the function $\pi(e_2)$. Set \( \frac{d \pi(e_2)}{d e_2} = 0 \) to get $e_2(l) = e_0 - \frac{e_0 + k}{\mu [\beta + (r-\beta) l]}$.

Then, submit $e_2(l)$ into formula (1) to obtain the Hessian matrix $H = \begin{bmatrix} \frac{\partial^2 \pi(e_1, l)}{\partial e_1^2} & \frac{\partial^2 \pi(e_1, l)}{\partial e_1 \partial l} \\ \frac{\partial^2 \pi(e_1, l)}{\partial e_1 \partial l} & \frac{\partial^2 \pi(e_1, l)}{\partial l^2} \end{bmatrix}$.

Due to $\beta < r < 2 \beta$, $0 < l < 1$, then $H > 0$, \( \frac{\partial^2 \pi(e_1, l)}{\partial l^2} < 0 \), \( \frac{\partial^2 \pi(e_1, l)}{\partial e_1^2} < 0 \), and $\pi(e_1, l)$ is a joint concave function of $e_1$ and $l$, so there exists an optimal solution. Set \( \frac{\partial^2 \pi(e_1, l)}{\partial e_1} = 0 \), \( \frac{\partial^2 \pi(e_1, l)}{\partial l} = 0 \), and solve the system of equations to obtain $e^*_1 = e_0 - \frac{e_0 + k}{\mu}$, $l^* = \frac{\beta}{r-\beta}$.

Finally, submit $l^*$ into $e_2(l)$ to obtain $e^*_2 = e_0 - \frac{e_0 + k}{2 \mu \beta}$. This completes the proof.

Submit $e^*_1$, $e^*_2$, $l^*$ into formula (1) and formula (2) respectively, and obtain that the maximum profit of the subcontractor is $\pi(e^*_2) = P_2 + \frac{(e_0 + k)^2}{4 \mu \beta} - C_2 - (e_0 - K_2)k$; the maximum profit of the general contractor is $\pi(e^*_1, l^*) = P_1 + \frac{(e_0 + k)^2}{2 \mu} + \frac{(e_0 + k)^2 r}{\mu \beta (r-\beta)} - C_1 - P_2 - (e_0 - K_1)k$; the maximum profit of the construction supply chain is $\pi = \pi(e^*_2) + \pi(e^*_1, l^*) = P_1 + \frac{(e_0 + k)^2}{2 \mu} + \frac{(e_0 + k)^2 r}{\mu \beta (r-\beta)} + \frac{(e_0 + k)^2}{4 \mu \beta} - C_1 - C_2 - (e_0 - K_2)k - (e_0 - K_2)k$.

5. Sensitive analysis

In order to achieve better understanding the impact of the parameters $r$, $\beta$ and $k$ on the optimal decisions and the maximum profit. This part applies sensitivity analysis on the parameters $r$, $\beta$ and $k$. The following propositions are obtained.

Proposition 2 It can be derived the conclusions: $\frac{\partial \Delta e_1}{\partial k} > 0$; $\frac{\partial \Delta e_2}{\partial k} > 0$; $\frac{\partial \Delta e_2}{\partial \beta} < 0$; $\frac{\partial l^*}{\partial r} < 0$, $\frac{\partial l^*}{\partial \beta} > 0$.

Proof. From the above, we can obtain $\Delta e_1 = \frac{e_0 + k}{2 \mu \beta}$, $\Delta e_2 = \frac{e_0 + k}{2 \mu}$, $l^* = \frac{\beta}{r-\beta}$; The deviation of $\frac{\partial \Delta e_1}{\partial k} = \frac{1}{2 \mu} > 0$; $\frac{\partial \Delta e_2}{\partial k} = \frac{1}{2 \mu} > 0$, $\frac{\partial \Delta e_2}{\partial \beta} = \frac{e_0 + k}{2 \mu \beta^2} < 0$, $\frac{\partial l^*}{\partial r} = -\frac{\beta}{r-\beta} < 0$, $\frac{\partial l^*}{\partial \beta} = \frac{r}{(r-\beta)^2} > 0$. Thus, $\Delta e_1$ and $\Delta e_2$ increase in $k$; $\Delta e_2$ increases in $\beta$; $l^*$ decreases in $r$ and increases in $\beta$. This completes the proof.
Proposition 2 is corresponding to reality. When \( k \) increases, contractors will increase emission reduction efforts in order to sell surplus carbon emission rights to get higher revenue. When \( \beta \) and \( r \) increase, the subcontractor will reduce the emission reduction efforts to avoid high financing interest. When \( \beta \) increases, the general contractor will increase the proportion of internal financing to improve the income. When \( r \) increases, the subcontractor will reduce the emission reduction efforts to avoid high financing interest, and then the general contractor will decrease the proportion of internal financing.

**Proposition 3**

(1) If \( 0 \leq k \leq \max\{0, 4\mu\beta(r-\beta)(e_0-K_1)/[4\beta(r-\beta)+r] - e_0\} \), \( \pi(e_1^*, l^*) \) decreases in \( k \); if \( k > \max\{0, 4\mu\beta(r-\beta)(e_0-K_1)/[4\beta(r-\beta)+r] - e_0\} \), \( \pi(e_1^*, l^*) \) increases in \( k \).

(2) If \( 0 \leq k \leq \max\{0, \mu\beta(e_0-K_2) - e_0\} \), \( \pi(e_2^*) \) decreases in \( k \); if \( k > \max\{0, \mu\beta(e_0-K_2) - e_0\} \), \( \pi(e_2^*) \) increases in \( k \).

(3) If \( 0 \leq k \leq \max\{0, 4\mu\beta(r-\beta)(2e_0-K_1-K_2)/[4\beta(r-\beta)+3r-\beta] - e_0\} \), \( \pi \) decreases in \( k \); if \( k > \max\{0, 4\mu\beta(r-\beta)(2e_0-K_1-K_2)/[4\beta(r-\beta)+3r-\beta] - e_0\} \), \( \pi \) increases in \( k \).

**Proof.**

Due to analyze the impact of carbon trading price \( k \) on the maximum profit, thinking that \( \pi(e_1^*, l^*) \) is a quadratic function of \( k \). Therefore, set \( \frac{d\pi(e_1^*, l^*)}{dk} = 0 \) to get \( k = 4\mu\beta(r-\beta)(e_0-K_1)/[4\beta(r-\beta)+r] - e_0 \). If \( 0 \leq k \leq \max\{0, 4\mu\beta(r-\beta)(e_0-K_1)/[4\beta(r-\beta)+r] - e_0\} \), \( \pi(e_1^*, l^*) \) is a decreasing function of \( k \), so \( \pi(e_1^*, l^*) \) decreases in \( k \); if \( k > \max\{0, 4\mu\beta(r-\beta)(e_0-K_1)/[4\beta(r-\beta)+r] - e_0\} \), \( \pi(e_1^*, l^*) \) is an increasing function of \( k \), so \( \pi(e_1^*, l^*) \) increases in \( k \). This completes the proof. And other proofs are the same as above.

Proposition 3 is also corresponding to reality. When \( k \) is below a critical point, within this range, if \( k \) increases, in order to reduce the carbon trading cost and thus improve the emission reduction efforts, the emission reduction cost also increases, so the maximum profit decreases in \( k \). When \( k \) exceeds the critical point, with the increase of \( k \), in order to increase carbon trading income and thus improve the emission reduction efforts, the bonus will also increase, so the maximum profit will increase in \( k \).

**Proposition 4** It is shown that \( \frac{d\pi(e_1^*, l^*)}{d\beta} < 0 \), \( \frac{d\pi(e_2^*)}{dr} < 0 \), \( \frac{d\pi(e_1^*, l^*)}{d\beta} < 0 \), \( \frac{d\pi(e_2^*)}{dr} < 0 \), \( \frac{d\pi}{d\beta} < 0 \), \( \frac{d\pi}{dr} < 0 \).

**Proof.**

Due to analyze the impact of parameters \( r \) and \( \beta \) on the maximum profit, thinking that \( \pi(e_1^*, l^*) \) is a quadratic function of \( r \) and \( \beta \). Therefore, according to the above, we can obtain \( \frac{d\pi(e_1^*, l^*)}{d\beta} = \frac{r(e_0+k)^2}{8\mu} + \frac{r-2\beta}{[\beta(r-\beta)]^2} \), \( \frac{d\pi(e_2^*)}{dr} = \frac{-(e_0+k)^2}{8\mu(r-\beta)^2} < 0 \), so \( \pi(e_1^*, l^*) \) decreases in \( r \) and \( \beta \). This completes the proof. And other proofs are the same as above.

Proposition 4 is also easy to understand. When \( \beta \) increases, which leads to the increase of \( l \). In order to avoid high financing interest, the subcontractor will reduce the emission reduction efforts, and the financing interest obtain by the general contractor decreases, so the maximum profit decreases. For the subcontractor, when \( \beta \) increases, resulting in the increase of the financing cost, so the maximum profit decreases. When \( r \) increases, which leads to the decrease of \( l \). Then the financing interest obtain by the general contractor decreases, and the financing cost of the subcontractor increases, so the maximum profit will be reduced. And with the increase of \( r \), the financing cost increases, so the maximum profit of the construction supply chain decreases in \( r \).

6. Conclusion and future research

Under the cap-and-trade and the incentive of emission reduction bonus, we examined a two-stage construction supply chain consisting of a subcontractor with capital constraints and a general contractor, and investigated the emission reduction decision-making model considering mix financing. In addition, this study also analyzed the impact of financing interest rate and carbon trading price on the optimal
decisions and the maximum profit. On the one hand, this paper enriches the theory of construction supply chain management; on the other hand, the results of this study provide relevant management enlightenment for the management decisions of construction supply chain enterprises facing the constraint of emission reduction funds.

There are some limitations in this paper. We only studied a two-stage construction supply chain consisting of a general contractor and a subcontractor. In the future, it can be further extended to the situation that one general contractor corresponds to several subcontractors on the basis of the research in this paper, so as to obtain more reference for the management of construction supply chain.

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