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Profit Distribution Model of Green Building Supply Chain with Fairness Preferences and Cap-and-Trade Policy

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Abstract. The green building is a sustainable form of construction. Carbon emissions are one of the important criteria for measuring the green building. The cap-and-trade policy is widely used by governments as an effective emission reduction policy. Green building supply chain companies need to decide how to distribute profit under the cap-and-trade policy. At the same time, supply chain members with fairness preferences have an impact on supply chain decisions. The paper formulates the profit distribution models under the cap-and-trade policy, which are the model without considering fairness preferences and the other model considering the subcontractor cares about fairness preferences. The paper drives the optimal proportion of the profit and the unit carbon emissions in the two models. The fairness preferences degree of the subcontractor is considered to analyse the effect of fairness preferences degree on the unit carbon emissions and the profit of the supply chain. Our study also shows that subcontractors' fairness preferences will damage the profit of the general contractor and the supply chain. So, when the general contractor chooses the subcontractor, he should try to choose the subcontractor that does not pay too much attention to fairness.

1. Introduction

The green building is a sustainable form of construction. Whether the green building is “green”, the most intuitive measure is carbon emissions. In order to control carbon emissions, the cap-and-trade policy is implemented in nearly 40 countries around the world. The implementation of cap-and-trade policy challenges firm decision-making and also attracts firm's attention to carbon reduction efforts in the green building supply chain. On the other hand, many studies have found that most of the companies care about fairness preferences. They care about their own profit and whether they can be treated fairly. Unfair profit distribution model can lead to contractors reducing low carbon investment.

Two research streams are closely related to this paper and will be reviewed to highlight our contributions. First is the literature on decision-making of supply chain under cap-and-trade policy. Jiang et al. investigated the pricing and carbon reduction mode of a two-echelon supply chain consisting of a supplier and a prefabricated building manufacturer under cap-and-trade policy^[1]. Jiang also investigated the supply chain decisions and coordination with strategic customer behavior under cap-and-trade policy^[2]. Chen et al. analysed the optimal decisions in warehouse management and technology investment under the cap-and-trade policy to assist the practitioners in making efficient decisions^[3]. The second stream related to our work is the literature on profit distribution in the supply chain. Zhang et al. established a profit distribution model for the general contractor and subcontractor based on stackelberg game and found the maximum effort level and the optimal allocation proportions^[4]. Lv et al. established a profit distribution model for engineering procurement



construction (EPC) based on the cooperative alliance model and used the Shapley value method as the distribution method of cooperative interest^[5]. The literature abovementioned discussed the profit distribution but didn't considered fairness preferences. In order to fill the gap presented by the literature review, this paper studies the profit distribution mechanism that considering the subcontractor cares about fairness preferences under cap-and-trade policy.

2. Model descriptions and assumptions

The paper considers a two-echelon green building supply chain that consists of a general contractor and a subcontractor. The general contractor and the owner sign the cost-plus remuneration contract, and the general contractor and the subcontractor also sign the same contract. Meanwhile, the general contractor and the subcontractor can input low carbon efforts to reduce their products' carbon emissions respectively in response to the cap-and-trade policy.

Throughout this paper, the paper uses the parameters and variables using the notations presented in Table 1.

Table 1 Notations of parameters and variables

Notation	Descriptions
P_1	The fixed price portion which paid by the owner to the general contractor.
P_2	The fixed price portion which paid by the general contractor to the subcontractor.
μ	The rate of remuneration.
s	Green building area.
C	The total cost of green building supply chain, $C = C_1 + C_2$.
C_{1i}	The cost of the general contractor/subcontractor's normal completion of the project, $i = 1, 2$.
C_1	The cost of the supply chain for the normal completion of the project, $C_1 = C_{11} + C_{12}$.
C_{2i}	The cost of the general contractor/subcontractor's low carbon investment, $i = 1, 2$.
C_2	The low carbon efforts cost of the green building supply chain, $C_2 = C_{21} + C_{22}$.
e_0	The initial unit carbon emissions of the general contractor and subcontractor.
e_i	The unit carbon emissions after low carbon investment of the general contractor and subcontractor respectively, $i = 1, 2$.
t_i	The cost coefficient of low carbon investment and represents the efficiency of the general contractor and subcontractor, $i = 1, 2$.
K_i	The general contractor's and subcontractor's initial carbon allowances, $i = 1, 2$.
k	Unit price of carbon emission trading with the outside market.
E_i	Carbon emission trading quantities with the outside market, $E_i = e_i s - K_i$, $i = 1, 2$.

In addition, the following assumptions are employed in this study:

- (1) The subcontractor cares about fairness preferences and the general contractor is fairness-neutral.
- (2) $C_{2i} = st_i(e_0 - e_i)^2$, $i = 1, 2$. This assumption means that the general contractor and subcontractor's carbon emission reduction cost is convexity on e_i , which attributes to diminishing returns from expenditures.

Based on the model assumptions, the contract price that the owner ultimately pays to the general contractor is: $P(e_1, e_2) = P_1 + \mu s[(e_0 - e_1) + (e_0 - e_2)]$, where $\mu s[(e_0 - e_1) + (e_0 - e_2)]$ indicates the emission reduction rewards that the owner finally paid to the general contractor.

The contract price paid by the general contractor to the subcontractor can be expressed as $R(\lambda, e_1, e_2) = P_2 + (1 - \lambda)\mu s[(e_0 - e_1) + (e_0 - e_2)]$, where λ is the proportion of profit distribution between the general contractor and the subcontractor, $0 < \lambda < 1$.

Under the above conditions, the profit functions of the green building supply chain, the general contractor and the subcontractor are:

$$\Pi_{sc}(e_1, e_2) = P_1 + \mu s[(e_0 - e_1) + (e_0 - e_2)] - kE_1 - kE_2 - C_1 - C_2 \quad (1)$$

$$\Pi_1(\lambda, e_1) = P_1 - P_2 + \lambda \mu s[(e_0 - e_1) + (e_0 - e_2)] - kE_1 - C_{21} - C_{11} \quad (2)$$

$$\Pi_2(\lambda, e_2) = P_2 + (1 - \lambda) \mu s[(e_0 - e_1) + (e_0 - e_2)] - kE_2 - C_{22} - C_{12} \quad (3)$$

3. Profit distribution model without considering fairness preferences

In this section, the paper doesn't consider fairness preferences, that is both parties are fairness-neutral. The general contractor and the subcontractor carry out the emission reduction input separately, and maximize the profit of the supply chain as the decision-making goal, then formulate the optimal decision of the enterprises.

In the profit distribution model without considering fairness preferences, the decision problem faced by the general contractor is to decide the optimal carbon emissions and so as to maximize his profit $\Pi_1(\lambda, e_1)$, subject to the carbon emission constraint being satisfied. The decision problem faced by the general contractor is:

$$\begin{aligned} \max \Pi_1(\lambda, e_1) \\ \text{s.t. } e_1 s - E_1 = K_1 \end{aligned}$$

Similarly, the decision problem faced by the subcontractor is:

$$\begin{aligned} \max \Pi_2(\lambda, e_2) \\ \text{s.t. } e_2 s - E_2 = K_2 \end{aligned}$$

Lemma 1: When both parties are fairness-neutral, the unit carbon emissions of the general contractor and subcontractor after low carbon investment under cap-and-trade policy are:

$$e_1(\lambda) = e_0 - \frac{k + \lambda \mu}{2t_1} \quad (4)$$

$$e_2(\lambda) = e_0 - \frac{k + (1 - \lambda) \mu}{2t_2} \quad (5)$$

Proof: From equation (1) and (2), $\frac{\partial \Pi_1(\lambda, e_1)}{\partial e_1} = -\lambda \mu s + 2st_1(e_0 - e_1) - ks$, $\frac{\partial \Pi_2(\lambda, e_2)}{\partial e_2} = -(1 - \lambda) \mu s + 2st_2(e_0 - e_2) - ks$ can be got and $\frac{\partial^2 \Pi_1(\lambda, e_1)}{\partial e_1^2} = -2st_1 < 0$, $\frac{\partial^2 \Pi_2(\lambda, e_2)}{\partial e_2^2} = -2st_2 < 0$. Let $\frac{\partial \Pi_1(\lambda, e_1)}{\partial e_1} = 0$, $\frac{\partial \Pi_2(\lambda, e_2)}{\partial e_2} = 0$. $e_1(\lambda) = e_0 - \frac{k + \lambda \mu}{2t_1}$, $e_2(\lambda) = e_0 - \frac{k + (1 - \lambda) \mu}{2t_2}$ can be obtained. This completes the proof.

Proposition 1: When both parties are fairness-neutral, the optimal profit distribution proportion under cap-and-trade policy is $\lambda^* = \frac{t_2}{t_1 + t_2}$.

Proof: Substitute equation (4) and (5) into (1). $\Pi_{sc}(\lambda) = P_1 + s\mu \left[\frac{k + \lambda \mu}{2t_1} + \frac{k + (1 - \lambda) \mu}{2t_2} \right] - st_1 \left(\frac{k + \lambda \mu}{2t_1} \right)^2 - st_2 \left(\frac{k + (1 - \lambda) \mu}{2t_2} \right)^2 - k(e_1 s - K_1) - k(e_2 s - K_2) - C_1$. Then $\frac{\partial \Pi_{sc}(\lambda)}{\partial \lambda} = \frac{\mu^2 s}{2t_1} - \frac{\mu^2 s}{2t_2} - \frac{2\mu s(\lambda \mu + k)}{4t_1} + \frac{2\mu s[(1 - \lambda) \mu + k]}{4t_2} + \frac{\mu ks}{2t_1} - \frac{\mu ks}{2t_2}$, $\frac{\partial^2 \Pi_{sc}(\lambda)}{\partial \lambda^2} = -\frac{2\mu^2 s}{4t_1} - \frac{2\mu^2 s}{4t_2} < 0$, that is, $\Pi_{sc}(\lambda)$ is concave in λ . Let $\frac{\partial \Pi_{sc}(\lambda)}{\partial \lambda} = 0$, then $\lambda^* = \frac{t_2}{t_1 + t_2}$. This completes the proof.

From lemma 1 and proposition 1, the optimal unit carbon emissions of the general contractor and subcontractor are $e_1^* = e_1(\lambda^*) = e_0 - \frac{k + \lambda^* \mu}{2t_1}$ and $e_2^* = e_2(\lambda^*) = e_0 - \frac{k + (1 - \lambda^*) \mu}{2t_2}$.

Proposition 1 shows that the profit distribution proportion is only related to the cost coefficient of low carbon investment. The higher the subcontractor cost coefficient t_2 , that is, the lower the R&D efficiency, the lower the distribution ratio obtained. Therefore, the subcontractor needs to improve R&D efficiency in order to obtain more profit.

4. Profit distribution model considering the subcontractor cares about fairness preferences

Behavioral research shows that supply chain members are not completely self-interested in real society. The subcontractor cares about fairness preferences means that the subcontractor focuses not only on

his own profit, but also on the profit of the general contractor, and that the gap can affect their actual profit levels by the degree of fairness preferences.

Fehr and Schmidt (1999) proposed a simple linear utility function that includes individual fairness preferences^[6]. On the basis of the model proposed by Fehr and Schmidt (1999), the paper builds the subcontractor's fairness preferences utility function. To facilitate the research, the paper assumes that the subcontractor cares about fairness preferences and the general contractor is fairness-neutral. Therefore, the general contractor and the subcontractor's utility functions are:

$$U_1(\lambda, e_1) = P_1 - P_2 + \lambda\mu s[(e_0 - e_1) + (e_0 - e_2)] - st_1(e_0 - e_1)^2 - kE_1 - C_{11} \quad (6)$$

$$U_2(\lambda, e_2) = \Pi_2 - \gamma(\Pi_1 - \Pi_2) = (1 + \gamma)\Pi_2 - \gamma\Pi_1 \quad (7)$$

The subcontractor cares about fairness preferences, so $\gamma > 0$. It is worth noting that when $\gamma = 0$, the subcontractor is fairness-neutral, and $U_2(\Pi) = \Pi_2$, which is equivalent to the model without considering fairness preferences.

In the profit distribution model considering the subcontractor cares about fairness preferences, the decision problem faced by the general contractor is to decide the optimal carbon emissions and so as to maximize his utility $U_1(\lambda, e_1)$, subject to the carbon emission constraint being satisfied. The decision problem faced by the general contractor is:

$$\begin{aligned} \max U_1(\lambda, e_1) \\ \text{s.t. } e_1 s - E_1 = K_1 \end{aligned}$$

Similarly, the decision problem faced by the subcontractor is:

$$\begin{aligned} \max U_2(\lambda, e_2) \\ \text{s.t. } e_2 s - E_2 = K_2 \end{aligned}$$

Lemma 2: When the subcontractor cares about fairness preferences, the unit carbon emissions of the general contractor and subcontractor after low carbon investment under cap-and-trade policy are:

$$e_1(\lambda) = e_0 - \frac{k + \lambda\mu}{2t_1} \quad (8)$$

$$e_2(\lambda) = e_0 - \frac{(1 + \gamma)(k + \mu) - (1 + 2\gamma)\lambda\mu}{2t_2(1 + \gamma)} \quad (9)$$

Proof: From equation (6) and (7), $\frac{\partial U_1(\lambda, e_1)}{\partial e_1} = -\lambda\mu s + 2st_1(e_0 - e_1) - ks$, $\frac{\partial U_2(\lambda, e_2)}{\partial e_2} = (1 + \gamma)[-(1 - \lambda)\mu s + 2st_2(e_0 - e_2) - ks] + \lambda\gamma\mu s$, $\frac{\partial^2 U_1(\lambda, e_1)}{\partial e_1^2} = -2st_1 < 0$, $\frac{\partial^2 U_2(\lambda, e_2)}{\partial e_2^2} = -2st_2 < 0$. Let $\frac{\partial U_1(\lambda, e_1)}{\partial e_1} = 0$, $\frac{\partial U_2(\lambda, e_2)}{\partial e_2} = 0$, then $e_1^{**}(\lambda) = e_0 - \frac{k + \lambda\mu}{2t_1}$ and $e_2^{**}(\lambda) = e_0 - \frac{(1 + \gamma)(k + \mu) - (2\gamma + 1)\lambda\mu}{2t_2(1 + \gamma)}$.

Proposition 2: When the subcontractor cares about fairness preferences, the optimal profit distribution proportion under cap-and-trade policy is $\lambda^{**} = \frac{t_2(1 + \gamma)^2}{t_1(1 + 2\gamma)^2 + t_2(1 + \gamma)^2}$.

Proof: Substitute equation (8) and (9) into (1). So $\Pi_{sc}(\lambda) = P_1 + \mu s[\frac{k + \lambda\mu}{2t_1} + \frac{(1 + \gamma)(k + \mu) - (1 + 2\gamma)\lambda\mu}{2t_2(1 + \gamma)}] - st_1(\frac{k + \lambda\mu}{2t_1})^2 - st_2[\frac{(1 + \gamma)(k + \mu) - (2\gamma + 1)\lambda\mu}{2t_2(1 + \gamma)}]^2 - k(e_1 s - K_1) - k(e_2 s - K_2) - C_1$. $\frac{\partial \Pi_{sc}(\lambda)}{\partial \lambda} = \frac{k\mu s}{2t_1} - \frac{k\mu s(1 + 2\gamma)}{2t_2(1 + \gamma)} + \mu s(1 + 2\gamma)[\frac{(k + \mu)(1 + \gamma) - \mu\lambda(1 + 2\gamma)}{2t_2(1 + \gamma)^2}] + \frac{\mu^2 s}{t_1} - \frac{\mu s(k + \lambda\mu)}{2t_1}$, then $\frac{\partial^2 \Pi_{sc}(\lambda)}{\partial \lambda^2} = -\frac{\mu^2 s}{2t_1} - \frac{\mu^2 s(1 + 2\gamma)^2}{2t_2(1 + \gamma)^2} < 0$, that is, $\Pi_{sc}(\lambda)$ is concave in λ . Let $\frac{\partial \Pi_{sc}(\lambda)}{\partial \lambda} = 0$, then $\lambda^{**} = \frac{t_2(1 + \gamma)^2}{t_1(1 + 2\gamma)^2 + t_2(1 + \gamma)^2}$. This completes the proof.

From lemma 2 and proposition 2, the optimal unit carbon emissions of the general contractor and subcontractor are $e_1^{**} = e_1(\lambda^{**}) = e_0 - \frac{k + \lambda^{**}\mu}{2t_1}$ and $e_2^{**} = e_2(\lambda^{**}) = e_0 - \frac{(1 + \gamma)(k + \mu) - (1 + 2\gamma)\lambda^{**}\mu}{2t_2(1 + \gamma)}$.

Proposition 2 means that in the profit distribution model considering the subcontractor cares about fairness preferences under cap-and-trade policy, the profit distribution proportion not only related to t_i , but also closely related to γ . As γ increases, the general contractor has to give the subcontractor

more profit. When $\gamma = 0$, $\lambda^{**} = \lambda^* = \frac{t_2}{t_1+t_2}$, it can be seen that the green building supply chain profit distribution model considering both parties are fairness-neutral is a special kind of the profit distribution model considering the subcontractor cares about fairness preferences in this paper.

The paper compares the impact of two profit distribution models on the proportion of the profit distribution and the unit carbon emissions from the general contractor and subcontractor in proposition 3.

Proposition 3:

(i) $\lambda^* > \lambda^{**}$;

(ii) $e_1^{**} > e_1^*$;

(iii) if $\gamma \leq \frac{t_2-t_1}{2t_1-t_2}$, then $e_2^{**} \geq e_2^*$; if $\gamma > \frac{t_2-t_1}{2t_1-t_2}$, then $e_2^{**} < e_2^*$.

Proof: $\lambda^* - \lambda^{**} = \frac{t_1 t_2 \gamma (2+3\gamma)}{(t_1+t_2)[t_1(1+2\gamma)^2+t_2(1+\gamma)^2]} > 0$, so $\lambda^* > \lambda^{**}$. $e_1^{**} - e_1^* = \frac{\mu \gamma t_2 (2+3\gamma)}{2(t_1+t_2)[t_1(1+2\gamma)^2+t_2(1+\gamma)^2]} > 0$, so $e_1^{**} > e_1^*$. $e_2^{**} - e_2^* = \frac{\mu \gamma [(t_2-t_1)+\gamma((t_2-2t_1))]}{2(t_1+t_2)[t_1(1+2\gamma)^2+t_2(1+\gamma)^2]}$, let $e_2^{**} - e_2^* \geq 0$, then $\gamma \leq \frac{t_1-t_2}{t_2-2t_1}$. This completes the proof.

Proposition 3 shows that the general contractor needs to distribute more profit to the subcontractor when the subcontractor cares about fairness preferences, resulting in damage to his own profit, so he will reduce low carbon investment.

5. Discussion

In the section, the paper discusses the effect of subcontractor's fairness preference degree on the unit carbon emissions and the supply chain's profit by numerical analysis. Set $e_0 = 10$, $t_1 = 6$, $t_2 = 10$, $k = 10$, $\mu = 5$, $P_1 = 600000$, $P_2 = 200000$, $s = 1000$, $K_1 = K_2 = 5000$, $C_{11} = 30000$, $C_{12} = 20000$. In order to observe the change of the unit carbon emissions and the profit when the degree of fairness preferences is increasing, the paper sets $\gamma \in [0,4]$.

The effect of subcontractor's fairness preferences degree γ on the unit carbon emissions of the general contractor, the subcontractor and the green supply chain is shown in figure 1.

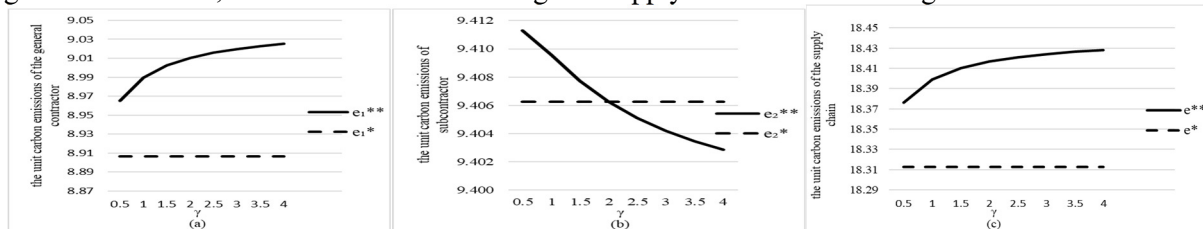


Figure 1: The effect of subcontractor's fairness preferences degree on the unit carbon emissions

Figure 1(a) shows that the general contractor is unwilling to reduce carbon emissions because he has to give the subcontractor more profits when the subcontractor cares about fairness preferences. From figure 1(b), when $\gamma \in [0,2]$, the subcontractor's unit carbon emissions considering fairness preferences is higher than that without considering fairness preferences. From figure 1(c), the total supply chain carbon emissions considering the subcontractor cares about fairness preferences is higher than that without considering fairness preferences.

The effect of subcontractor's fairness preferences degree γ on the profit of the general contractor, the subcontractor and the green building supply chain is shown in figure 2.

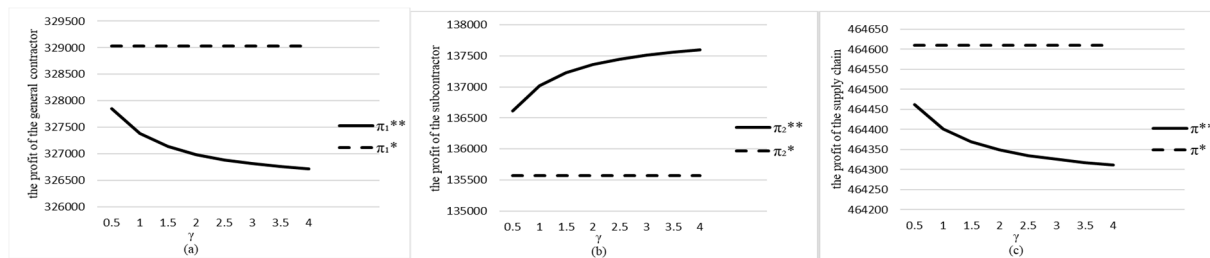


Figure 2: The effect of subcontractor's fairness preferences degree on the profit

Figure 2(b) shows that the subcontractor can get more profit when the subcontractor cares about fairness preferences. From 2(a) and 2(c) show that subcontractor's fairness preferences will damage the profit of the general contractor and the supply chain. So, when the general contractor chooses the subcontractor, he should try to choose the subcontractor that does not pay too much attention to fairness. The general contractor should also pay attention to protecting his own information, and not let the subcontractors know the profit of the general contractor.

6. Conclusions and future researches

This paper studies the profit distribution mechanism of green building supply chain composed of the general contractor and the subcontractor. On the basis of cap-and-trade policy, the paper compares the model without considering fairness preferences with the model considering the subcontractor cares about fairness preferences. The paper derives the optimal proportion of the profit, the unit carbon emissions between the general contractor and the subcontractor in the two cases. Then the paper analyzes the effect of subcontractor's fairness preferences degree on the unit carbon emissions and the profit of the general contractor, the subcontractor and the green building supply chain by a numerical study. Our study shows that it will damage the profit of the general contractor and reduce the overall profit of the supply chain when the subcontractor pays attention to fairness.

The paper assumes that only the subcontractor cares about fairness preferences. In real life, the general contractor also cares about fairness preferences, and even the general contractor's fairness preferences have a greater impact on the supply chain. Thus, the next research direction is to study a green building supply chain considering both parties care about fairness preferences under cap-and-trade policy. On the other hand, the fair reference point is the profit of the general contractor in this paper, but the subcontractor doesn't need absolutely fair in most cases. Therefore, the next study will change the fair reference point in order to be in line with the actual situation.

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