

Research Article

The Effect of Fairness Concern on Carbon Emission Reduction and Revenue Distribution in Construction Supply Chain: Power Structure Perspective

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This paper investigated a two-echelon construction supply chain that consists of a general contractor and a subcontractor. This paper constructs the centralized model and the decentralized models, respectively, and studies the emission reduction and revenue distribution strategies of construction supply chain considering fairness concern and cap-and-trade. Numerical analysis is carried out to analyze the influence of cap-and-trade and fairness concern on the optimal decision and the maximum profit of construction supply chain. This paper shows that, under cap-and-trade policy, the centralized model has the best emission reduction effect and the highest supply chain profit without fairness concern, while the general contractor's Stackelberg model has the best emission reduction effect and the highest supply chain profit with fairness concern. In the two scenarios, the Vertical Nash model is the most unfavorable to emission reduction, and it will also seriously damage the interests of enterprises. In practice, supply chain should choose the general contractor's Stackelberg model and avoid the Vertical Nash model. Because fairness concern of the subcontractor will damage the supply chain profits and emission reduction performance, the general contractor shall try to select the subcontractor with lower fairness concern to avoid the loss of profit. Besides, enterprises should actively take measures to reduce fairness concern, such as enterprises signing the contract price confidentiality clause, which aims to reduce fairness concern of the subcontractor. The results of this paper can not only enrich the research content of construction supply chain management, but also provide references for the government to formulate emission reduction policies.

1. Introduction

Nowadays, the accumulation of greenhouse gases has led to the rising global climate [1], and the survival and development of human are seriously affected. The results show that 90% of the main causes of global warming are human factors [2]. In 2016, China's total carbon emissions were 9.11 billion tons [3], including 1.96 billion tons of carbon emissions from the construction industry, accounting for 21.5% of the national carbon emissions [4]. Construction industry is not only the pillar industry of the country, but also one of the industries with excessive carbon emissions. The construction industry accounted for 7% of China's GDP but was responsible for approximately 30% of China's total CO₂ emissions [5]. Moreover, due to the lack of scientific management, construction enterprises have the problems,

which are low efficiency and high cost of emission reduction [6]. Therefore, ensuring the rapid development of the construction industry and effectively controlling carbon emissions simultaneously are an urgent problem in China.

The cap-and-trade policy, with the dual means of government regulation and market regulation, has a significant control effect. The policy has become the preferential emission reduction policy of governments. By the end of 2018, China's carbon emission trading volume is close to 800 million tons, and the total trading volume is more than 11 billion yuan [7]. China's carbon trading market covers more than ten industries, including building materials, steel, and other construction related industries [8]. On the other hand, the industries are also actively taking measures to reduce carbon emissions, such that the incentive of emission reduction bonus can effectively inspire the construction

enterprises to make more efforts reducing the carbon emission of building [9]. Due to the dual role of cap-and-trade and emission reduction bonus incentive, enterprises not only have traditional construction costs/benefits, but also have significant emission reduction benefits, that is, emission reduction bonus and carbon trading benefits. Therefore, with the implementation of cap-and-trade, how to make decisions about emission reduction is an important part of the construction supply chain [10, 11].

In the traditional supply chains, decision researches mostly assume that the decision-maker is completely rational [12]. However, the researches in behavioral operation field show that, in practice, decision-makers are not all rational; when they have irrational behavior, supply chain members will care about the fairness of profit distribution [13]. Some researchers also found that fairness concern can affect decisions of enterprises. Ho and Zhang (2008) [14] confirmed that fairness concern exists in contract negotiation and implementation, which will have a great impact on enterprise decisions. In practice, the cooperation between supply chain companies is usually hindered by the fairness of profit distribution. In 2004, Gome, the Chinese household electric appliance retailer who terminates cooperation with Gree due to unfair distribution of profits, Wal-Mart, and Procter and Gamble have caused unpleasant and even conflicts because of unfair distribution of benefits; In 2007, Langsha Knitting Co., the world's largest hosiery company, and Walmart, due to unfair profit distribution, result in termination of cooperation [15]. At the same time, most of the existing researches take the general contractor as a strong side and study construction supply chain decision when the general contractor is the leader [6, 16]. This is in line with most of the construction projects in real life. However, as the general contractor gradually transforms from a constructor to a manager, the degree of professional subcontractors gradually increases, and even as many subcontractors have irreplaceable patents and professional technologies, the dependence of the general contractor on such professional subcontractors gradually increases. Meanwhile, as "the Belt and Rode" initiative was proposed, China has been involved in international projects, and the construction of projects has also been more dependent on local professional contractors. And subcontractors will follow the management of the general contractor, but they will also protect their own revenues [17]. On the other hand, the status, scale, and economic strength of contractors are gradually improving, such as China State Construction Engineering Corporation Limited, China Railway Construction Corporation, and Vinci Group. Therefore, there are three scenarios (the general contractor dominant model, the subcontractor dominant model, and the Vertical Nash model) in the market. Under different power structures, construction supply chain companies will also make completely different decisions. Therefore, this paper studies the emission reduction and revenue distribution strategies of the general contractor and the subcontractor under different power structures when considering both cap-and-trade and fairness concern and analyzes and compares the optimal solutions to find the most favorable decentralized models for

the low-carbon development of construction supply chain. This paper is going to address the following research questions:

- (1) How to formulate the optimal carbon emission and emission reduction revenue distribution strategy without fairness concern under cap-and-trade? In this case, which model is most beneficial to the emission reduction and performance of construction supply chain?
- (2) How to formulate the optimal carbon emission and emission reduction revenue distribution strategy considering that the subcontractor has fairness concern under cap-and-trade? In this case, which model is most beneficial to the emission reduction and performance of construction supply chain?
- (3) What are the impacts of cap-and-trade and fairness concern on the optimal decision and maximum profit of the supply chain?
- (4) Which power structure is the most beneficial for reducing emissions and maximizing profits in construction supply chain? When considering cap-and-trade and fairness concern, what kind of power structure should be avoided?

In order to answer these four questions, a two-echelon construction supply chain is considered. It consists of a general contractor and a subcontractor who has fairness concern. The contributions of this paper are significant. The first contribution is incorporating fairness concern, cap-and-trade policy, and power structure simultaneously into decision optimization of supply chain. The existing researches have explored fairness concern, cap-and-trade policy, and power structure, respectively [18–20]. For achieving a resource-conscious and environmentally-friendly society, it is necessary to study the impact of fairness concern and power structure on supply chain decision under cap-and-trade. The second contribution is bringing the construction industry into the scope of cap-and-trade. The existing researches mainly focus on the emission reduction decisions of manufacturing and other industries but lack research on the construction industry [21, 22]. At present, the construction industry is one of the industries with excessive carbon emissions. Studying its emission reduction strategy under cap-and-trade policy can effectively reduce carbon emissions. The model provides management implications for the study of the impact of fairness concern and power structure on supply chain decision and can provide suggestions for the government to formulate policies to promote carbon emission reduction.

The remaining part of this paper is organized as follows. After a review of the literature in Section 2, the model description and assumptions are presented in Section 3. In Section 4, the emission reduction and revenue distribution strategies in the centralized and decentralized models without fairness concern are discussed. In Section 5, the emission reduction and revenue distribution strategies with the subcontractor's fairness concern in different power structure are discussed. We conduct numerical analysis in

Section 6 and conclude our work and point out future research directions in Section 7.

2. Literature Review

The literature reviewed in this paper primarily relates to three research streams: (1) construction supply chain emission reduction strategy under cap-and-trade; (2) the revenue distribution strategy of construction supply chain considering fairness concern; (3) supply chain revenue distribution and reduction strategies under different decentralized models.

2.1. Construction Supply Chain Emission Reduction Strategy under Cap-and-Trade. In 1997, the Kyoto Protocol put forward “carbon emission right trade,” which makes carbon emission right become an important resource [23]. Ekins and Baker (2001) [24] and Stern (2007) [25], respectively, investigated advantages and disadvantages of cap-and-trade and carbon tax policies. The research showed that, for manufacturers, cap-and-trade can bring long-term incentives. China vigorously promotes cap-and-trade and actively builds and improves the carbon trading market. In April 2019, China issued the “carbon emission standard for buildings,” in which the calculation requirements and methods of carbon emission in the whole life cycle of buildings are clearly specified.

Most of the existing researches on the construction industry under cap-and-trade are focused on the carbon trading system and the measurement of the construction carbon emissions. Carbon emission accounting also directly affects the formulation of carbon emission policies [26]. Rehan and Nehdi (2005) [10] studied the impact of cap-and-trade on the cement industry, took the cement industry in Canada as an empirical research object, and put forward some improvement measures. Shao et al. (2014) [27] conducted a quantitative study on the energy consumption and carbon emissions of buildings and measured the carbon emissions of landmark buildings in Beijing. The results showed that materials accounted for about 90% of carbon emissions, of which steel accounted for nearly half. The researches on carbon emission measurement of the construction industry provide a basis for the feasibility of this study.

There are many researches on the reduction strategies of other industries under cap-and-trade [21, 28]. Xu et al. (2017) [29] investigated the production and emission reduction decision problem of a make-to-order supply chain under cap-and-trade. In the study, they assumed that the carbon trading price is a fixed value, which has certain limitations. Yang et al. (2018) [22] investigated the channel selection and emission reduction decision of the manufacturer in two-echelon supply chain under cap-and-trade. They only discussed the emission reduction behavior of manufacturers. In fact, some retailers also have emission reduction behavior. Xu et al. (2018) [30] studied the decision and coordination of low-carbon preference and channel substitution in dual-channel supply chain considering cap-

and-trade. The results showed that the government should formulate cap-and-trade policy to effectively reduce carbon emissions. Wang et al. (2020) [31] investigated production and carbon emission reduction strategies of a two-echelon supply chain that consists of one manufacturer and one retailer under cap-and-trade. Qu et al. (2021) [19] studied the impact of cap-and-trade regulation on product warranty policy and carbon emission reduction strategy. However, there are few researches on construction supply chain reduction strategy under cap-and-trade.

From the macro perspective, the construction industry is one of the main sources of carbon emissions, so it is necessary to study how to extend the cap-and-trade policy to the construction industry. The carbon emission of the construction industry is large, so its trading volume is also large, and its transaction cost accounts for a large proportion of the total cost. Moreover, there are many participants in the construction industry, and the control of carbon emissions of all parties is different, which is easy to cause the participants to shift responsibility for emission reduction. From the micro perspective, the contract mode of the traditional industry is relatively fixed, but the construction industry has more participants, different forces, long construction period, and high risk. Therefore, the game mode and contract signing between the parties are relatively diverse. This paper aims to study the decision changes of the general contractor and the subcontractor under the more typical game mode.

2.2. The Revenue Distribution Strategy of Construction Supply Chain considering Fairness Concern. At the beginning, most of the research assumes that the participants are “rational person” while studying the revenue distribution of construction supply chain. Love et al. (2011) [32] investigated participants in eight infrastructure projects in Australia and found that the key factor for the success of the project is the design of revenue sharing contract when all participants in the infrastructure project form a consortium. Yang et al. (2017) [33] combined the improved Shapley method with TOPSIS method, analyzed and calculated the single factor and multifactor profit distribution based on risk correction factor and risk compensation value in construction supply chain, and modified the single factor profit distribution. Wen et al. (2021) [34] investigated the financing and pricing decision of construction supply chain under capital constraints and obtained that there is a profit distribution model under centralized decision, which makes construction developers and contractors more profitable. In recent years, Fehr and Schmidt (1999) [35], Ho et al. (2014) [36], An et al. (2018) [37], and many other researchers [38, 39] have found that most supply chain participants in real life have fairness concern, and they care about their own profits as well as whether they can be treated fairly. Zhou and Zhang (2011) [40] introduced fairness concern into large-scale ship excavation project and studied the influence of fairness concern on incentive mode and bidding price of construction companies. Jian et al. (2020) [41] analyzed the impact of a revenue sharing contract on the pricing decision and profit distribution of a competitive supply chain considering

fairness concern. Zhang et al. (2020) [42] discussed the impact of a green retailer's fairness concern on the product greenness and profit and explored how to distribute surplus profits under the fairness concern using cooperative game theory. Jian et al. (2021) [20] proposed a game theory model under the centralized decision and decentralized decision of green closed-loop supply chain with manufacturer's fairness concern, to study the problem of profit distribution between manufacturers and retailers.

Due to the establishment of carbon trading market, the carbon emission revenue of construction supply chain enterprises is not only the emission reduction bonus, but also the carbon trading revenue. With the gradual increase of carbon trading price, the carbon trading revenue will become an important asset of enterprises. The distribution of emission reduction revenue will become an important issue for construction enterprises. Jiang et al. (2019) [11] considered cap-and-trade, respectively, established the emission reduction revenue distribution model of construction supply chain under the centralized and decentralized models, and obtained the optimal distribution proportion. Most of the existing studies on fairness concerns in the construction industry do not consider cap-and-trade. Jiang and Yuan (2019) [6] described fairness concern based on the Nash bargaining game, respectively, considering three situations: fairness concern of the subcontractor, the general contractor, and both parties. They constructed the game model of competition and cooperation between a general contractor and a subcontractor and obtained the optimal profit distribution ratio and the optimal emission reduction of both parties. The amount of money involved in the construction industry is too much, and in most practical cases, there is a big gap between the position and ability of the general contractor and the subcontractor, which is easy to cause the occurrence of fairness concern affecting their cooperation [43]. Because the improvement of emission reduction technology in the construction industry needs to invest a lot of cost, the fairness concern behavior is more likely to occur. Therefore, research on the sensitivity of fairness concern and its impact on decisions of all parties will be an important part of whether the construction industry can reduce emissions scientifically.

2.3. Supply Chain Revenue Distribution and Reduction Strategies under Different Power Structure. The decision of enterprises will vary with the change of power structure [44]. Studying the different power structure patterns formed by two adjacent supply chain members can better grasp the basic rules of power structure, then promote the interaction of the whole supply chain, and finally realize the analysis and improvement of the whole supply chain network [45]. Supply chain members often play Stackelberg game and Vertical Nash game. Ertek and Griffin (2002) [46] analyzed the influence of decentralized model on pricing, market price sensitivity, and supply chain profit when the supply chain has bargaining power, and the buyer has bargaining power. Zhang et al. (2012) [47] also investigated the pricing strategies of dual-channel supply chain and formulated

manufacturer Stackelberg, retailer Stackelberg, and Vertical Nash model. Research showed that although all members of the supply chain have the motivation to be the leader, any decentralized model is not the best for the whole supply chain. Vertical Nash model is a kind of equilibrium state for supply chain members, but it will lead to "prisoner's dilemma," and consumers could get the most benefit from it. Ghosh et al. (2012) [48] analyzed the low-carbon level and pricing strategy under three decentralized models: retailer Stackelberg, manufacturer Stackelberg, and Vertical Nash. Shi et al. (2013) [49] studied the effect of decentralized model and demand on the performance of supply chain and pointed out that the effect of decentralized model on supply chain efficiency depends on the expected demand and demand shock. Gao et al. (2016) [18] studied the influence of different decentralized models on the optimal decision and performance of closed-loop supply chain. Research showed that the profit of retailers and manufacturers will increase as the dominant power shifts from manufacturer to retailer when the demand for recovery becomes larger. Teng et al. (2019) [50] analyzed the profit distribution among design, construction contractors, owners, and BIM consultants with the method of cooperative game theory and established a modified Shapley value model including four risk factors of operation risk, economic risk, profit risk, and market risk.

In the existing research on the construction industry under cap-and-trade policy, most of them are limited to the measurement of carbon footprint, and the research on decisions of construction supply chain is less. Moreover, the research on decisions of supply chain enterprises focuses on single mode research and lacks the comparison of multiple game models. On the other hand, with fairness concern as an unavoidable irrational behavior, the research on this behavior in the construction industry mostly lies in the progress and cost research and lacks research on emission reduction decision. Based on this situation, this paper considers cap-and-trade policy in the macro level, while it considers fairness concern of participants in the micro level and integrates them to study the emission reduction and profit distribution decision of construction supply chain.

2.4. Comparative Analysis of Literature Related to the Study. This section makes comparative analysis of literature related to the study and summarizes the benefits of the literature to this study in Table 1.

3. Model Description and Assumptions

In the section, firstly, the paper describes the research problems in detail and clarifies the specific research content. Then, it assumes the relevant parameters and notations required for the study.

3.1. Problem Description. This paper studies the optimal emission reduction and revenue distribution strategies of construction supply chain consists of a general contractor and a subcontractor. This paper considers that the subcontractor has fairness concern, and the general contractor

TABLE 1: Comparative analysis of research streams.

Research streams involved in literature review	Literature	Content
Construction supply chain emission reduction strategy under cap-and-trade	Begg [23], Ekins [24], Stern [25]	Introduce cap-and-trade policy
	Zhou et al. [26], Rehan and Nehdi [10], Shao et al. [27]	Study the carbon trading system and the measurement of the construction carbon emissions under cap-and-trade
	Wang et al. [21], Sabzevar et al. [28], Xu et al. [29], Yang et al. [51], Xu et al. [30], Wang et al. [31], Qu et al. [19]	Study carbon emission reduction decision and profit distribution of supply chains in various industries
The revenue distribution strategy of construction supply chain considering fairness concern	Love et al. [32], Yang et al. [33], Wen et al. [34]	Study the revenue distribution of construction supply chain without fairness concern
	Fehr and Schmidt [35], Ho et al. [36], An et al. [37], Cui et al. [38], Loch et al. [39], Zhou and Zhang [40], Zhang et al. [42], Jian et al. [20, 41]	Study the revenue distribution of supply chain without fairness concern
Supply chain revenue distribution and reduction strategies under different power structure	Jiang et al. [6], Jiang and Yuan. [6], Liu et al. [43]	Study the distribution of emission reduction revenue for construction enterprises
	Pasquinelli [44], El-Ansary and Stern [45], Ertek and Griffin [46], Zhang et al. [47], Ghosh et al. [48], Shi et al. [49], Gao et al. [18], Teng et al. [50]	Study decision optimization of supply chain with different power structures

and the subcontractor face the regulation of cap-and-trade. The owner signs a fixed total price plus emission reduction bonus contract with the general contractor. At the same time, the general contractor also signs a fixed total price plus emission reduction bonus contract with the subcontractor. The decision environment of this paper is as follows:

- (1) Under the dual incentives of cap-and-trade policy and the owner’s emission reduction bonus, the general contractor and the subcontractor will increase the emission reduction investment (such as research and development of emission reduction technology and use of low-carbon materials and equipment), but the cost of emission reduction will increase with the increase of emission reduction. Without loss of generality, the emission reduction cost of the general contractor/subcontractor is $t_i e_i^2$ [28, 51], $i = 1, 2$, which shows that the cost of emission reduction is a quadratic function of the emission reduction.
- (2) Under the cap-and-trade policy, the government adopts the “benchmark emission rate method” to design the cap; that is, the government formulates the cap based on the carbon emission level of advanced unit construction area in the construction industry [52]. When the enterprise exceeds the cap, it needs to purchase additional carbon emission rights from the carbon trading market. On the contrary, if the carbon emission of the enterprise after the completion of the construction is less than the cap, the enterprise can sell the remaining rights to obtain revenue. This paper assumes that the carbon emission per unit building area is jointly undertaken by the general contractor and the subcontractor, and the general contractor is responsible for carbon trading. The total amount of carbon trading per unit building area is

$E_0 = e_0 - e_1 - e_2 - e_{cap}$. $E_0 > 0$ indicates that the unit carbon emission of the construction project exceeds the cap, and the carbon rights need to be purchased, while $E_0 < 0$ indicates that the carbon rights is still surplus after the completion of the construction; it can be sold. The cost/benefit of carbon trading is skE_0 .

Under the decision environment of cap-and-trade policy, this paper investigates the optimal strategies of different power structure models without fairness concern. Then, the paper takes fairness concern into account in construction supply chain to investigate the optimal strategies of different power structure models with fairness concern.

3.2. *Assumptions.* Throughout this paper, we use the parameters and notations presented in Table 2.

In addition, the assumptions in this paper are as follows:

- (1) $t_2 > t_1 > 2t_1 - t_2 > 0$, t_i reflects the emission reduction efficiency of enterprises. In real life, the ability of the general contractor is often higher than that of the subcontractor, so the emission reduction efficiency of the general contractor is higher than that of the subcontractor. This assumption is in line with the reality.
- (2) $P_1 > P_2$, the general contractor’s fixed price portion is higher than that of the subcontractor. This is consistent with what is true in practice.

Based on the above model description and assumption, the fixed total price plus emission reduction bonus contract signed by the owner and the general contractor is as follows:

$$H_1 = P_1 + \mu sE. \tag{1}$$

H_1 represents the contract price signed by the owner and the general contractor. μsE indicates that the bonus amount

TABLE 2: Notation of parameters and variables.

Decision variables	Description
λ	Distribution ratio of emission reduction revenue
e_i	Unit carbon emission reduction of the general contractor and the subcontractor, respectively, $i = 1, 2$. The values 1 and 2 represent the general contractor and the subcontractor respectively
Parameters	
P_i	Fixed price portion of enterprise i , $i = 1, 2$
μ	Carbon emission bonus coefficient obtained by the owner.
s	Construction area
c_{1i}	Construction cost without emission reduction investment, $i = 1, 2$
c_1	Total cost of construction supply chain without emission reduction investment, $c_1 = c_{11} + c_{12}$
e_0	Initial unit carbon emissions of the general contractor and the subcontractor
e_{cap}	Carbon emission cap
E_0	Carbon trading volume in the carbon trading market
E	Total emission reduction of construction supply chain, $E = e_1 + e_2$
t_i	Carbon emission reduction cost coefficient of the general contractor and the subcontractor, $i = 1, 2$
k	Unit carbon emission price in the carbon trading market
γ	The subcontractor's fairness concern coefficient, reflecting the subcontractor's emphasis on fairness
A	Emission reduction revenue per unit of emission reduction, $A = k + \mu$
B	Minimum emission reduction without additional purchase of carbon emission rights, $B = e_0 - e_{\text{cap}}$

of the owner is linearly related to the carbon emission reduction of the building.

Similarly, in order to obtain more emission reduction incentives, the general contractor will also encourage the subcontractor to increase emission reduction efforts. And cap-and-trade policy is constrained to the general contractor, and the general contractor and the subcontractor must consider the mandatory constraint of cap-and-trade policy. Therefore, the general contractor also signed a fixed price plus bonus contract with the subcontractor. The contract between the general contractor and the subcontractor is as follows:

$$H_2 = P_2 + (1 - \lambda)f. \quad (2)$$

$f = \mu s(e_1 + e_2) - skE_0 = s(AE - Bk)$. f is the emission reduction revenue, i.e., the emission reduction bonus and carbon trading revenue. $f = \mu s(e_1 + e_2) - skE_0 = \mu sE - skE_0$, $f < \mu sE$, $(1 - \lambda)f < \mu sE$, $P_1 > P_2$, so $H_1 > H_2$.

The profit function of the general contractor:

$$\pi_1(\lambda, e_1) = P_1 - P_2 + \lambda f - st_1 e_1^2 - c_{11}. \quad (3)$$

The profit function of the subcontractor:

$$\pi_2(e_2) = P_2 + (1 - \lambda)f - st_2 e_2^2 - c_{12}. \quad (4)$$

The profit function of construction supply chain:

$$\pi_{\text{sc}}(e_1, e_2) = \pi_1(\lambda, e_1) + \pi_2(\lambda, e_2) = P_1 + f - st_1 e_1^2 - st_2 e_2^2 - c_1. \quad (5)$$

4. Model without Fairness Concern under Cap-and-Trade

In order to reduce carbon emission, China must control the carbon emissions of the construction industry effectively. In

this paper, cap-and-trade is introduced into the construction industry. The implementation of cap-and-trade by the government will affect construction supply chain enterprises to make strategies. First, the centralized model is constructed to study the optimal emission reduction strategy of both parties without fairness concern. Secondly, the three decentralized models are studied, that is, Stackelberg models, one party dominated, and Vertical Nash model, two parties balanced, and the optimal strategies of both parties under three decentralized models are obtained.

4.1. Centralized Model. In this section, this paper studies the emission reduction strategy of construction supply chain under the centralized model (CE), which is actually a "super organization model." In CE model, the general contractor and the subcontractor are regarded as a whole to make decisions, and the optimal emission reduction strategies of both parties are decided by maximizing the profits of construction supply chain, and the emission reduction revenue is no longer distributed. At this time, the decision problems faced by both parties are as follows:

$$\begin{aligned} \max \pi_{\text{sc}}(e_1, e_2) \\ \text{s.t. } e_0 - e_1 - e_2 = E_0 + e_{\text{cap}}. \end{aligned} \quad (6)$$

Proposition 1. In CE model, the optimal emission reduction of the general contractor is

$$e_1^{\text{CE-n}} = \frac{A}{2t_1}. \quad (7)$$

The optimal emission reduction of the subcontractor is

$$e_2^{\text{CE-n}} = \frac{A}{2t_2}. \quad (8)$$

Proof. From equations (3) and (4), we get $(\partial^2 \pi_{sc}(e_1, e_2)/\partial e_1^2) = -2st_1 < 0$ and $(\partial^2 \pi_{sc}(e_1, e_2)/\partial e_2^2) = -2st_2 < 0$. Then, $\begin{vmatrix} -2st_1 & 0 \\ 0 & -2st_2 \end{vmatrix} > 0$; that is, $\pi_{sc}(e_1, e_2)$ is a joint concave in e_1 and e_2 . From equation (5), we get $(\partial \pi_{sc}(e_1, e_2)/\partial e_1) = s(A - 2t_1 e_1)$ and $(\partial \pi_{sc}(e_1, e_2)/\partial e_2) = s(A - 2t_2 e_2)$. Let $(\partial \pi_{sc}(e_1, e_2)/\partial e_1) = (\partial \pi_{sc}(e_1, e_2)/\partial e_2) = 0$; we can get $e_1^{CE-n} = (A/2t_1)$ and $e_2^{CE-n} = (A/2t_2)$. This completes the proof.

In order to better distinguish different situations, the subscripts 1, 2, sc represent the general contractor, the subcontractor, and construction supply chain, respectively. As to the superscript, the former represents different models, and the latter n represents the case without fairness concern, f represents considering fairness concern. For example, e_1^{CE-n} represents the emission reduction of the general contractor without fairness concern in CE model. Proposition 1 shows that there is a unique optimal solution to maximize the profits of construction supply chain without fairness concern in CE model. The emission reduction of both parties is directly proportional to the carbon trading price and emission reduction incentive coefficient, and inversely proportional to their own emission reduction cost coefficient. \square

4.2. Decentralized Models. In this section, we study the optimal emission reduction and revenue distribution strategies of construction supply chain under the different decentralized models. In different decentralized models, the power of both sides is different, and the way of game is also different. In order to study different decentralized models of construction supply chain systematically, the paper discusses the models with three decentralized models, which are the General Contractor Stackelberg model, the Subcontractor Stackelberg model, and the Vertical Nash model.

4.2.1. The General Contractor Stackelberg Model. The General Contractor Stackelberg (GS) model represents the common situation of the construction industry, the power of the general contractor is higher than that of the subcontractor, and the decision behavior of the subcontractor depends on the general contractor.

In GS model, the general contractor is the leader, and the subcontractor is the follower. The general contractor and the subcontractor make their decisions in sequence. The order of events is as follows. Firstly, the general contractor makes decisions according to the comprehensive conditions to obtain the optimal distribution ratio of emission reduction revenue and the optimal unit carbon emission reduction of the general contractor (λ, e_1) . Then, the subcontractor shall optimize the decision to obtain the optimal unit emission reduction (e_2) according to the optimal distribution ratio and the optimal unit carbon emission of the general contractor.

At this time, the general contractor's decision problem is

$$\begin{aligned} & \max \pi_1^{GS-n}(\lambda, e_1), \\ & \text{s.t. } e_0 - e_1 - e_2 = E_0 + e_{cap}. \end{aligned} \quad (9)$$

The subcontractor's decision problem is

$$\max \pi_2^{GS-n}(e_2). \quad (10)$$

Proposition 2. In GS model, the optimal emission reduction of the general contractor is

$$e_1^{GS-n} = \frac{A^2 - 2Bkt_2}{2A(2t_1 - t_2)}. \quad (11)$$

The optimal emission reduction of the subcontractor is

$$e_2^{GS-n} = \frac{A(1 - \lambda)}{2t_2} = \frac{A^2(t_1 - t_2) + 2Bkt_1 t_2}{2At_2(2t_1 - t_2)}. \quad (12)$$

The optimal distribution ratio of emission reduction revenue is

$$\lambda^{GS-n} = \frac{t_1(A^2 - 2Bkt_2)}{A^2(2t_1 - t_2)}. \quad (13)$$

Proof: From equation (4), we get $(\partial \pi_2(\lambda, e_2)/\partial e_2) = s[A(1 - \lambda) - 2t_2 e_2]$. Let $(\partial \pi_2(\lambda, e_2)/\partial e_2) = 0$; we can get $e_2 = (A(1 - \lambda)/2t_2)$. Replace e_2 with equation (3); we get $(\partial \pi_1(\lambda, e_1)/\partial e_1) = s(A\lambda - 2t_1 e_1)$ and $(\partial \pi_1(\lambda, e_1)/\partial \lambda) = s[(A^2/t_2)((1/2) - \lambda) + Ae_1 - Bk]$. Because $(\partial^2 \pi_1(\lambda, e_1)/\partial e_1^2) = -2st_1 < 0$, $(\partial^2 \pi_1(\lambda, e_1)/\partial \lambda^2) = -(sA^2/t_2)$, $(\partial^2 \pi_1(\lambda, e_1)/\partial e_1 \partial \lambda) = (\partial^2 \pi_1(\lambda, e_1)/\partial \lambda \partial e_1) = sA$, when $2t_1 - t_2 > 0$, $\begin{vmatrix} -2st_1 & sA \\ sA & -(sA^2/t_2) \end{vmatrix} > 0$. Let $(\partial \pi_1(\lambda, e_1)/\partial e_1) = (\partial \pi_1(\lambda, e_1)/\partial \lambda) = 0$; we can get $e_1^{GS-n} = ((A^2 - 2Bkt_2)/2A(2t_1 - t_2))$ and $\lambda^{GS-n} = (t_1(A^2 - 2Bkt_2)/A^2(2t_1 - t_2))$. Replace λ^{GS-n} with e_2 ; we can get $e_2^{GS-n} = (A(1 - \lambda)/2t_2) = ((A^2(t_1 - t_2) + 2Bkt_1 t_2)/2At_2(2t_1 - t_2))$. This completes the proof.

Proposition 2 shows that the GS model has a unique optimal strategy to maximize the profits of construction supply chain without fairness concern. Both sides should take into account each other's reactions when making decisions. \square

4.2.2. The Subcontractor Stackelberg Model. This section studies the optimal decision of construction supply chain enterprises under the Subcontractor Stackelberg model (SS). In SS model, the subcontractor has strong professional ability. Although the general contractor has advanced economic strength and management level, it lacks a certain professional ability and relies heavily on the subcontractor. At this time, the subcontractor, as a leader, is in a strong position. The decision sequence is as follows. First, the subcontractor makes decisions to obtain the optimal emission reduction (e_2) . Then, the general contractor shall optimize decisions to obtain the optimal distribution ratio of emission reduction revenue and the optimal unit carbon emission reduction (λ, e_1) according to the optimal emission reduction (e_2) .

At this time, the subcontractor's decision problem is

$$\max \pi_2(e_2). \quad (14)$$

The general contractor's decision problem is

$$\begin{aligned} & \max \pi_1(\lambda, e_1), \\ & \text{s.t. } e_0 - e_1 - e_2 = E_0 + e_{\text{cap}}. \end{aligned} \quad (15)$$

Proposition 3. In SS model, the optimal emission reduction of the general contractor is

$$e_1^{\text{SS}-n} = \frac{Bk}{A}. \quad (16)$$

The optimal emission reduction of the subcontractor is

$$e_2^{\text{SS}-n} = 0. \quad (17)$$

The optimal distribution ratio of emission reduction revenue is

$$\lambda^{\text{SS}-n} = 2Bkt_1. \quad (18)$$

Proof: From equation (3), we get $(\partial\pi_1(\lambda, e_1)/\partial e_1) = s(A\lambda - 2t_1e_1)$ and $(\partial\pi_1(\lambda, e_1)/\partial\lambda) = s[A(e_1 + e_2) - Bk]$. Let $(\partial\pi_1(\lambda, e_1)/\partial e_1) = (\partial\pi_1(\lambda, e_1)/\partial\lambda) = 0$; we can get $e_1 = (Bk/A) - e_2$ and $\lambda = (-2t_1(Ae_2 - Bk)/A^2)$. Replace e_1 and λ with equation (4); we get $(\partial\pi_2(\lambda, e_2)/\partial e_2) = -2st_2e_2$. Let $(\partial\pi_2(\lambda, e_2)/\partial e_2) = 0$; we can get $e_2^{\text{SS}-n} = 0$. Replace $e_2^{\text{SS}-n}$ with e_1 and λ ; we can get $e_1^{\text{SS}-n} = (Bk/A)$ and $\lambda^{\text{SS}-n} = 2Bkt_1$. This completes the proof.

Proposition 3 shows that the distribution ratio of emission reduction revenue in SS model is directly proportional to the emission reduction cost coefficient of the general contractor and has nothing to do with the emission reduction cost coefficient of the subcontractor when fairness concern is not taken into account. When the subcontractor is the leader, he will not invest in emission reduction, and all emission reduction tasks shall be undertaken by the general contractor. The optimal emission reduction of the general contractor is independent of its own emission reduction cost coefficient. At this time, the optimal total emission reduction of construction supply chain is Bk/A . Bk indicates the cost of carbon purchase without carbon reduction investment. \square

4.2.3. The Vertical Nash Model. The Vertical Nash (VN) model represents a kind of the general contractor and the subcontractor with little difference in capability and position, neither of which can dominate the market. The general contractor and the subcontractor make their decisions simultaneously. The order of events is as follows. The general contractor determines the response function of distribution ratio and emission reduction to maximize profit, and the subcontractor determines to maximize profit.

At this time, the general contractor's decision problem is

$$\begin{aligned} & \max \pi_1^{\text{VN}-n}(\lambda, e_1), \\ & \text{s.t. } e_0 - e_1 - e_2 = E_0 + e_{\text{cap}}. \end{aligned} \quad (19)$$

The subcontractor's decision problem is

$$\max \pi_2^{\text{VN}-n}(e_2). \quad (20)$$

Proposition 4. In VN model, the optimal emission reduction of the general contractor is

$$e_1^{\text{VN}-n} = \frac{2Bkt_2 - A^2}{2A(t_2 - t_1)}. \quad (21)$$

The optimal emission reduction of the subcontractor is

$$e_2^{\text{VN}-n} = \frac{A^2 - 2Bkt_1}{2A(t_2 - t_1)}. \quad (22)$$

The optimal distribution ratio of emission reduction revenue is

$$\lambda^{\text{VN}-n} = \frac{t_1(2Bkt_2 - A^2)}{A^2(t_2 - t_1)}. \quad (23)$$

Proof: From equation (4), we get $(\partial\pi_2(e_2)/\partial e_2) = s[A(1 - \lambda) - 2t_2e_2]$, and from equation (3), we get $(\partial\pi_1(\lambda, e_1)/\partial e_1) = s(A\lambda - 2t_1e_1)$ and $(\partial\pi_1(\lambda, e_1)/\partial\lambda) = s[A(e_1 + e_2) - Bk]$; let $(\partial\pi_1(\lambda, e_1)/\partial e_1) = (\partial\pi_1(\lambda, e_1)/\partial\lambda) = (\partial\pi_2(e_2)/\partial e_2) = 0$; we can get $e_1^{\text{VN}-n} = ((2Bkt_2 - A^2)/2A(t_2 - t_1))$, $e_2^{\text{VN}-n} = ((A^2 - 2Bkt_1)/2A(t_2 - t_1))$ and $\lambda^{\text{VN}-n} = (t_1(2Bkt_2 - A^2)/A^2(t_2 - t_1))$. This completes the proof.

Proposition 4 indicates the optimal emission reduction and emission reduction revenue distribution ratio strategies of construction supply chain in VN model without fairness concern. At this time, the total emission reduction of construction supply chain is Bk/A , which shows that the total emission reduction in VN model is not related to the emission reduction cost coefficient of both parties, but only related to the carbon trading price and emission reduction incentive coefficient. \square

4.3. Comparative Analysis

Proposition 5. (a) $e_1^{\text{CE}-n} > e_1^{\text{GS}-n} > e_1^{\text{SS}-n} > e_1^{\text{VN}-n}$;

$$(b) e_2^{\text{VN}-n} > e_2^{\text{CE}-n} > e_2^{\text{GS}-n} > e_2^{\text{SS}-n};$$

$$(c) E^{\text{CE}-n} > E^{\text{GS}-n} > E^{\text{SS}-n} = E^{\text{VN}-n};$$

Proof:

$$(a) 2t_1 > t_2 > t_1 > 2t_1 - t_2 > 0, \quad \text{we can get}$$

$$\begin{aligned} & e_1^{\text{CE}-n} - e_1^{\text{GS}-n} = (A/2t_1) - (A/2(2t_1 - t_2)) \\ &) + (2Bkt_2/2A(2t_1 - t_2)) > 0, \text{ that is, } e_1^{\text{CE}-n} > e_1^{\text{GS}-n}. \\ & A^2 > 2Bkt_2; \text{ we can get } e_1^{\text{GS}-n} - e_1^{\text{SS}-n} = \\ & ((A^2/2Bk)/(2t_1 - t_2)) - (t_2/(2t_1 - t_2)) > 0, \text{ that is, } \\ & e_1^{\text{GS}-n} > e_1^{\text{SS}-n}. \text{ So } e_1^{\text{CE}-n} > e_1^{\text{GS}-n} > e_1^{\text{SS}-n} > e_1^{\text{VN}-n}. \end{aligned}$$

$$(b) A^2 > 2Bkt_2, \quad \text{we can get}$$

$$e_2^{\text{VN}-n} - e_2^{\text{CE}-n} = (t_1(A^2 - 2Bkt_2)/4At_2(t_2 - t_1)) > 0,$$

that is, $e_2^{\text{VN}-n} > e_2^{\text{CE}-n}$. $e_2^{\text{CE}-n} - e_2^{\text{GS}-n} = (t_1(A^2 - 2Bkt_2)/2At_2(2t_1 - t_2)) > 0$, that is, $e_2^{\text{CE}-n} > e_2^{\text{GS}-n} > 0$, so $e_2^{\text{VN}-n} > e_2^{\text{CE}-n} > e_2^{\text{GS}-n} > e_2^{\text{SS}-n}$.

$$(c) E^{\text{SS}-n} = E^{\text{VN}-n} = (Bk/A),$$

$$E^{\text{CE}-n} = (A(t_1 + t_2)/2t_1t_2),$$

$$E^{\text{GS}-n} = ((A^2t_1 + 2Bkt_2(t_1 - t_2))/2At_2(2t_1 - t_2)),$$

$$E^{\text{GS}-n} - E^{\text{VN}-n} = (t_1(A^2 - 2Bkt_2)/2At_2$$

$(2t_1 - t_2) > 0$, so $E^{CE-n} > E^{GS-n} > E^{SS-n} = E^{VN-n}$.
This completes the proof.

In Proposition 5, it can be seen that CE model has the largest total emission reduction and the best emission reduction effect. GS model is second, and SS model and VN model have the same total emission reduction and the worst emission reduction effect. In VN model, the subcontractor undertakes all the emission reduction tasks, and the general contractor will not carry out emission reduction at all. \square

5. Model with Fairness Concern of Subcontractor under Cap-and-Trade

5.1. Portray Fairness reference Point. The key to establish a fairness concern model is to determine the fairness reference point [53]; most researches adopt the F-S model, which takes the profit of the other party as its absolute fairness reference point. When the profit of one party is lower than that of the other party, the utility decreases; otherwise, the utility increases. However, this model only considers the profit gap between the two sides and ignores the efficiency, status, and contribution of both sides. It is an absolute fairness model. In fact, fairness is relative. The status and efficiency of supply chain members will affect the fairness of revenue distribution in supply chain [54]. Nash bargaining game puts forward a balanced revenue distribution scheme from the perspective of the strength and contribution of all stakeholders [55]. In this section, Nash bargaining game solution is taken as the reference point of fairness concern, and then, the fairness of the subcontractor is depicted, which reflects the relative fairness and is more in line with the real environment.

When the subcontractor is concerned about fairness, the utility function of the general contractor is

$$U_1^f(\lambda, e_1) = \pi_1. \quad (24)$$

The utility function of the subcontractor is

$$U_2^f(\lambda, e_2) = \pi_2 + \gamma(\pi_2 - \bar{\pi}_2^f) = (1 + \gamma)\pi_2 - \gamma\bar{\pi}_2^f. \quad (25)$$

In the above formula, $\bar{\pi}_2^f$ refers to the reference point of the subcontractor's fairness concern. The utility function of construction supply chain is

$$U_{sc}^f(e_1, e_2, \lambda) = U_1^f(\lambda, e_1) + U_2^f(\lambda, e_2). \quad (26)$$

According to the definition of Nash bargaining theory, the optimal solution is to maximize the utility product of both parties, that is, to maximize the utility product of the general contractor and the subcontractor [56].

$$\begin{aligned} U_p^f &= U_1^f U_2^f = \pi_1 [(1 + \gamma)\pi_2 - \gamma\bar{\pi}_2^f], \\ \max U_p^f, \\ \text{s.t. } \pi_1 + \pi_2 &= \pi_{sc}, \end{aligned} \quad (27)$$

$$U_1^f, U_2^f > 0.$$

We can obtain $U_p^f = (1 + \gamma)\pi_{sc}\pi_2 - \gamma\pi_{sc}\bar{\pi}_2 - (1 + \gamma)\pi_2^2 + \gamma\bar{\pi}_2\pi_2$, and we take the first derivative and the second derivative with respect to π_2 : $(\partial U_p^f / \partial \pi_2) = (1 + \gamma)\pi_{sc} - 2(1 + \gamma)\pi_2 + \gamma\bar{\pi}_2$ and $(d^2 U_p^f / d^2 \pi_2) = -2(1 + \gamma) < 0$.

U_p^f is a concave function with a maximum value. π_2^* is the optimal value of U_p^f .

$$\frac{\partial U_p^f(\pi_2^*)}{\partial \pi_2} = 0, \quad (28)$$

$$(1 + \gamma)\pi_{sc} - 2(1 + \gamma)\pi_2^* + \gamma\bar{\pi}_2 = 0.$$

According to fixed-point theorem, $\pi_2^* = \bar{\pi}_2$. Therefore, the fairness reference point of the subcontractor is

$$\bar{\pi}_2^f = \frac{1 + \gamma}{2 + \gamma}\pi_{sc}. \quad (29)$$

To sum up, replace $\bar{\pi}_2^f$ with equation (25) and simplify it; we can get the utility function of the subcontractor:

$$U_2^f(e_2) = \pi_2 + \gamma(\pi_2 - \bar{\pi}_2) = \frac{2 + 2\gamma}{2 + \gamma}\pi_2 - \frac{\gamma + \gamma^2}{2 + \gamma}\pi_1. \quad (30)$$

The utility function of construction supply chain is

$$U_{sc}^f(e_1, e_2, \lambda) = \frac{2 - \gamma^2}{2 + \gamma}\pi_1 + \frac{2 + 2\gamma}{2 + \gamma}\pi_2. \quad (31)$$

5.2. Centralized Model. At this point, the centralized model needs to consider fairness concern of the subcontractor. Both sides take the maximization profit of construction supply chain as their goal to make decisions. There is λ in the profit function of construction supply chain, which indicates that both parties are a cooperative alliance, not the same company, so both parties still need to distribute emission reduction revenue.

At this time, the decision problems faced by both parties are

$$\begin{aligned} \max U_{sc}^f(e_1, e_2, \lambda), \\ \text{s.t. } e_0 - e_1 - e_2 &= E_0 + e_{cap}. \end{aligned} \quad (32)$$

Proposition 6. In CE model, when $0 < \gamma < \sqrt{2}$, the optimal emission reduction of the general contractor is

$$e_1^{CE-f} = \frac{2Bkt_2(1 + \gamma)}{A[(2 - \gamma^2)t_1 + 2(1 + \gamma)t_2]}. \quad (33)$$

The optimal emission reduction of the subcontractor is

$$e_2^{CE-f} = \frac{Bk(2 - \gamma^2)t_1}{A[(2 - \gamma^2)t_1 + 2(1 + \gamma)t_2]}. \quad (34)$$

The optimal distribution ratio of emission reduction revenue is

$$\lambda^{\text{CE-f}} = \frac{2(1+\gamma)[2A^2(1+\gamma)t_2 + (2-\gamma^2)(A^2 - 2Bkt_2)t_1]}{A^2\gamma_2(2+\gamma)[(2-\gamma^2)t_1 + 2(1+\gamma)t_2]} \quad \max U_2^f(e_2). \quad (35)$$

Proof:

$$\begin{pmatrix} \frac{\partial^2 U_{sc}^{ce}}{\partial e_1^2} & \frac{\partial^2 U_{sc}^{ce}}{\partial e_1 \partial e_2} & \frac{\partial^2 U_{sc}^{ce}}{\partial e_1 \partial \lambda} \\ \frac{\partial^2 U_{sc}^{ce}}{\partial e_2 \partial e_1} & \frac{\partial^2 U_{sc}^{ce}}{\partial e_2^2} & \frac{\partial^2 U_{sc}^{ce}}{\partial e_2 \partial \lambda} \\ \frac{\partial^2 U_{sc}^{ce}}{\partial \lambda \partial e_1} & \frac{\partial^2 U_{sc}^{ce}}{\partial \lambda \partial e_2} & \frac{\partial^2 U_{sc}^{ce}}{\partial \lambda^2} \end{pmatrix} = \begin{pmatrix} \frac{2s(2-\gamma^2)t_1}{2+\gamma} & 0 & -As\gamma \\ 0 & \frac{4s(1+\gamma)t_2}{2+\gamma} & -As\gamma \\ -As\gamma & -As\gamma & 0 \end{pmatrix}. \quad (36)$$

To have a maximum, then, $2 - \gamma^2 > 0, 0 < \gamma < \sqrt{2}$. $H_{11} < 0, H_{12} > 0, H_{13} < 0$, so there is a unique optimal solution. From equations (24) and (30), we can get $(\partial U_{sc}^f / \partial e_1) = (s[2A(1+\gamma)(1+\lambda) + (2-\gamma^2)(A\lambda - 2e_1 t_1)] / (2+\gamma))$, $(\partial U_{sc}^f / \partial e_2) = (s\{A\lambda(2-\gamma^2) + 2(1+\gamma)[A(1-\lambda) - 2e_2 t_2]\} / (2+\gamma))$ and $(\partial U_{sc}^f / \partial \lambda) = s\gamma_2[Bk - A(e_1 + e_2)]$. Let $(\partial U_{sc}^f / \partial e_1) = (\partial U_{sc}^f / \partial e_2) = (\partial U_{sc}^f / \partial \lambda) = 0$; we can get $e_1^{\text{CE-f}} = (2Bkt_2(1+\gamma)/A[(2-\gamma^2)t_1 + 2(1+\gamma)t_2])$, $e_2^{\text{CE-f}} = (Bk(2-\gamma^2)t_1/A[(2-\gamma^2)t_1 + 2(1+\gamma)t_2])$ and $\lambda^{\text{CE-f}} = ((2(1+\gamma)[2A^2(1+\gamma)t_2 + (2-\gamma^2)(A^2 - 2Bkt_2)t_1] / (A^2\gamma(2+\gamma)[(2-\gamma^2)t_1 + 2(1+\gamma)t_2]))$. This completes the proof.

Proposition 6 shows that when $0 < \gamma < \sqrt{2}$, there is a unique optimal strategy in the centralized model considering fairness concern, which maximizes the utility of construction supply chain. When fairness concern is not taken into account, the decentralized model is equivalent to the centralized model, and the two parties are a whole, so $\lambda^{\text{CE-n}} = 0$; that is, the two parties do not need to distribute emission reduction revenue. However, when considering fairness concern of the subcontractor, both parties need to distribute the emission reduction revenue of both parties even in the centralized model. The total emission reduction of construction supply chain is (Bk/A) , which has nothing to do with the subcontractor's fairness concern. \square

5.3. Decentralized Models. In this section, this paper invested the optimal strategy of construction supply chain considering fairness concern of the subcontractor under cap-and-trade in decentralized models.

5.3.1. The General Contractor Stackelberg Model. At this time, the general contractor's decision problem is

$$\begin{aligned} & \max U_1^f(\lambda, e_1), \\ & \text{s.t. } e_0 - e_1 - e_2 = E_0 + e_{\text{cap}}. \end{aligned} \quad (37)$$

The subcontractor's decision problem is

Proposition 7. In GS model, the optimal emission reduction of the general contractor is

$$e_1^{\text{GS-f}} = \frac{A^2 - 2Bkt_2}{2A[(2+\gamma)t_1 - t_2]}. \quad (39)$$

The optimal emission reduction of the subcontractor is

$$e_2^{\text{GS-f}} = \frac{A}{2t_2} - \frac{(A^2 - 2Bkt_2)(2+\gamma)t_1}{4At_2[(2+\gamma)t_1 - t_2]}. \quad (40)$$

The optimal distribution ratio of emission reduction revenue is

$$\lambda^{\text{GS-f}} = \frac{t_1(A^2 - 2Bkt_2)}{A^2[(2+\gamma)t_1 - t_2]}. \quad (41)$$

Proof: From equation (30), we get $(\partial U_2^f(e_2)/\partial e_2) = ((s(1+\gamma)\{A[2-\lambda(2+\gamma)] - 4e_2 t_2\}) / (2+\gamma))$, so $e_2 = ((A[2 - (2+\gamma)](1-\lambda)) / 4t_2)$.

Replace it with equation (24), because $(\partial^2 U_1^f((\lambda, e_1))/\partial e_1^2) = -2st_1 < 0$, $(\partial^2 U_1^f((\lambda, e_1))/\partial \lambda^2) = -(sA^2(2+\gamma)/2t_2) < 0$, so

$$\begin{vmatrix} -2st_1 & sA \\ sA & \frac{sA^2(2+\gamma)}{2t_2} \end{vmatrix} > 0, \quad (42)$$

$$\frac{\partial \pi_1(\lambda, e_1)}{\partial e_1} = s(A\lambda - 2t_1 e_1),$$

$$\frac{\partial \pi_1(\lambda, e_1)}{\partial \lambda} = \frac{s\{A^2[1 - (2+\gamma)\lambda] + 2(Ae_1 - Bk)t_2\}}{2t_2}.$$

Let $(\partial \pi_1(\lambda, e_1)/\partial e_1) = (\partial \pi_1(\lambda, e_1)/\partial \lambda) = 0$; we can get $e_1^{\text{GS-f}} = ((A^2 - 2Bkt_2)/2A[(2+\gamma)t_1 - t_2])$ and $\lambda^{\text{GS-f}} = (t_1(A^2 - 2Bkt_2)/A^2[(2+\gamma)t_1 - t_2])$. Replace $\lambda^{\text{GS-f}}$ with e_2 ; we can get $e_2^{\text{GS-f}} = (A/2t_2) - (((A^2 - 2Bkt_2)(2+\gamma)t_1) / 4At_2[(2+\gamma)t_1 - t_2])$. This completes the proof.

Proposition 7 shows the optimal strategy of construction supply chain in GS model considering fairness concern of the subcontractor. The proposition shows that the emission reduction and emission reduction revenue distribution ratio are inversely proportional to the fairness concern coefficient of the subcontractor, which shows that fairness concern of the subcontractor will affect the interests of the general contractor and the emission reduction effect. \square

5.3.2. The Subcontractor Stackelberg Model. At this time, the subcontractor's decision problem is

$$\max U_2^f(e_2). \quad (43)$$

The general contractor's decision problem is

$$\begin{aligned} \max U_1^f(\lambda, e_1), \\ \text{s.t. } e_0 - e_1 - e_2 = E_0 + e_{\text{cap}}. \end{aligned} \quad (44)$$

Proposition 8. *In SS model, the optimal emission reduction of the general contractor is*

$$e_1^{\text{SS}-f} = \frac{-2Bkt_1t_2}{A^2(\gamma t_1 - 2t_2)}. \quad (45)$$

The optimal emission reduction of the subcontractor is

$$e_2^{\text{SS}-f} = \frac{Bkt_2\gamma}{A(\gamma t_1 - 2t_2)}. \quad (46)$$

The optimal distribution ratio of emission reduction revenue is

$$\lambda^{\text{SS}-f} = \frac{-4Bkt_1t_2}{A^2(\gamma t_1 - 2t_2)}. \quad (47)$$

Proof: From equation (24), we get $(\partial\pi_1(\lambda, e_1)/\partial e_1) = s(A\lambda - 2t_1e_1)$ and $(\partial\pi_1(\lambda, e_1)/\partial\lambda) = s[A(e_1 + e_2) - Bk]$; let $(\partial\pi_1(\lambda, e_1)/\partial e_1) = (\partial\pi_1(\lambda, e_1)/\partial\lambda) = 0$; we can get $e_1 = (Bk/A) - e_2$ and $\lambda = -2t_1(Ae_2 - Bk)$. Replace e_1 and λ with equation (25); we get $(\partial\pi_2(\lambda, e_2)/\partial e_2) = ((2s(1 + \gamma)[-2Ae_2t_2 + t_1\gamma(Ae_2 - Bk)]/A(2 + \gamma))$. Let $(\partial\pi_2(\lambda, e_2)/\partial e_2) = 0$; we can get $e_2^{\text{SS}-f} = (Bkt_2\gamma/A(\gamma t_1 - 2t_2))$. Replace $e_2^{\text{SS}-f}$ with e_1 and λ ; we can get $e_1^{\text{SS}-f} = (-2Bkt_1t_2/A^2(\gamma t_1 - 2t_2))$ and $\lambda^{\text{SS}-f} = (-4Bkt_1t_2/A^2(\gamma t_1 - 2t_2))$. This completes the proof.

Proposition 8 shows the optimal strategy of construction supply chain in SS model considering fairness concern of the subcontractor. Because $0 < \gamma < \sqrt{2}$, $t_2 > t_1$, so $\gamma t_1 - 2t_2 < 0$, therefore, the subcontractor's emission reduction is negative, which means that when the subcontractor is the leader, it will not only not reduce its own emission, but also make its carbon emission higher than that of the traditional construction process because of fairness concern, which means that the enterprises with fairness concern prefer to lose their own interests to get fair treatment. \square

5.3.3. The Vertical Nash Model. At this time, the general contractor's decision problem is

$$\begin{aligned} \max \pi_1^{\text{VN}-f}(\lambda, e_1), \\ \text{s.t. } e_0 - e_1 - e_2 = E_0 + e_{\text{cap}}. \end{aligned} \quad (48)$$

The subcontractor's decision problem is

$$\max \pi_2^{\text{VN}-f}(e_2). \quad (49)$$

Proposition 9. *In VN model, the optimal emission reduction of the general contractor is*

$$e_1^{\text{VN}-f} = \frac{2Bkt_2 - A^2}{A[2t_2 - (2 + \gamma)t_1]}. \quad (50)$$

The optimal emission reduction of the subcontractor is

$$e_2^{\text{VN}-f} = \frac{A^2 - 2Bk(2 + \gamma)t_1}{A[2t_2 - (2 + \gamma)t_1]}. \quad (51)$$

The optimal distribution ratio of emission reduction revenue is

$$\lambda^{\text{VN}-f} = \frac{2t_1(2Bkt_2 - A^2)}{A^2[2t_2 - (2 + \gamma)t_1]}. \quad (52)$$

Proof: From equation (30), we get $(\partial\pi_2(e_2)/\partial e_2) = ((-s(1 + \gamma)[A\lambda(2 + \gamma) - 2A + 4e_2t_2])/(2 + \gamma))$. From equation (24), we get $(\partial\pi_1(\lambda, e_1)/\partial e_1) = s(A\lambda - 2t_1e_1)$ and $(\partial\pi_1(\lambda, e_1)/\partial\lambda) = s[A(e_1 + e_2) - Bk]$. Let $(\partial\pi_1(\lambda, e_1)/\partial e_1) = (\partial\pi_1(\lambda, e_1)/\partial\lambda) = (\partial\pi_2(e_2)/\partial e_2) = 0$; we can get $e_1^{\text{VN}-f} = ((2Bkt_2 - A^2)/A[2t_2 - (2 + \gamma)t_1])$, $e_2^{\text{VN}-f} = ((A^2 - 2Bk(2 + \gamma)t_1)/A[2t_2 - (2 + \gamma)t_1])$ and $\lambda^{\text{VN}-f} = (2t_1(2Bkt_2 - A^2)/A^2[2t_2 - (2 + \gamma)t_1])$. This completes the proof.

Proposition 9 represents the optimal decision of construction supply chain in VN model considering fairness concern of the subcontractor. The proposition shows that the emission reduction strategy of the general contractor is inversely proportional to the fairness concern coefficient of the subcontractor and its own emission reduction cost coefficient. The distribution ratio of emission reduction revenue is also inversely proportional to the fairness concern coefficient of the subcontractor. \square

6. Numerical Analysis

6.1. The Impact of Cap-and-Trade without Fairness Concern.

In this part, numerical analysis is carried out to analyze the impact of cap-and-trade on the optimal decisions and profit of construction supply chain without fairness concern, and reasonable management suggestions are obtained. Set $e_0 = 9$, $e_{\text{cap}} = 7$, $t_1 = 6$, $t_2 = 8$, $\mu = 15$, $P_1 = 3200000$, $P_2 = 1200000$, $s = 1000$, $C_{11} = 1500000$, $C_{12} = 1000000$, $k \in (10, 25)$.

Figure 1 reflects the impact of cap-and-trade on emission reduction under different decentralized models, that is, the impact of carbon trading price (k) on emission reduction. Figures 1(a)–1(d) reflect the change trend of emission reduction in CE/GS/SS/VN models successively. In CE model, with the increase of k , the emission reductions of both sides are also increasing. In GS model, with the increase of k , the emission reduction of both parties is increasing. However, the emission reduction of the subcontractor will tend to be gentle at last, which shows that, as a follower, the emission reduction benefits of the subcontractor are limited, and their own emission reduction efficiency is not high, and the cost of emission reduction is relatively large, so the emission reduction will be limited. In VN model, the general contractor is completely unwilling to reduce emissions, and all the emission reduction work needs to be undertaken by the subcontractor. Figure 1(e) shows the trend of total emission reduction of construction supply chain with respect to k . Overall, the total emission reduction of construction supply

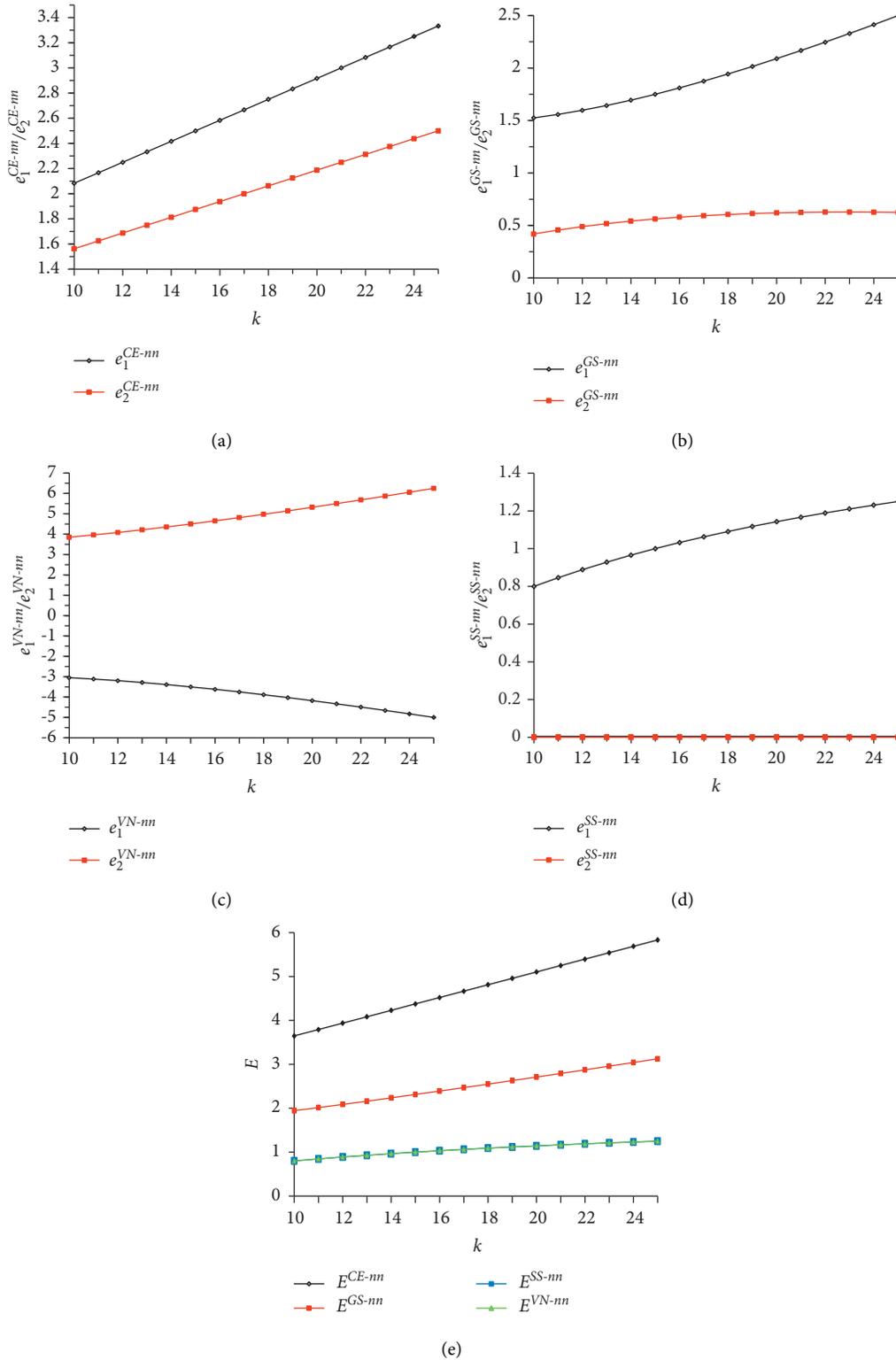


FIGURE 1: Effects of k on emission reduction (a-e).

chain is directly proportional to the carbon trading price. The CE model as the best emission reduction effect, followed by GS model. SS/VN models have the same total emission reduction. Although the total emission reduction increases with the increase of k ; it is still the model with the worst

emission reduction effect. It can be seen that SS/VN models are not suitable for emission reduction of construction supply chain.

Figure 2 shows the impact of cap-and-trade on the distribution ratio of emission reduction revenue (λ). It can

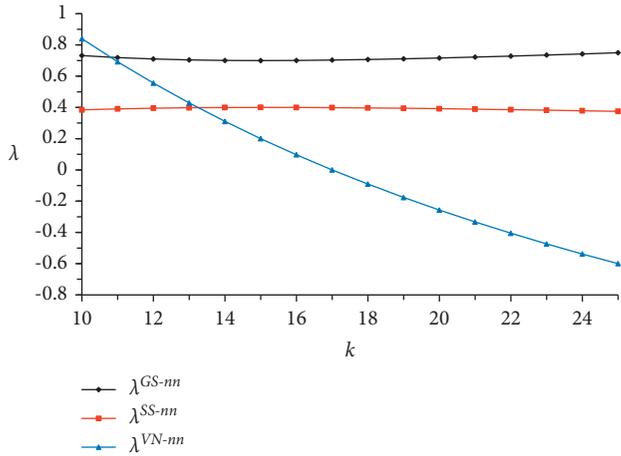


FIGURE 2: Effects of k on emission reduction revenue distribution ratio.

be seen from Figure 2 that when k changes in the range of 10–15, λ fluctuates between 0.70 and 0.75 in GS model, indicating that the general contractor, as a leader, will share most of the emission reduction benefits. In SS model, λ fluctuates between 0.38 and 0.40, which indicates that the subcontractor, as a leader, will also get more emission reduction benefits. In VN model, λ begins to decrease sharply with the increase of k . λ decreased from 0.84–0.6. This shows that the general contractor is very reluctant to invest in emission reduction under this model. Even if the price of carbon trading increases, the general contractor will not only give all the emission reduction benefits to the subcontractor, but also give additional subsidies to the subcontractor.

Figure 3 shows the impact of cap-and-trade on the profit of construction supply chain under different decentralized model. Figures 3(a)–3(c) reflect the trend of profit change of both parties under GS/SS/VN model successively. In GS model, with the increase of k , the maximum profits of both parties are increasing. In SS model, the profit of the subcontractor is fixed value, and the profit of the general contractor is decreasing. In VN model, both parties' profits are declining. The decrease in profits indicates that the emission reduction does not meet the cap, so it is necessary to purchase carbon emission rights in the carbon trading market and pay additional carbon trading costs. With the increase of k , the carbon trading costs increase. Figure 3(d) shows the variation trend of the profit with respect to k under different decentralized models. It can be seen from the figure that, under CE model, the total profit of construction supply chain is the largest, followed by GS model. Under SS model, the maximum profit has nothing to do with k . In VN model, with the increase of k , the total profit of construction supply chain is decreasing.

6.2. The Impact of Fairness Concern with Subcontractor's Fairness Concern. In this part, numerical analysis is carried out to analyze the impact of the subcontractor's fairness concern coefficient (γ) on the optimal decision and maximum profit of construction supply chain under different

decentralized models when cap-and-trade and the subcontractor's fairness concern are considered simultaneously, and reasonable management suggestions are obtained through analysis. Set $\gamma \in [0, 1], k = 20$, and other parameters are consistent with 6.1.

Figure 4 reflects the impact of the subcontractor's fairness concern on emission reduction under different decentralized models considering cap-and-trade and the subcontractor's fairness concern simultaneously. Figures 4(a)–4(d) in turn reflect the change trend of emission reduction in CE/GS/SS/VN model. In CE and SS models, the trend of emission reduction is the same. When $\gamma = 0$, i.e., both parties are fair-and-neutral, the emission reduction of the general contractor is at the lowest point, and that of the subcontractor is at the highest point. With the increase of γ , the emission reduction of the general contractor increases gradually, and the emission reduction of the subcontractor decreases gradually, which indicates that the subcontractor does not want to reduce emissions due to the fairness concern behavior, and with the increase of fairness concern, the subcontractor will be more negative. In GS model, when $\gamma = 0$, the subcontractor's emission reduction is at the lowest point. With the increase of γ , the subcontractor's emission reduction is increasing, and the general contractor's emission reduction is decreasing. When $\gamma = 0.6$, the emission reduction of the two sides is the same. With the increase of γ , the subcontractor's emission reduction will be greater than that of the general contractor. This shows that fairness concern of the subcontractor under this mode will motivate himself to increase emission reduction but will lead to the reduction of emission reduction of the general contractor. In VN model, the total emission reduction of construction supply chain is the same, so the emission reduction of the two sides is completely symmetrical. e_1 is decreasing up to $\gamma = 0.6$, then drastically increases for $\gamma = 0.7$, and then again decreases as from $\gamma = 0.8$. Due to the symmetry of emission reduction, the change of e_2 is opposite to that of e_1 . e_2 is increasing up to $\gamma = 0.6$, then drastically decreases for $\gamma = 0.7$, and then again increases as from $\gamma = 0.8$. Figure 4(e) shows the change trend of total emission reduction of construction supply chain with respect to γ under different decentralized models. It can be seen from the figure that the emission reduction effect of GS model is better, followed by CE model, and the emission reduction amounts of VN and SS models are exactly the same, and the emission reduction effect of these two models is the worst. At the same time, it can also be seen that fairness concern of the subcontractor under GS model will have a negative impact on the emission reduction of construction supply chain.

Figure 5 shows the effect of γ on the distribution ratio of emission reduction revenue (λ). In CE model, when $\lambda > 1$, it means that the general contractor not only obtains all the emission reduction revenue, but also deducts part of the revenue of the subcontractor. However, with the increase of γ , λ will decrease greatly. In GS model, λ decreases from 0.62 to 0.29 with the increase of γ . Due to fairness concern of the subcontractor, the general contractor needs to distribute more emission reduction revenue to him. In SS model, λ

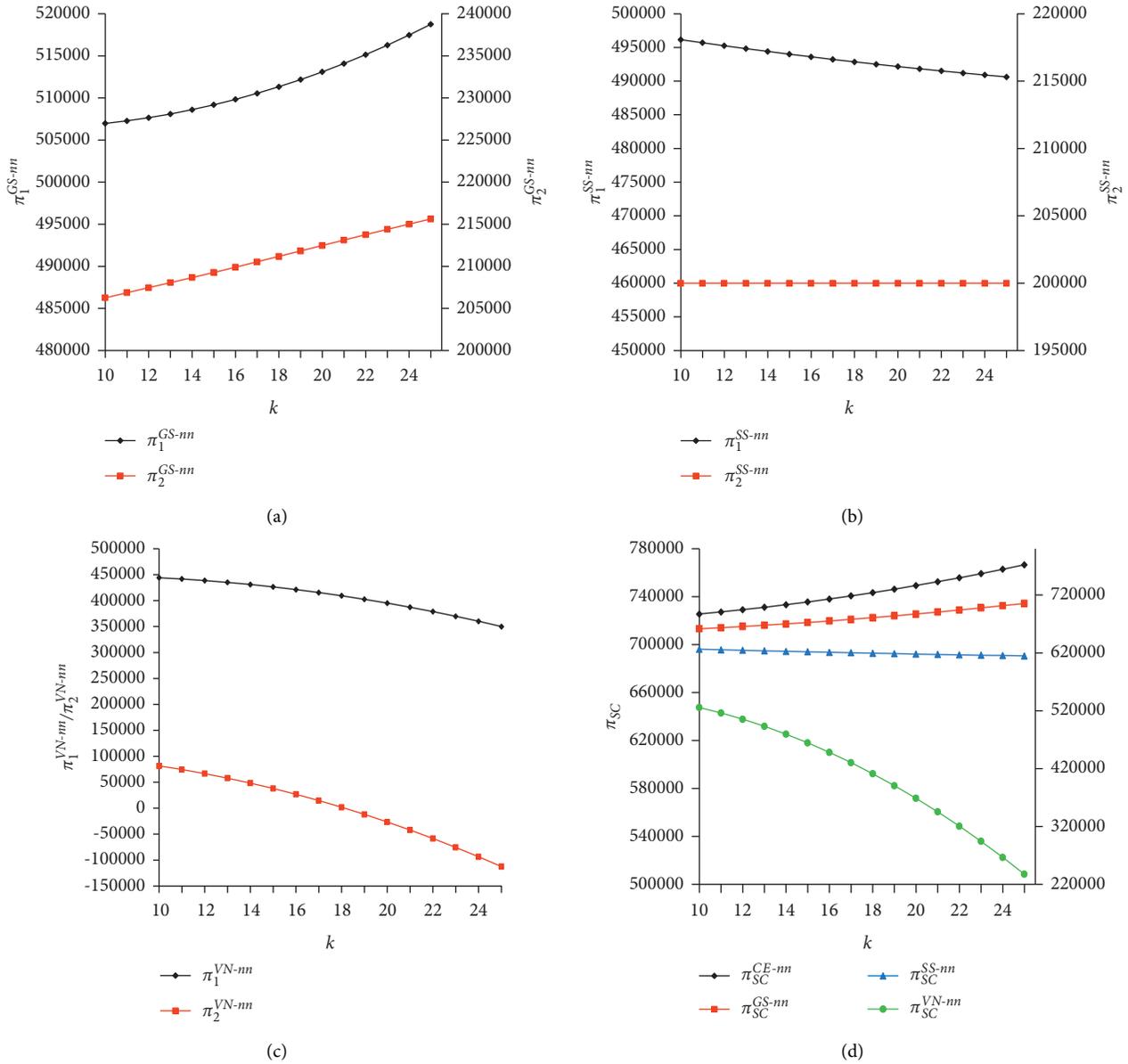


FIGURE 3: Effects of k on profit (a–d).

fluctuates between 0.40 and 0.62. In VN model, λ fluctuates greatly. When $\gamma < 0.7$, the subcontractor can get all the emission reduction bonus and the additional bonus of the general contractor. When $1 > \gamma > 0.7$, the general contractor will get all bonus, and the subcontractor will be fined. Through the analysis of the change of distribution ratio under different decentralized models, we can see that CE and VN models will lead to huge loss of revenue for one side of construction supply chain. In GS model, fairness concern of the subcontractor can gain more revenue for himself, while, in SS model, fairness concern of the subcontractor will damage their own revenue.

Figure 6 shows the influence of γ on the maximum profit of construction supply chain under different decentralized models considering cap-and-trade and the subcontractor's fairness concern. Figures 6(a)–6(d) in turn reflect the change

trend of maximum profits of both parties under CE/GS/SS/VN model. In CE model, the profit of the general contractor decreases to a certain extent with the increase of γ from zero, and the profit of the subcontractor increases to a certain extent. In GS model, the profit of the general contractor is gradually reduced, and the profit of the subcontractor begins to increase to a certain extent and then gradually decreases. In VN model, the profits of both parties will become negative. In real life, this will cause the two parties no longer to cooperate. In SS model, with the increase of γ , the profits of both sides are decreasing. Figure 6(e) shows the change of the total profit of construction supply chain in different decentralized models. The GS model has the largest total profit, followed by CE model. In VN model, the total profit decreases with the increase of γ . In VN model, the total profit is decreasing and even becomes negative. Therefore, when

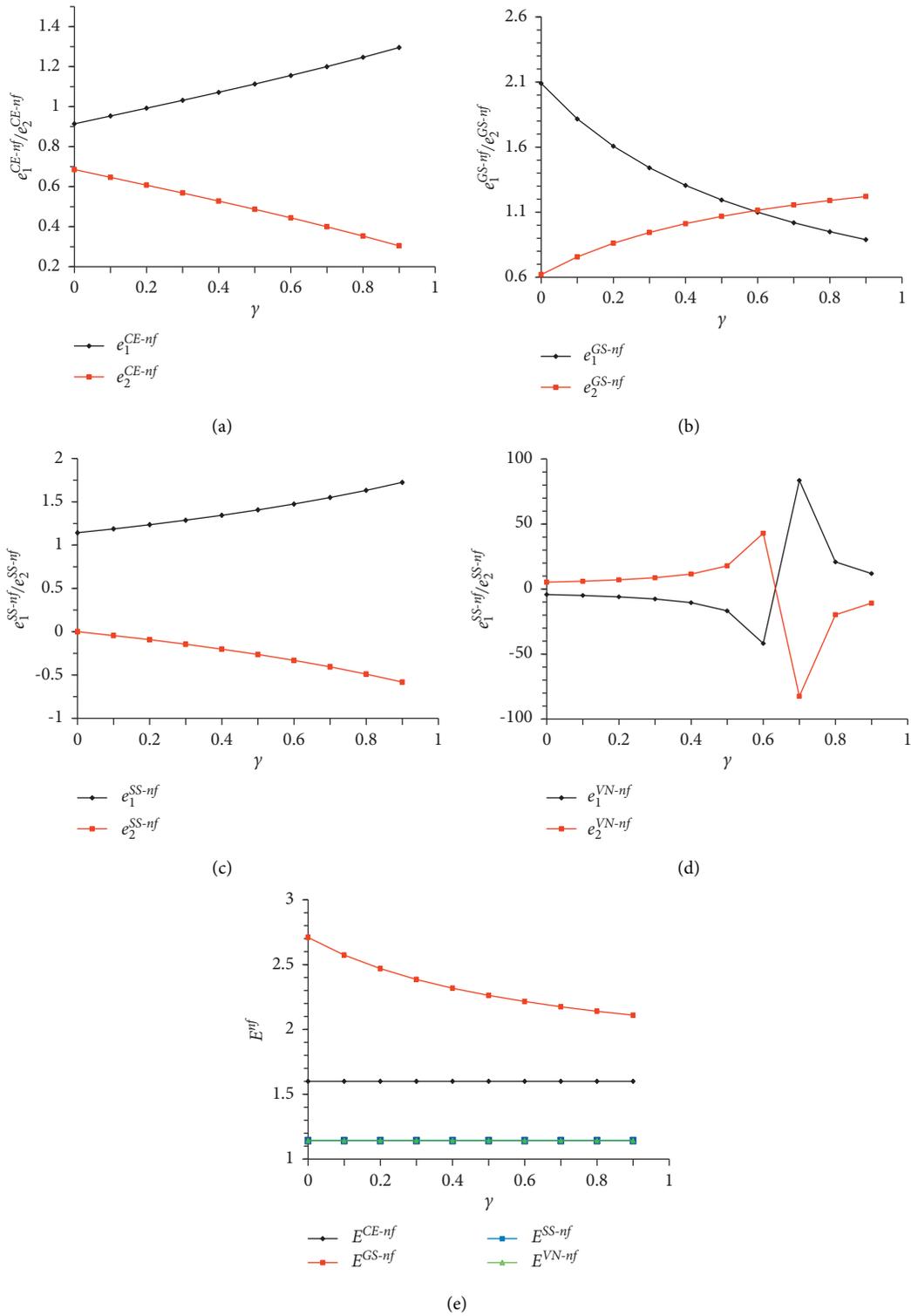


FIGURE 4: Effects of γ on emission reduction (a-e).

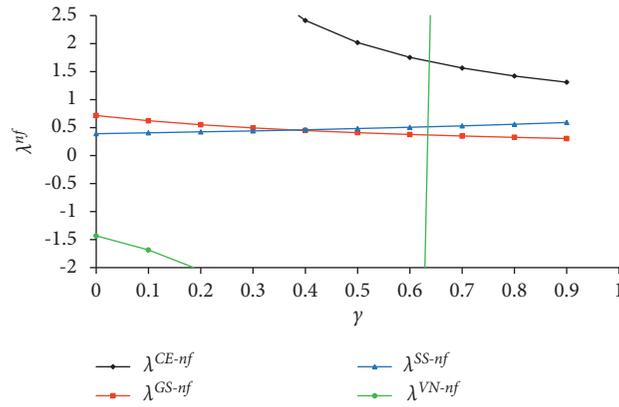


FIGURE 5: Effects of γ on distribution ratio.

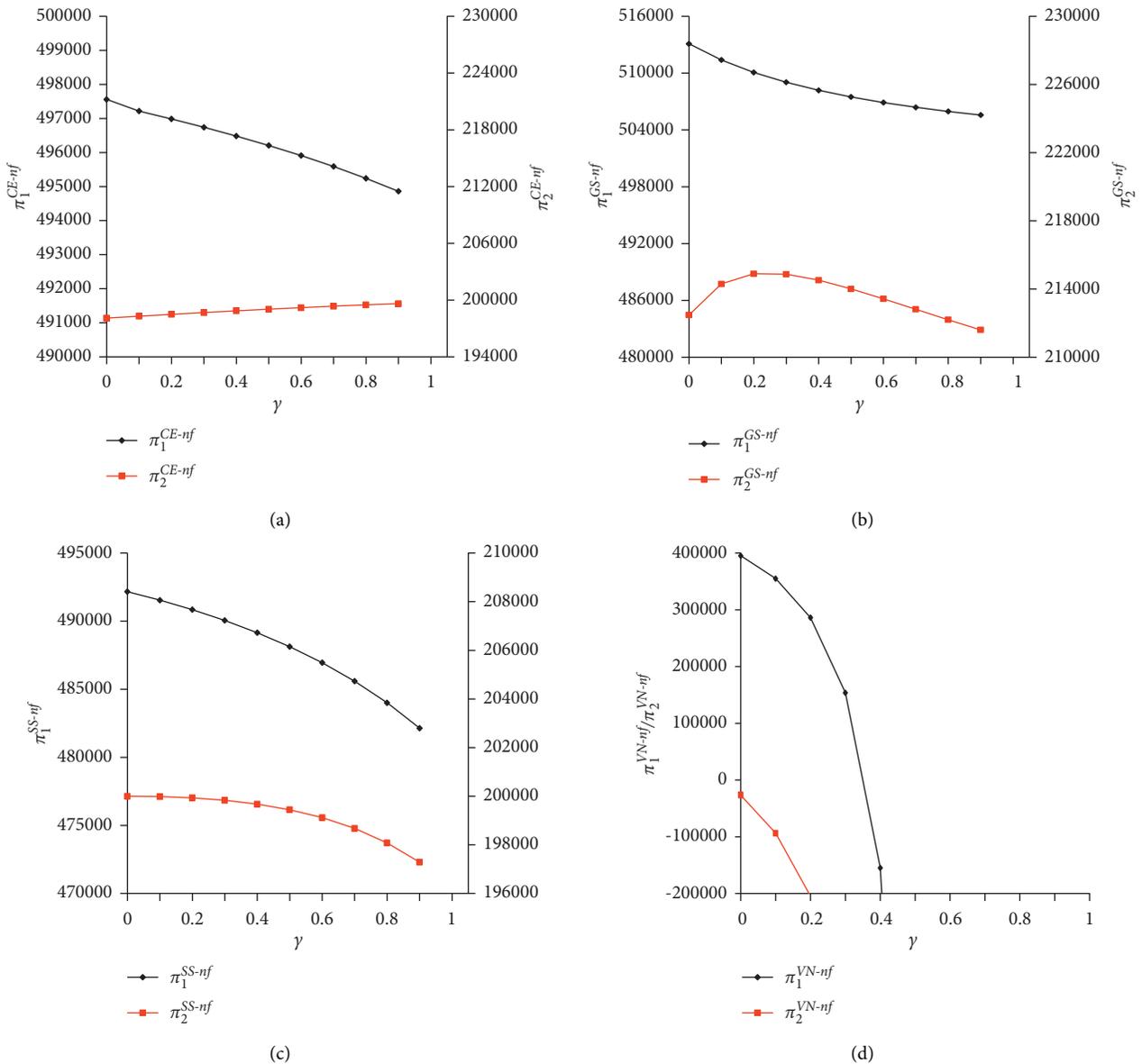


FIGURE 6: Continued.

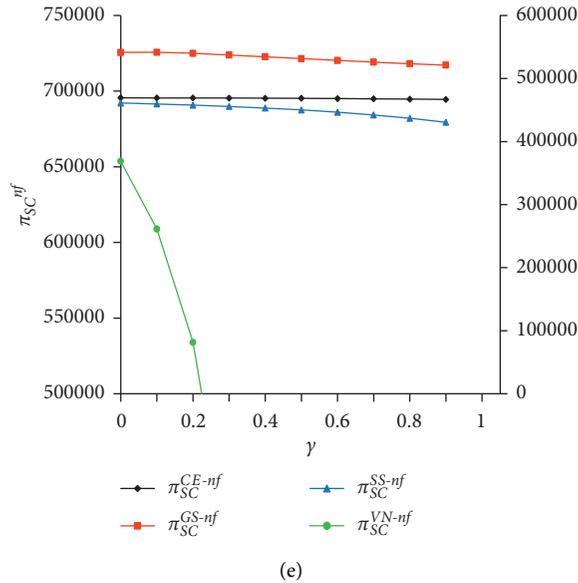


FIGURE 6: Effects of γ on profit (a–e).

the subcontractor has fairness concern, the VN model will cause huge losses to the members of construction supply chain and eventually lead to the breakdown of cooperation.

7. Conclusions and Suggestions for the Further Research

7.1. *Conclusions.* Nowadays, “green development” has become the core concept of social development in China. At the national level, the Chinese government vigorously promotes cap-and-trade policy and makes effort to build a carbon trading market, aiming to change from the traditional economic development model to the ecological and sustainable development model. As the key industry of “green development,” it is the general trend to integrate the construction industry into the supervision of cap-and-trade. The cost/benefit of carbon trading will also become an important asset of construction enterprises. On the social level, people’s awareness of energy conservation and emission reduction has been gradually improved, and more attention has been paid to the issues such as whether the housing environment is beautiful, whether the construction materials are environmentally friendly, and consumers are more willing to buy low-carbon houses. In order to meet the low-carbon requirements of needs and policies, real estate enterprises encourage contractors to reduce carbon emissions and build low-carbon buildings. In the face of the dual incentives of cap-and-trade and emission reduction bonus, how the general contractor and the subcontractor decide the emission reduction amount and the distribution of emission reduction revenue is the key issue that needs urgent decision.

In addition, the purpose of construction supply chain management is to achieve “win-win,” which needs to consider the psychological state of the general contractor and the subcontractor, that is, fairness concern, ensuring the satisfaction of both parties in the process of cooperation. At

the same time, the two sides will have different game processes and decision objectives under different decentralized models, so the optimal emission reduction decisions of the two sides under different decentralized modes are also greatly different.

In response to national green development and low-carbon calling, combined with the psychological characteristics of construction supply chain members, this paper first studies the strategies of emission reduction and revenue distribution of construction supply chain without fairness concern under different decentralized models; then, on this basis, it introduces fairness concern of the subcontractor and studies the different decentralized models considering cap-and-trade and the subcontractor’s fairness concern. At the same time, through numerical analysis, the optimal decisions of different decentralized models are compared, and scientific and reasonable management strategies are obtained. In summary, the conclusions and management suggestions of this paper include the following aspects.

When we do not consider fairness concern and only consider the impact of cap-and-trade on construction supply chain, this study shows that, (i) in terms of emission reduction effect, CE model has the best emission reduction effect, followed by GS model. The emission reduction amount of the two models is close, and the effect of SS/VN model is the worst; (ii) for the decision of emission reduction revenue distribution, the enterprise as a leader will give more benefits to himself, and the distribution ratio fluctuates the most under VN model, and it will also cause serious damage to the interests of one side, which will lead to unreasonable distribution scheme; (iii) for the profit of construction supply chain, the profit of supply chain is the biggest, followed by that of GS model. The profits of the two models are similar, and the profit of construction supply chain is the least in VN model; (iv) the carbon trading price is directly proportional to the emission reduction effect of construction

supply chain, and the increase of the carbon trading price in CE/GS model can increase the profit of construction supply chain, while the profit of VN mode will decrease; (v) the emission reduction efficiency of the general contractor has no impact on the emission reduction of VN model, which is directly proportional to the emission reduction effect of other models.

To sum up, when facing cap-and-trade, construction enterprises should adopt GS model and avoid VN model and SS model. At the same time, both sides should strive to improve their own emission reduction efficiency. Supply chain members should actively cooperate and work together to maximize the profits of construction supply chain, so as to obtain the optimal emission reduction strategy and the optimal profit distribution ratio. Besides, it should appropriately increase the emission reduction incentives for enterprises, which can stimulate enterprises to pay attention to carbon emission problems and formulate reasonable emission reduction strategies.

When considering the impact of cap-and-trade and the subcontractor's fairness concern on construction supply chain, this study shows that, (i) in terms of emission reduction effect, GS model has the best emission reduction effect, followed by CE model and SS/VN model that have the same emission reduction amount, and the two models have the worst emission reduction effect; (ii) in terms of emission reduction revenue distribution strategy, CE/VN models have the largest fluctuation in distribution ratio; (iii) in terms of the profits of construction supply chain, the profits under GS model are the highest, followed by CE model, and VN model is the lowest, even leading to loss, which will lead to the breakdown of the cooperation relationship; (iv) the increase of fairness concern of the subcontractor leads to the reduction of emissions under GS model, thus leading to the decrease of emissions resulting in a decrease in profits. There is no effect on the emission reduction of CE/SS/VN models.

To sum up, when the general contractor is faced with cap-and-trade, and the subcontractor has fairness concern, (i) in practice, it should adopt the decision model with the general contractor as the leader as far as possible, which can not only ensure that its own profits are not damaged, but also ensure the maximum profits of construction supply chain. It is conducive to the stable development of construction supply chain. Besides, it should avoid VN model, it will lead to loss. (ii) Fairness concern of the subcontractor will adversely affect the optimal decisions of supply chain members, which makes the emission reduction effect and profit of construction supply chain the worst and even undermine the cooperation between the two sides. When selecting subcontractors for cooperation, the general contractor shall try to select the subcontractor with lower fairness concern to avoid the loss of profit. Besides, the enterprises should actively take measures to reduce fairness concern, such as enterprises sign the contract price confidentiality clause, which aim to reduce fairness concern of the subcontractor.

Based on the above two cases, we can see that GS model is conducive to the emission reduction and revenue of construction supply chain. VN model should be avoided, because it does not consider the reaction of the other party

and makes decisions from the goal of maximizing its own profits. This will lead to a "double loss" situation, resulting in profit reduction or even loss. GS model is in line with the actual situation of most of the construction industry today. At this time, fairness concern of the subcontractor will damage the profits of construction supply chain. When encountering strong subcontractors, SS model appears, and the general contractor should try to reduce fairness concern of the subcontractor. At the policy level, the conclusions can provide reference for the government to formulate carbon emission limit and adjust carbon trading prices in the construction industry and promote the implementation of emission reduction policies. At the industry level, the conclusions provide emission reduction management suggestions for participants in the construction industry. Participants can understand the optimal competition mode and emission reduction intensity. The paper also provides reference on emission reduction incentives, which is helpful for construction enterprises to carry out low-carbon transformation scientifically and efficiently.

7.2. Limitations and Suggestions for the Further Research.

In this paper, we study the emission reduction and revenue distribution strategies of construction supply chain under different decentralized models and get a series of innovative research conclusions and management implications. The conclusions of this paper can provide theoretical guidance for the decision of emission reduction and emission reduction revenue distribution of construction supply chain enterprises and provide micro theoretical basis and reference suggestions for the government's emission reduction policymaking. However, there are still some deficiencies in this study, and there are still a series of problems worthy of improvement and in-depth study. For one thing, the paper studies emission reduction strategy and profit distribution of construction supply chain considering fairness concern under cap-and-trade. Supply chain members aim at their own optimal profits and optimal emission reduction, ignoring the performance of the whole supply chain, which may cause double marginalization. Yet, coordination strategy can effectively reduce or even eliminate double marginalization and improve supply chain performance. Therefore, one future extension is to design a coordination strategy of construction supply chain in consideration of cap-and-trade and fairness concern, which is conducive to improve the management efficiency and competitiveness of enterprises. Furthermore, this paper mainly studies construction supply chain emission reduction decision, only considering the construction emission reduction target. In the process of construction, three traditional goals of construction cost, construction period, and quality need to be considered. Combining the emission reduction objectives with the three traditional objectives and studying the emission reduction, cost, duration, and quality decision can better reflect the characteristics of construction supply chain and more fit the actual situation. Therefore, combining the three objectives will be another important research direction of this paper. Last, the paper only studies emission reduction

strategy and profit distribution of construction supply chain with fairness concern of the subcontractor, and the conclusions are not comprehensive. No matter which party's fairness concern behavior has a great impact on the decision of supply chain, therefore, the third important research direction of this paper is studying the emission reduction strategy and profit distribution of construction supply chain, in which the contractor has fairness concern, and both parties have fairness concern.

Data Availability

All the data are included in this article.

Conflicts of Interest

All authors declare that they have no conflicts of interest.

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References

- [1] G. Z. Ghafoor, F. Sharif, A. U. Khan, M. U. Hayyat, M. Farhan, and L. Shahzad, "Energy consumption and carbon dioxide emissions of residential buildings in lahore, Pakistan," *Polish Journal of Environmental Studies*, vol. 29, no. 2, pp. 1613–1623, 2020.
- [2] L. Bernstein, P. Bosch, O. Canziani, Z. Chen, R. Christ, and K. Riahi, "Climate change 2007," Synthesis Report, IPCC, Geneva, Switzerland, 2008.
- [3] BP Group, "Statistical review of world energy," Report, BP Group, London, UK, 2018.
- [4] China Building Energy Efficiency Association, "China building energy consumption research report (2017)," Report in Chinese, China Building Energy Efficiency Association, Beijing, China, 2017.
- [5] W. Jiang and L. Wu, "Flow shop optimization of hybrid make-to-order and make-to-stock in precast concrete component production," *Journal of Cleaner Production*, vol. 297, Article ID 126708, 2021.
- [6] W. Jiang, L. Yuan, L. Wu, and S. Guo, "Carbon emission reduction and profit distribution mechanism of construction supply chain with fairness concern and cap-and-trade," *PLoS One*, vol. 14, no. 10, Article ID e0224153, 2019.
- [7] Prospective Industry Research Institute, *Analysis on the Current Situation and Development Prospect Of China's Carbon Emission Trading Market in 2018*[EB/OL]Prospective Industry Research Institute, 2018, <https://www.tanpaifang.com/tajiaoyi/2018/1229/62717.html> in Chinese.
- [8] National Development and Reform Commission of the people's Republic of China, "Notice of the general office of the national development and reform commission on doing a good job in launching the national carbon emission trading market," Report in Chinese, National Development and Reform Commission of the people's Republic of China, Beijing, China, 2016.
- [9] S. Lambropoulos, "The use of time and cost utility for construction contract award under European Union legislation," *Building and Environment*, vol. 42, no. 1, pp. 452–463, 2007.
- [10] R. Rehan and M. Nehdi, "Carbon dioxide emissions and climate change: policy implications for the cement industry," *Environmental Science & Policy*, vol. 8, no. 2, pp. 105–114, 2005.
- [11] W. Jiang, W. Lu, and Q. Xu, "Profit distribution model for construction supply chain with cap-and-trade policy," *Sustainability*, vol. 11, no. 4, p. 1215, 2019.
- [12] D. Li, *Models and Methods for Interval-Valued Cooperative Games in Economic Management* pp. 154–196, Springer International Publishing, Switzerland, UK, 1st edition, 2016.
- [13] J. Rawls, "Justice as fairness," *The Philosophical Review*, vol. 67, no. 2, pp. 164–194, 1958.
- [14] T.-H. Ho and J. Zhang, "Designing pricing contracts for boundedly rational customers: does the framing of the fixed fee matter?" *Management Science*, vol. 54, no. 4, pp. 686–700, 2008.
- [15] T. Nie and S. Du, "Dual-fairness supply chain with quantity discount contracts," *European Journal of Operational Research*, vol. 258, no. 2, pp. 491–500, 2017.
- [16] Q. Wang and Q. Shi, "The incentive mechanism of knowledge sharing in the industrial construction supply chain based on a supervisory mechanism," *Engineering Construction and Architectural Management*, vol. 26, no. 6, pp. 989–1003, 2019.
- [17] X. Wang, S. Geng, and T. C. E. Cheng, "Negotiation mechanisms for an order subcontracting and scheduling problem," *Omega*, vol. 77, pp. 154–167, 2018.
- [18] J. Gao, H. Han, L. Hou, and H. Wang, "Pricing and effort decisions in a closed-loop supply chain under different channel power structures," *Journal of Cleaner Production*, vol. 112, pp. 2043–2057, 2016.
- [19] S. Qu, H. Yang, and Y. Ji, "Low-carbon supply chain optimization considering warranty period and carbon emission reduction level under cap-and-trade regulation," *Environment, Development and Sustainability*, pp. 1–28, 2021.
- [20] J. Jian, B. Li, N. Zhang, and J. Su, "Decision-making and coordination of green closed-loop supply chain with fairness concern," *Journal of Cleaner Production*, vol. 298, Article ID 126779, 2021.
- [21] S. Wang, L. Wan, T. Li, B. Luo, and C. Wang, "Exploring the effect of cap-and-trade mechanism on firm's production planning and emission reduction strategy," *Journal of Cleaner Production*, vol. 172, pp. 591–601, 2018.
- [22] L. Yang, J. Ji, M. Wang, and Z. Wang, "The manufacturer's joint decisions of channel selections and carbon emission reductions under the cap-and-trade regulation," *Journal of Cleaner Production*, vol. 193, pp. 506–523, 2018.
- [23] K. Begg, "The Kyoto Protocol - international climate policy for the 21st century sebastian oberthür and E. Ott, springer-verlag, berlin, heidelberg, 1999, 359 pp., UK£ 37.50, ISBN 354066470X," *Climate Policy*, vol. 1, no. 1, pp. 145–146, 2001.
- [24] P. Elkins and T. Baker, "Carbon taxes and carbon emissions trading," *Journal of Economic Surveys*, vol. 15, no. 3, pp. 325–376, 2001.
- [25] N. Stern, "The economics of climate change: the stern review," *Cambridge University Press*, p. 75, 2007.
- [26] Y. Zhou, T. Wang, R. Peng, and H. Hu, "Spatial-temporal characteristics and factors of agricultural carbon emissions in

- the belt and road region of China,” *Polish Journal of Environmental Studies*, vol. 30, no. 3, pp. 2445–2457, 2021.
- [27] L. Shao, G. Q. Chen, Z. M. Chen et al., “Systems accounting for energy consumption and carbon emission by building,” *Communications in Nonlinear Science and Numerical Simulation*, vol. 19, no. 6, pp. 1859–1873, 2014.
- [28] N. Sabzevar, S. T. Enns, J. Bergerson, and J. Kettunen, “Modeling competitive firms’ performance under price-sensitive demand and cap-and-trade emissions constraints,” *International Journal of Production Economics*, vol. 184, pp. 193–209, 2017.
- [29] X. Xu, P. He, H. Xu, and Q. Zhang, “Supply chain coordination with green technology under cap-and-trade regulation,” *International Journal of Production Economics*, vol. 183, pp. 433–442, 2017.
- [30] L. Xu, C. Wang, and J. Zhao, “Decision and coordination in the dual-channel supply chain considering cap-and-trade regulation,” *Journal of Cleaner Production*, vol. 197, no. 1, pp. 551–561, 2018.
- [31] Z. Wang, A. E. I. Brownlee, and Q. Wu, “Production and joint emission reduction decisions based on two-way cost-sharing contract under cap-and-trade regulation,” *Computers & Industrial Engineering*, vol. 146, Article ID 106549, 2020.
- [32] P. E. D. Love, P. R. Davis, R. Chevis, and D. J. Edwards, “Risk/Reward compensation model for civil engineering infrastructure alliance projects,” *Journal of Construction Engineering and Management*, vol. 137, no. 2, pp. 127–136, 2011.
- [33] H. Yang, X. Sun, W. Liu, and J. Hao, “Optimization of profit distribution method under multifactor in construction supply chain,” *Journal of Interdisciplinary Mathematics*, vol. 20, no. 6-7, pp. 1435–1440, 2017.
- [34] Y. Wen, L. Wu, and F. Yao, “Financing and pricing strategies of construction supply chain under capital constraint,” *MATEC Web of Conferences*, vol. 336, Article ID 09004, 2021.
- [35] E. Fehr and K. M. Schmidt, “A theory of fairness, competition, and cooperation,” *The Quarterly Journal of Economics*, vol. 114, no. 3, pp. 817–868, 1999.
- [36] T.-H. Ho, X. Su, and Y. Wu, “Distributional and peer-induced fairness in supply chain contract design,” *Production and Operations Management*, vol. 23, no. 2, pp. 161–175, 2014.
- [37] X. An, H. Li, O. Omoleye, Z. Wang, and J. Ding, “Negotiation model of design optimization profit distribution with fairness concerns in construction projects,” *KSCE Journal of Civil Engineering*, vol. 22, no. 7, pp. 2178–2187, 2018.
- [38] T. Haitao Cui, J. S. Raju, and Z. J. Zhang, “Fairness and channel coordination,” *Management Science*, vol. 53, no. 8, pp. 1303–1314, 2007.
- [39] C. H. Loch and Y. Wu, “Social preferences and supply chain performance: an experimental study,” *Management Science*, vol. 54, no. 11, pp. 1835–1849, 2008.
- [40] B. Zhou and Z. G. Zhang, “Study on incentive mechanism of large-scale dredging project based on fairness preference,” *Advanced Materials Research*, vol. 219-220, pp. 144–150, 2011.
- [41] J. Jian, Y. Zhang, L. Jiang, and J. Su, “Coordination of supply chains with competing manufacturers considering fairness concerns,” *Complexity*, vol. 2020, no. 5, 15 pages, Article ID 4372603, 2020.
- [42] R. Zhang, W. Ma, H. Si, J. Liu, and L. Liao, “Cooperative game analysis of coordination mechanisms under fairness concerns of a green retailer,” *Journal of Retailing and Consumer Services*, vol. 59, Article ID 102361, 2020.
- [43] J. Liu, P. Yang, B. Xia, and M. Skitmore, “Effect of perceived justice on subcontractor willingness to cooperate: the mediating role of relationship value,” *Journal of Construction Engineering and Management*, vol. 143, no. 9, Article ID 04017062, 2017.
- [44] C. Pasquinelli, “Competition, cooperation and co-opetition: unfolding the process of inter-territorial branding,” *Urban Research & Practice*, vol. 6, no. 1, pp. 1–18, 2013.
- [45] A. I. El-Ansary and L. W. Stern, “Power measurement in the distribution channel,” *Journal of Marketing Research*, vol. 9, no. 1, pp. 47–52, 1972.
- [46] G. Ertek and P. M. Griffin, “Supplier- and buyer-driven channels in a two-stage supply chain,” *IIE Transactions*, vol. 34, no. 8, pp. 691–700, 2002.
- [47] R. Zhang, B. Liu, and W. Wang, “Pricing decisions in a dual channels system with different power structures,” *Economic Modelling*, vol. 29, no. 2, pp. 523–533, 2012.
- [48] D. Ghosh and J. Shah, “A comparative analysis of greening policies across supply chain structures,” *International Journal of Production Economics*, vol. 135, no. 2, pp. 568–583, 2012.
- [49] R. Shi, J. Zhang, and J. Ru, “Impacts of power structure on supply chains with uncertain demand,” *Production and Operations Management*, vol. 5, no. 22, pp. 1232–1249, 2013.
- [50] Y. Teng, X. Li, P. Wu, and X. Wang, “Using cooperative game theory to determine profit distribution in IPD projects,” *International Journal of Construction Management*, vol. 19, no. 1, pp. 32–45, 2019.
- [51] W. Yang, Y. Pan, J. Ma, M. Zhou, Z. Chen, and W. Zhu, “Optimization on emission permit trading and green technology implementation under cap-and-trade scheme,” *Journal of Cleaner Production*, vol. 194, pp. 288–299, 2018.
- [52] H. Groenenberg and K. Blok, “Benchmark-based emission allocation in a cap-and-trade system,” *Climate Policy*, vol. 2, no. 1, pp. 105–109, 2002.
- [53] M. Rabin, “Incorporating fairness into game theory and economics,” *The American Economic Review*, vol. 83, no. 5, pp. 1281–1302, 1993.
- [54] S. Du, T. Nie, C. Chu, and Y. Yu, “Newsvendor model for a dyadic supply chain with Nash bargaining fairness concerns,” *International Journal of Production Research*, vol. 52, no. 17, pp. 5070–5085, 2014.
- [55] J.-C. Li, J.-H. Lu, Q.-L. Wang, and C. Li, “Quality and pricing decisions in a two-echelon supply chain with Nash bargaining fairness concerns,” *Discrete Dynamics in Nature and Society*, vol. 2018, no. 3, 19 pages, Article ID 4267305, 2018.
- [56] C. Wei, Z. Li, and Z. Zou, “Ordering policies and coordination in a two-echelon supply chain with Nash bargaining fairness concerns,” *Journal of Management Analytics*, vol. 4, no. 1, pp. 55–79, 2017.