In the context of low-carbon economy, in order to explore the impact of the fairness concern and reference low-carbon effect on supply chain members’ balanced emission reduction decisions and profits, supply chain joint emission reduction dynamic optimization models under four different scenarios are built, in which the manufacturer’s optimal emission reduction strategy, the retailer’s optimal low-carbon promotion strategy and other equilibrium solutions are solved by differential game theory. On the basis of analysis, a contract is designed to achieve the coordination of the supply chain when members are fairness concern. Some findings are as follows. First, when consumers’ purchasing behavior is significantly affected by the reference low-carbon effect, and they have higher expectations for the product’s emission reduction level, consumers’ reference low-carbon effect will discourage the manufacturer’s enthusiasm to reduce emissions, and do harm to the profits of the manufacturer and the retailer. Second, the fairness concern behavior of both parties will aggravate the adverse effects of reference low-carbon effect, bring a detrimental effect on the performance of the supply chain, aggravate the double marginal effect of the supply chain, and cause continuous negative social influence. Third, the bilateral cost-sharing contract can encourage the manufacturer to increase emission reduction investment, the retailer to increase low-carbon promotion investment, and can achieve a Pareto improvement of both parties’ profits and utilities. In addition, the two cost-sharing ratios are only proportional to the marginal revenue and fairness concern intensity of both parties. Finally, when the two cost-sharing ratios and the revenue-sharing coefficient meet a certain relationship and are within a reasonable range, the bilateral cost sharing-revenue sharing hybrid contract can reduce the double marginal effect and achieve supply chain coordination.
economy. Subsequently, international coalition organizations and governments of various countries have issued a series of regulations to restrict relevant companies to reduce carbon emissions. Therefore, the issue of emission reduction has become a prominent issue that companies have to face today. At the same time, affected by relevant publicity from the government, environmental organizations and retailers, low-carbon products are becoming more and more popular with consumers\cite{35}. A consumer behavior survey of American consumers showed that 80% of consumers are willing to buy low-carbon products with a higher price\cite{37}. Similarly, more and more Chinese consumers are willing to purchase low-carbon products on the Ali platform, and the compound growth rate of annual sales of low-carbon products was greater than 80% between 2011 and 2015\cite{29}. Facing the pressure of emission reduction and market competition, the cooperation of upstream and downstream enterprises in the supply chain to reduce emissions is becoming an effective way. For instance, Wal-Mart requires its suppliers to increase their emissions reduction investment and join the carbon emission disclosure program as required. At the same time, it will also use its strong network to provide special product promotion for the suppliers in the plan\cite{44}. In view of the significant value of the joint emission reduction mode for effectively reducing the overall carbon emissions and enhancing the overall competitiveness of the supply chain. Therefore, this paper will study the supply chain members' joint emission reduction issue.

In the context of low-carbon economy, consumers' low-carbon consumption behavior is an important factor that cannot be ignored for companies. With the deepening of research on their consumption behavior, scholars find that when consumers are going to buy products, both the current attributes and the expected attributes formed by their previous purchase experiences will affect their purchasing behavior. This kind of purchasing psychology is defined as reference effect\cite{5, 15}. Accordingly, when consumers choose to buy low-carbon products, they will not only be affected by the present low-carbon level of the products, but also be affected by the reference point of low-carbon level formed from their past purchase experience. Based on the definition of the reference effect, we define it as reference low-carbon effect. Because of the significant impact of the reference low-carbon effect on consumers' low-carbon purchasing behavior, it is very meaningful to introduce it into the issue of joint emission reduction and study its impact on supply chain members' emission reduction decisions.

In addition, many behavioral economics experiments and studies have shown that people not only pay attention to their own interests, but also the gap between their own benefits and the benefits of their partners in the transaction process, and this gap will prompt people to make changes in decision-making to improve their own utilities, this psychology is defined as fairness concern\cite{19}. The ultimatum game, the dictator game, the public goods game and other behavioral game experiments have confirmed that people generally have fairness concern behavior. Ruffle's ultimatum game also shows that if one party to the game believes that it has been treated unfairly with the distribution plan, it will refuse to accept the plan. Ignoring the fairness concern of individuals, the research results often deviate from reality\cite{2}. At present, with the increasing complexity of members' interest relationships in the supply chain, uneven distribution of benefits occurs from time to time. For example, Haier Electric has launched a zero-carbon conversion strategy with retail companies such as Gome and Suning. Haier Electric is committed to the development and production of low-carbon products, while retailers such as Gome
and Suning sell products. However, because manufacturers are in a strong position, when making decisions, they are more concerned with their own interests, which makes retail companies feel unfair and affects retailers’ sales enthusiasm. As the interest relationships among supply chain members are becoming closer and closer, there is no doubt that their fairness concern will become more and more obvious and will have a significant impact on their decision-making. Therefore, introducing supply chain members’ fairness concern behavior into the issue of joint emission reduction, and exploring its impact on supply chain members’ optimal emission reduction strategies from a long-term perspective will be very necessary.

Based on the above background and Stackelberg differential game method, this paper explores the issue of the joint emission reduction of supply chain considering fairness concern behavior and consumers’ reference low-carbon effect from a long-term perspective. This paper is mainly committed to solving the following problems:

How do supply chain members’ fairness concern behavior and consumers’ reference low-carbon effect jointly affect supply chain members’ optimal emission reduction strategies and profits under different decision scenarios?

How will the bilateral cost-sharing contract affect supply chain members’ emission reduction strategies and profits? Can the bilateral cost-sharing contract achieve perfect coordination of the supply chain?

How to effectively coordinate the supply chain if supply chain members have fairness concern behavior.

By answering the above questions, this paper mainly has the following contributions:

First, this paper integrates the supply chain members’ fairness concern behavior and consumer’s reference low-carbon effect these two factors to discuss their impact on supply chain members’ joint emission reduction decisions and supply chain coordination. Second, this paper establishes supply chain emission reduction dynamic optimization models under four different decision scenarios, and presents the equilibrium strategies of supply chain members from a long-term perspective. Third, through mathematical derivation and numerical analysis, this paper designs a supply chain coordination contract to achieve perfect coordination of the supply chain. In short, this paper has deeply discussed the joint emission reduction issue of supply chain with the consideration of consumers’ reference low-carbon effect and supply chain members’ fairness concern behavior, and can provide theoretical support for long-term cooperative emission reduction among supply chain members.

The rest of this paper is organized as follows. Section 2 provides the literature review. Section 3 is problem description section. The equilibrium solutions under four scenarios are presented in Section 4. Section 5 is comparison and analysis section. A supply chain coordination contract is presented in Section 6. Section 7 gives some numerical examples to test the findings and derive some managerial insights. Section 8 summarizes conclusions and limitations of this paper.

2. Literature review. Based on the content of our research, we will mainly review two types of literature about supply chain operation issues in this section. One stream is about joint emission reduction issues of supply chain considering fairness concern or not, another one is about supply chain operation issues considering reference effect.

Currently, there has been a lot of literature discussed the joint emission reduction issue in the supply chain[3]. Liu et al.[16] took the agricultural supply chain
as the research object, and compared the optimal decisions and profits of retailers under three situations. Pu et al. [23] studied government policy and supply chains’ competition with the consideration of consumers’ low-carbon preference. Zhang et al. [34] considered competition and cooperation within companies for a co-opetition supply chain consisting of two manufacturers to explore the operation strategies in the context of a carbon tax mechanism. Yu and Hou [33] considered stochasticity and consumers’ low-carbon preference and studied supply chain members’ emission reduction decisions. Considering consumers’ strategic consumption behavior and low-carbon technology investment, Jiang et al. [13] studied supply chain members’ equilibrium strategies in a low carbon supply chain. Based on carbon concerned product demand, Du et al. [6] studied supply chain members’ performance in a low-carbon supply chain. Liu and Li [17] built a differential game model, and discussed the equilibrium strategies of the supply chain under centralized and decentralized decision-makings, then designed a bilateral component sharing contract to coordinate the supply chain. Wang et al. [26] explored emission reduction decisions and production decisions with the consideration of cap-and-trade policy, then used the two-way cost-sharing contract to realize the coordination under cap-and-trade regulation policy. Considering a dual-channel low-carbon supply chain and consumers’ low-carbon preference, Zhang et al. [42] studied supply chain members’ emission reduction decisions. Wang et al. [27] explored the governmental carbon emission tax strategy and the optimal emission reduction strategies of enterprises by using the three-stage Stackelberg game model. Considering financial constraints, Cao et al. [4] studied low-carbon supply chain members’ carbon reduction decisions and product order quantity decisions. Huang et al. [11] established four models: two cooperative manufacturers and one retailer are completely self-interested, one retailer has altruistic preference, two cooperative manufacturers have altruistic preferences, then studied the impact of supply chain members’ altruistic behavior on their emission reduction and pricing decisions. Xia et al. [30] introduced reciprocal preferences and consumers’ low-carbon awareness into the dyadic supply chain, and investigated how reciprocity and CLA affect the emission reduction decisions and performances of the supply chain members.

Although the above-mentioned papers have studied the emission reduction issues of the supply chain from different perspectives such as consumers’ low-carbon preference, government regulations, supply chain competition and coordination, they are all based on the premise that the decision makers are completely rational, and do not consider the fairness concern behavior of supply chain members.

As the researches relevant to fairness concern behavior continue to deepen, discussing the impact of fairness concern behavior in the issue of supply chain joint emission reduction has gradually attracted the attention of scholars. Qian et al. [24] considered a fair-minded retailer, developed four contracts to investigate the environmental performance and channel profit under the framework of two non-cooperative contracts: wholesale price and two-part tariff, and two cooperative contracts: Nash bargaining and Rubinstein bargaining. Considering the fairness concerns of retailers and the low-carbon preferences of consumers, Zhou et al. [44] investigated the coordination of the low-carbon supply chain based on advertising and abatement cost sharing contracts. Li et al. [22] investigated price and carbon emission reduction decisions considering fairness concerns, and designed a revenue-sharing contract. Based on a green e-commerce supply chain, Wang
et al.\cite{25} studied the optimal decisions and coordination considering green manufacturer's fairness concerns. Zhang et al.\cite{41} discussed carbon emission reduction decisions of low-carbon supply chain members with retailer's fairness concern and subsidies. Considering government carbon subsidies and fairness concerns, Han et al.\cite{12} investigated the optimal decisions and coordination of low-carbon e-commerce supply chain. Considering the fairness concern behavior and government subsidy, Zhang et al.\cite{37} studied supply chain members' emission reduction and pricing decisions from different scenarios.

Although the above studies discuss the impact of fairness concern behavior of supply chain members on their emission reduction decisions, the emission reduction optimization models they establish are all static optimization models. The strategies got by the static decision-making models can just report the supply chain members' short-term optimal decisions, but the dynamic decision-making models can better report the long-term effects of supply chain members' emission reductions. Different from general game theory, which only discusses the static decisions of participants in the short-term, differential game theory introduces state variables into the decision model and considers the inter-cycle effects of state variables. The dynamic optimization model constructed by the differential game theory can reveal the participants' dynamic decisions from a long-term perspective, thereby reflecting the long-term effect of the participants' decisions. As far as we know, at present, there are few literatures that consider the fairness concern behavior of supply chain members and use dynamic optimization models to discuss the issue of joint emission reduction in the supply chain. Ignoring the long-term dynamic characteristics of the joint emission reduction activities of supply chain members will inevitably cause models and research conclusions to deviate from reality.

Consumer behavior studies have shown that the difference between the actual product attribute level experienced by consumers after shopping and the product reference attribute level expected by consumers before shopping will have an important impact on product goodwill and market demand, that is, consumers' reference effect. Recently, there have been lots of literatures studying consumers' reference effect in the supply chain. Taking two competing retailers with asymmetric channel rights as the research object, based on the assumption that demand is simultaneously affected by market prices, competitor prices, and reference prices, Anderson et al.\cite{1} established a retailer’s pricing decision model. Liu et al.\cite{15} investigated the impacts of myopic behavior regarding the reference quality on the product quality and pricing strategies and profits of supply chain members. Considering consumers' reference price effect and the advertising effect, Zhang et al.\cite{40} designed a bilateral cost-sharing contract to realize supply chain coordination. Lu et al.\cite{20} explored supply chain members' joint pricing and advertising strategies considering consumers' reference price effect. Based on reference price effect, the joint dynamic pricing decisions and investment decisions of a supply chain was discussed by Dye et al.\cite{5}.Based on closed loop supply chain, Xu and Liu\cite{31} studied the impact of reference price effect. Considering reference price, Lin\cite{21} studied pricing and promotion decision-making issue of the supply chain. Based on a competitive supply chain and reference price effect, Zhang et al.\cite{39} studied the strategic pricing strategies of the supply chain. Zu and Chen\cite{46} considered reference price effect, and studied its impact on supply chain coordination and advertising decisions. Gavious et al.\cite{9} defined reference quality as the psychological reference value formed by consumers based on the product quality observed in the past purchase experience. On this
basis, they studied the influence of reference quality effect on supply chain pricing decisions. Taking a closed-loop supply chain as the research object, the impact of reference quality effect on supply chain members’ dynamic pricing decisions was studied by Zhang et al.[36].

The above literature shows that reference price effect and reference quality effect have been extensively and in-depth studied, but there are still few studies on consumers’ reference low-carbon effect. With the growing prosperity of the low-carbon economy, the awareness of low-carbon consumption has become increasingly popular, there is no doubt that consumers’ reference low-carbon effect will have a remarkable influence on their low-carbon consumption behavior. At the same time, as upstream and downstream members of the supply chain carrying out joint emission reduction activities is becoming increasingly common, studying the joint emission reduction issue considering their fairness concern behavior will be very necessary. In Table 1, we have summarized some literatures that have strong relevance to this paper to further reveal the innovation and contribution of this paper.

Therefore, considering the impact of supply chain members’ fairness concern behavior and consumers’ reference low-carbon effect, this paper will regard product low-carbon goodwill and consumer’s reference low-carbon level as both state variables, and consider the cross-cycle effects of the two factors. Based on the particularity of the model and the characteristics of differential game theory, so this paper will study how these two factors impact the supply chain members’ optimal emission reduction strategies, profits and utilities under different decision scenarios from a long-term perspective by differential game theory. Moreover, based on the comparison and analysis of equilibrium solutions, this paper will design a reasonable contract to achieve supply chain coordination when supply chain members have fairness concern behavior.

3. Model description. To simplify the model and highlight the research focus, we consider a supply chain system including a manufacturer and a retailer. The manufacturer produces a sort of low-carbon product by emission reduction investment, and the low-carbon level of the product will be higher when the manufacturer’s emission reduction level is higher. Meanwhile, the retailer will also implement low-carbon promotion will also be implemented by the retailer to draw consumers to purchase this sort of low-carbon product. Some related parameters and decision variables involved in this paper are explained in Table 2.

To better promote follow-up study, we propose some assumptions as follows:

| Author               | Reference Low Carbon on Effect | Fairness Concern | Low Carbon Goodwill | Supply Chain Coordination |
|----------------------|-------------------------------|------------------|--------------------|--------------------------|
| Wang et al.[28]      | √                             |                  |                    |                          |
| Liu et al.[18]       |                               | √                |                    |                          |
| Yu et al.[32]        | √                             |                  |                    |                          |
| Zhang et al.[41]     |                               | √                |                    |                          |
| Zou et al.[45]       |                               |                  | √                  |                          |
| This paper           | √                             | √                | √                  | √                        |
Assumption 1. It is assumed that the manufacturer is the leader and the retailer is the follower in the supply chain system. Both manufacturers and retailers grasp symmetrical and clear market information. When they do not have fairness concern behavior, they play Stackelberg game to maximize their own profits. But when they have fairness concern behavior, both of them will play Stackelberg game to maximize their own utilities.

Assumption 2. Based on the researches of Dye et al. [5] and Liu et al. [15], consumers’ reference low-carbon effect can be expressed as the reference point of the product low-carbon level. According to literature [8],

\[ R(t) = \epsilon \int_0^t e^{(s-t)} E(s) ds. \]

After further sorting, the consumer’s reference low-carbon level can be expressed as shown in equation (1).

\[ \dot{R}(t) = \epsilon (E(t) - R(t)) \]
\[ R(0) = R_0 \] (1)

Assumption 3. It is assumed that when retailers conduct low-carbon promotion, the effect of this low-carbon promotion can not only attract potential consumers to purchase the low-carbon product in the current period, but also promote consumers to purchase the low-carbon product intertemporal by establishing low-carbon goodwill for the low-carbon product. Refer to the literature [38, 43] and based on Nerlove–Arrow’s goodwill model, the product low-carbon goodwill function can be obtained as shown in equation (2).

\[ G(t) = \lambda A(t) - \sigma G(t) \]
\[ G(0) = G_0 \] (2)

Assumption 4. According to the literature [38, 14], we assume that the low-carbon product’s demand function is a deterministic and linear function. Products with higher low-carbon level, low-carbon promotion level and low-carbon goodwill level are most popular among consumers. At the same time, consumers will choose to purchase such product when its reference low-carbon level is lower than the actual low-carbon level at present, otherwise, they will be reluctant to buy the product because of the impact of reference low-carbon effect. What needs special explanation is that with the current product prices becoming more and more transparent, consumers are no longer as sensitive to product prices as they used to be. Instead, they pay more attention to non-price factors. Therefore, this paper does not consider the impact of product prices. Here, we can obtain the low-carbon product’s demand function as shown in equation (3).

\[ Q = \alpha [E(t) - R(t)] + \beta E(t) + \mu G(t) + kA(t) \] (3)

Assumption 5. Refer to the literature [10], we assume that the emission reduction cost of the manufacturer is \( c_m = \frac{\eta_m E(t)^2}{2} \), the low-carbon promotion cost of the retailer is \( c_r = \frac{\eta_r A(t)^2}{2} \).

Assumption 6. Without considering the impact of price, the manufacturer’s marginal revenue is assumed to be \( \pi_1 \), the retailer’s marginal revenue is assumed to be \( \pi_2, \pi_1 \) and \( \pi_2 \) are both assumed to be constants. It is also assumed that both parties have the equal discount rate \( \rho (\rho > 0) \) at any time during a business scope of unlimited time. Besides, the transportation and inventory costs of the product will not be considered.
Table 2. Related parameters and decision variables

| Parameters      | Definition                                                                 |
|-----------------|-----------------------------------------------------------------------------|
| $\alpha$        | Influence coefficient of reference low-carbon effect on the demand          |
| $\beta$         | Influence coefficient of manufacturer’s emission reduction on the demand   |
| $k$             | Influence coefficient of retailer’s low-carbon promotion on the demand      |
| $\rho$          | Discount rate                                                               |
| $\mu$           | Influence coefficient of low-carbon goodwill on the demand                  |
| $\pi_1$         | Manufacturer’s marginal revenue                                             |
| $\pi_2$         | Retailer’s marginal revenue                                                 |
| $G(t)$          | Low-carbon goodwill level at time $t$                                        |
| $R(t)$          | Consumer’s reference low-carbon level at time $t$                           |
| $\lambda$       | Influence coefficient of the low-carbon promotion on the low-carbon goodwill |
| $\sigma$        | Natural decay rate of low-carbon goodwill                                   |
| $\epsilon$      | Memory parameter                                                            |
| $\phi$          | Low-carbon promotion Cost-sharing ratio                                     |
| $\gamma$        | Emission reduction cost-sharing ratio                                       |
| $\theta$        | Revenue-sharing coefficient under the supply chain coordination            |
| $\tau_m$        | Manufacturer’s fairness concern intensity                                   |
| $\tau_r$        | Retailer’s fairness concern intensity                                       |
| $\eta_m, \eta_r$| Emission reduction cost coefficient and low-carbon promotion cost coefficient.|

4. Model solution. According to the research assumptions in the former section, in order to conduct a comparative analysis of fairness concern behavior, this section will analyze the strategies and performances of the members under centralized scenario and decentralized scenario without fairness concern. Then this section will analyze decentralized scenario with fairness concern and decentralized scenario with fairness concern and a bilateral cost-sharing contract these two decision scenarios. In order to distinguish among different scenarios, superscripts $c,n,f,fb$, respectively represent centralized scenario, decentralized scenario without fairness concern, decentralized scenario with fairness concern, decentralized decision scenario with fairness concern and a bilateral cost-sharing contract. Besides, subscripts $m,r$ and $sc$ respectively represent the manufacturer, retailer and the supply chain system these three decision makers. For the convenience of writing, the time will not be listed below.

4.1. Centralized scenario. To achieve the optimal profit of the supply chain system, both the manufacturer and the retailer will jointly determine their emission reduction decisions. Although the centralized decision scenario is the most ideal supply chain decision scenario, it is difficult to achieve in actual enterprise operations. Here we use it as the upper limit of reference for analyzing fairness concern. At this time, the supply chain system’s objective function is as follows:

$$J^*_{sc}(R, G, t) = \max_{E,A} \int_0^\infty e^{-\rho t}[(\pi_1 + \pi_2)(\alpha + \beta)E + \mu G + kA - \alpha R]$$
The optimal evolution path of reference low carbon level is as follows:

\[
\begin{align*}
J_m(R, G, t) &= \max \int_0^\infty e^{-\rho t} \left[ \frac{(\pi_1 + \pi_2)[\rho \alpha + \beta(\rho + \epsilon)]}{\eta_m} - \frac{\eta_m E^2}{2} \right] dt \\
s.t. & \dot{R}(t) = \epsilon(E(t) - R(t)), R(0) = R_0 \\
G(t) &= \lambda A(t) - \sigma G(t), G(0) = G_0 \geq 0
\end{align*}
\]

\textbf{Theorem 4.1.} (1) The manufacturer’s optimal emission reduction decision and retailer’s optimal low-carbon promotion decision are as follows:

\[
E^n = \frac{\pi_1[\rho \alpha + \beta(\rho + \epsilon)]}{\eta_m(\rho + \epsilon)}
\]

\[
A^n = \frac{\pi_2[\lambda \mu + k(\rho + \sigma)]}{\eta_r(\rho + \sigma)}
\]

(2) The optimal evolution path of low-carbon goodwill is as follows:

\[
G^n(t) = (G_0 - G_\infty) e^{-\sigma t} + G_\infty, G_\infty = \frac{\lambda A^n}{\sigma}
\]

(3) The optimal evolution path of reference low carbon level is as follows:

\[
R^n(t) = (R_0 - R_\infty) e^{-\rho t} + R_\infty, R_\infty = E^n
\]

(4) The optimal total profit of the supply chain system is as follows:

\[
\pi_{sc}(t) = \pi_{sc\infty} + a_5(R_0 - R_\infty) e^{-\rho t} + b_5(G_0 - G_\infty) e^{-\sigma t}
\]

where \( \pi_{sc\infty} = a_5 R_\infty + b_5 G_\infty + c_5 \), \( a_5 = -\frac{\alpha(\pi_1 + \pi_2)}{\rho + \epsilon} \), \( b_5 = -\frac{\mu(\pi_1 + \pi_2)}{\rho + \sigma} \),

\[c_5 = \frac{1}{\rho} \left\{ \frac{(\pi_1 + \pi_2)^2[\rho \alpha + \beta(\rho + \epsilon)]^2}{2\eta_m(\rho + \epsilon)^2} + \frac{(\pi_1 + \pi_2)^2[\lambda \mu + k(\rho + \sigma)]^2}{2\eta_r(\rho + \sigma)^2} \right\} \].

4.2. Decentralized scenario without fairness concern. At this time, both parties aim at maximizing their own profits to make decisions. This decision-making model is often used in the actual operation of enterprises, but the inherent double marginal effect of the decentralized decision-making model often leads to the loss of the supply chain system’s profit. Therefore, here, we will use it as the reference for analyzing fairness concern behavior. At this time, the objective functions of the manufacturer and retailer are as follows:

\[
J_m(R, G, t) = \max \int_0^\infty e^{-\rho t} \left[ \frac{(\alpha + \beta)E + \mu G + kA - \alpha R}{\rho} \right] dt
\]

\[
s.t. & \dot{R}(t) = \epsilon(E(t) - R(t)), R(0) = R_0 \\
G(t) &= \lambda A(t) - \sigma G(t), G(0) = G_0 \geq 0
\]

\[
J_r(R, G, t) = \max \int_0^\infty e^{-\rho t} \left[ \frac{(\alpha + \beta)E + \mu G + kA - \alpha R}{\rho} \right] dt
\]

\[
s.t. & \dot{R}(t) = \epsilon(E(t) - R(t)), R(0) = R_0 \\
G(t) &= \lambda A(t) - \sigma G(t), G(0) = G_0 \geq 0
\]

\textbf{Theorem 4.2.} (1) The manufacturer’s optimal emission reduction decision and retailer’s optimal low-carbon promotion decision are as follows:

\[
E^n = \frac{\pi_1[\rho \alpha + \beta(\rho + \epsilon)]}{\eta_m(\rho + \epsilon)}
\]

\[
A^n = \frac{\pi_2[\lambda \mu + k(\rho + \sigma)]}{\eta_r(\rho + \sigma)}
\]
(2) The optimal evolution path of low-carbon goodwill is as follows:

\[ G^n(t) = (G_0 - G^n_\infty)e^{-\sigma t} + G^n_\infty, G^n_\infty = \lambda A^n/\sigma \]

(3) The optimal evolution path of reference low carbon level is as follows:

\[ R^n(t) = (R_0 - R^n_\infty)e^{-\sigma t} + R^n_\infty, R^n_\infty = E^n \]

(4) The optimal profits of the manufacturer and retailer are as follows:

\[
\pi_m^n(t) = \pi_m^n + a_2(R_0 - R^n_\infty)e^{-\sigma t} + b_2(G_0 - G^n_\infty)e^{-\sigma t} \\
\pi_r^n(t) = \pi_r^n + a_1(R_0 - R^n_\infty)e^{-\sigma t} + b_1(G_0 - G^n_\infty)e^{-\sigma t}
\]

where \( \pi_m^n = a_2R^n_\infty + b_2G^n_\infty + c_2 \), \( \pi_r^n = a_1R^n_\infty + b_1G^n_\infty + c_1 \), \( a_1 = -\alpha A/\rho + \epsilon \),

\[ a_2 = -\alpha A/\rho + \epsilon \]

\[ b_1 = \mu A/\rho + \sigma \]

\[ b_2 = \mu A/\rho + \sigma \]

\[ c_1 = 1/\rho \]

\[ c_2 = 1/\rho \]

\[ \pi_m^n = \pi_m^n + a_2(R_0 - R^n_\infty)e^{-\sigma t} + b_2(G_0 - G^n_\infty)e^{-\sigma t} \]

\[ \pi_r^n = \pi_r^n + a_1(R_0 - R^n_\infty)e^{-\sigma t} + b_1(G_0 - G^n_\infty)e^{-\sigma t} \]

4.3. Decentralized scenario with fairness concern. When the manufacturer and retailer are fairness concern, if its own profit is lower than the other party’s profit, it will cause a feeling of unfair. At this time, both parties will make decisions with the goal of maximizing their own fairness utilities. Referring to the construction of the fairness utility function of Du et al.[7] in the static category, this section extends the fairness utility function to the dynamic category, so the fairness utility functions of the manufacturer and retailer are as follows:

\[ U_m(t) = \pi_m(t) + \tau_m[\pi_m(t) - \pi_r(t)] \quad (7) \]

\[ U_r(t) = \pi_r(t) + \tau_r[\pi_r(t) - \pi_m(t)] \quad (8) \]

At this time, the objective functions of the manufacturer and retailer are as follows:

\[ J_m^l(R, G, t) = \max \int_0^\infty e^{-\rho t}[(1 + \tau_m)(\pi_1(\alpha + \beta)E + \mu G + kA - \alpha R) - \eta_m E^2/2 - \tau_m[\pi_2(\alpha + \beta)E + \mu G + kA - \alpha R] - \eta_r A^2/2]]dt \quad (9) \]

\[ s.t. \dot{R}(t) = \epsilon(E(t) - R(t)), R(0) = R_0 \geq 0 \]

\[ \dot{G}(t) = \lambda A(t) - \sigma G(t), G(0) = G_0 \geq 0 \]

\[ J_r^l(R, G, t) = \max \int_0^\infty e^{-\rho t}[(1 + \tau_r)(\pi_2(\alpha + \beta)E + \mu G + kA - \alpha R) - \eta_m E^2/2 - \tau_r[\pi_1(\alpha + \beta)E + \mu G + kA - \alpha R] - \eta_r A^2/2]]dt \quad (10) \]

\[ s.t. \dot{R}(t) = \epsilon(E(t) - R(t)), R(0) = R_0 \geq 0 \]

\[ \dot{G}(t) = \lambda A(t) - \sigma G(t), G(0) = G_0 \geq 0 \]
Theorem 4.3. (1) The manufacturer’s optimal emission reduction decision and retailer’s optimal low-carbon promotion decision are as follows:

\[
\begin{align*}
E^f &= \frac{[(1 + \tau_m)\pi_1 - \tau_m \pi_2][\rho \alpha + \beta (\rho + \epsilon)]}{\eta_m(1 + \tau_m)(\rho + \epsilon)} \\
A^f &= \frac{[(1 + \tau_r)\pi_2 - \tau_r \pi_1][\lambda \mu + k(\rho + \sigma)]}{\eta_r(1 + \tau_r)(\rho + \sigma)}
\end{align*}
\]

(2) The optimal evolution path of low-carbon goodwill is as follows:

\[
G^f(t) = (G_0 - G^f_\infty)e^{-\sigma t} + G^f_\infty, G^f_\infty = \frac{\lambda A^f}{\sigma}
\]

(3) The optimal evolution path of reference low carbon level is as follows:

\[
R^f(t) = (R_0 - R^f_\infty)e^{-\epsilon t} + R^f_\infty, R^f_\infty = E^f
\]

(4) The optimal profits of the manufacturer and retailer are as follows:

\[
\pi^f_m(t) = \pi^f_m + a_4(R_0 - R^f_\infty)e^{-\epsilon t} + b_4(G_0 - G^f_\infty)e^{-\sigma t}
\]

\[
\pi^f_r(t) = \pi^f_r + a_3(R_0 - R^f_\infty)e^{-\epsilon t} + b_3(G_0 - G^f_\infty)e^{-\sigma t}
\]

(5) The optimal utilities of the manufacturer and retailer are as follows:

\[
U^f_m(t) = (1 + \tau_m)\pi^f_m - \tau_m \pi^f_{\infty} + [(1 + \tau_m)a_4 - \tau ma_3](R_0 - R^f_\infty)e^{-\epsilon t}
\]

\[
+ [(1 + \tau_m)b_4 - \tau mb_3](G_0 - G^f_\infty)e^{-\sigma t}
\]

\[
U^f_r(t) = (1 + \tau_r)\pi^f_r - \tau_r \pi^f_{\infty} + [(1 + \tau_r)a_3 - \tau ra_4](R_0 - R^f_\infty)e^{-\epsilon t}
\]

\[
+ [(1 + \tau_r)b_3 - \tau rb_4](G_0 - G^f_\infty)e^{-\sigma t}
\]

where \(\pi^f_{\infty} = a_4 R^f_\infty + b_4 G^f_\infty + c_4 \pi^f_{\infty} = a_3 R^f_\infty + b_3 G^f_\infty + c_3, a_3 = \frac{-\alpha \pi_2}{\rho + \epsilon}, b_3 = \frac{\mu \pi_2}{\rho + \epsilon}, b_4 = \frac{\mu \pi_1}{\rho + \sigma}, \epsilon_t, c_3 = \frac{1}{\beta} \left\{ \frac{2\eta_m(1 + \tau_m)[\rho \alpha + \beta (\rho + \epsilon)]^2}{\eta_m(1 + \tau_m)(\rho + \epsilon)^2} + \frac{\eta_r(1 + \tau_r)[\lambda \mu + k(\rho + \sigma)]^2}{\eta_r(1 + \tau_r)(\rho + \sigma)^2} \right\}, c_4 = \frac{1}{\beta} \left\{ \frac{2\eta_m(1 + \tau_m)^2(\rho + \epsilon)^2}{\eta_m(1 + \tau_m)^2(\rho + \epsilon)^2} + \frac{\eta_r(1 + \tau_r)^2(\rho + \sigma)^2}{\eta_r(1 + \tau_r)^2(\rho + \sigma)^2} \right\} \}

4.4. Decentralized scenario with fairness concern and a bilateral cost-sharing contract. At this time, in order to encourage each other to increase emission reduction investment, the two parties will share the cost of emissions reduction with each other. The low-carbon promotion cost-sharing ratio is \(\phi_h\), the emission reduction cost-sharing ratio is \(\gamma_h\). At this time, the objective functions of the manufacturer and retailer are as follows:

\[
J^f_m(R, G, t) = \max_{E} \int_0^\infty e^{-\sigma t}[(1 + \tau_m)[\pi_1[(\alpha + \beta)E + \mu G + kA - \alpha R]\]

\[
- \eta_m(1 - \gamma_h)E^2 - \eta_h \phi_h A^2] - \tau_m[\pi_2[(\alpha + \beta)E + \mu G + kA - \alpha R]
\]

\[
- \alpha R + \eta_r(1 - \phi_h)A^2 - \eta_m\gamma_h E^2]dt
\]

s.t. \(\dot{R}(t) = \epsilon(E(t) - R(t)), R(0) = R_0 \geq 0\)

\(\dot{G}(t) = \lambda A(t) - \sigma G(t), G(0) = G_0 \geq 0\)
\[
J^f_b(R, G, t) = \max_{A} \int_0^\infty e^{-\rho t} \left[ (1 + \tau_r) \left[ \pi_2 (\alpha + \beta) E + \mu G + kA - \alpha R \right] - \frac{\eta_c (1 - \phi_b) A^2}{2} - \frac{\eta_m \gamma_b E^2}{2} - \tau_r [\pi_1 (\alpha + \beta) E + \mu G + kA - \alpha R] \right] dt
\]

\[
s.t. \dot{R}(t) = \epsilon (E(t) - R(t)), R(0) = R_0 \geq 0 \]

\[
G(t) = \lambda A(t) - \sigma G(t), G(0) = G_0 \geq 0
\]

**Theorem 4.4.** (1) The manufacturer’s optimal emission reduction decision and retailer’s optimal low-carbon promotion decision are as follows:

\[
\begin{align*}
E^{fb} &= \frac{[(1 + \tau_m) \pi_1 - \pi_2][\rho \alpha + \beta (\rho + \epsilon)]}{\eta_m [(1 + \tau_m) - (1 + 2\tau_m) \gamma_b] [\rho + \epsilon]}

A^{fb} &= \frac{\eta_c [(1 + \tau_r) - (1 + 2\tau_r) \phi_b] [\rho + \epsilon]}{\eta_r [(1 + \tau_r) - (1 + 2\tau_r) \phi_b] [\rho + \epsilon]}
\end{align*}
\]

(2) The optimal evolution path of low-carbon goodwill is as follows:

\[
G^{fb}(t) = (G_0 - G^{fb}_\infty) e^{-\sigma t} + G^{fb}_\infty, G^{fb}_\infty = \frac{\lambda A^{fb}}{\sigma}
\]

(3) The optimal evolution path of reference low-carbon level is as follows:

\[
R^{fb}(t) = (R_0 - R^{fb}_\infty) e^{-\epsilon t} + R^{fb}_\infty, R^{fb}_\infty = E^{fb}
\]

(4) The optimal profits of the manufacturer and retailer are as follows:

\[
\begin{align*}
\pi_m^{fb}(t) &= \pi_m^{fb}(t) + a_4 (R_0 - R^{fb}_\infty) e^{-\epsilon t} + b_4 (G_0 - G^{fb}_\infty) e^{-\sigma t}
\pi_r^{fb}(t) &= \pi_r^{fb}(t) + a_3 (R_0 - R^{fb}_\infty) e^{-\epsilon t} + b_3 (G_0 - G^{fb}_\infty) e^{-\sigma t}
\end{align*}
\]

(5) The optimal utilities of the manufacturer and retailer are as follows:

\[
\begin{align*}
U_m^{fb}(t) &= (1 + \tau_m) \pi_m^{fb}(t) - \pi_m^{fb}(t) + \pi^{fb}(t) + [(1 + \tau_m) a_4 - \tau_m a_3] (R_0 - R^{fb}_\infty) e^{-\epsilon t}
+ [(1 + \tau_m) b_4 - \tau_m b_3] (G_0 - G^{fb}_\infty) e^{-\sigma t}
\end{align*}
\]

\[
U_r^{fb}(t) = (1 + \tau_r) \pi_r^{fb}(t) - \pi_r^{fb}(t) + [(1 + \tau_r) a_3 - \tau_r a_4] (R_0 - R^{fb}_\infty) e^{-\epsilon t}
+ [(1 + \tau_r) b_3 - \tau_r b_4] (G_0 - G^{fb}_\infty) e^{-\sigma t}
\]

where \(\pi_m^{fb} = a_4 R^{fb}_\infty + b_4 G^{fb}_\infty + c_7 \pi^{fb} = a_3 R^{fb}_\infty + b_3 G^{fb}_\infty + c_6, a_3 = \frac{-\alpha \pi_2}{\rho + \epsilon},\)

\[
a_4 = \frac{-\alpha \pi_1}{\rho + \epsilon}, b_4 = \frac{\mu \pi_2}{\rho + \sigma}, c_6 = \frac{\pi_1}{\rho + \sigma}.
\]
Table 3. The relationship between related parameters

|     | \(\pi_1\) | \(\pi_2\) | \(\tau_m\) | \(\tau_r\) | \(\eta_m\) | \(\eta_r\) | \(\alpha\) | \(\beta\) | \(k\) | \(\epsilon\) | \(\sigma\) | \(\lambda\) | \(\mu\) | \(\rho\) |
|-----|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-------|-----------|-----------|-----------|-------|-------|
| \(E\) | + | - | - | - | \(x\) | + | + | + | - | - | + | + | + | + |
| \(A\) | - | + | - | - | \(x\) | - | \(x\) | \(x\) | + | + | - | + | - | - |
| \(G_\infty\) | - | + | - | - | \(x\) | - | \(x\) | + | + | - | + | - | - | - |
| \(R_\infty\) | + | - | - | - | \(x\) | - | \(x\) | - | + | + | - | - | - | - |

\[ c_7 = \begin{cases} 
\frac{(1 + \tau_m) \pi_1}{\tau_m \pi_2} & + \left(\frac{(1 + \tau_m + \tau_r)(1 - \gamma_b) \tau_m \pi_2}{(1 + \tau_m) - (1 + \tau_r + \gamma_b)(1 + \tau_r)m \pi_2} \right) \left[\frac{2}{(1 + \tau_m + \tau_r) \eta_m (1 + \tau_m) \pi_2} \right] \pi_1^{\frac{(p+\alpha)(p+\beta)}{2}} \\
- \frac{(1 + \tau_r) \pi_2}{\tau_r \pi_1} & - \frac{1}{(1 + \tau_m + \tau_r)(1 + \tau_r) \phi_b \pi_2} \pi_1^{\frac{(p+\alpha)(p+\beta)}{2}} \\
2(1 + \tau_m + \tau_r) \pi_2 & + \frac{2}{(1 + \tau_m + \tau_r) \eta_m (1 + \tau_m) \pi_2} \pi_1^{\frac{(p+\alpha)(p+\beta)}{2}} \\
- (1 + \tau_m + \tau_r) \pi_2 & - (1 + \tau_m + \tau_r) \pi_2 \\
\end{cases} \]

Theorem 4.5. The optimal low-carbon promotion cost-sharing ratio provided by the manufacturer is as follows:

\[ \phi_b = \begin{cases} 
\frac{2(1 + 2\tau_r)(1 + \tau_r)(1 + \tau_m)\pi_1 - \tau_m \pi_2}{2(1 + 2\tau_r)^2(1 + \tau_m)\pi_1 - \tau_m \pi_2} & , \quad 2A \geq B, \\
0, & , \quad 2A < B \\
\end{cases} \]

where \(A = (1 + 2\tau_r)(1 + \tau_r)((1 + \tau_m)\pi_1 - \tau_m \pi_2)/(1 + \tau_r - 2\tau_r \tau_m)(1 + \tau_m)\pi_2 - \tau_r \pi_1).\)

The optimal emission reduction cost-sharing ratio provided by the retailer is as follows:

\[ \gamma_b = \begin{cases} 
\frac{2(1 + 2\tau_m)(1 + \tau_m)(1 + \tau_r)\pi_2 - \tau_r \pi_1}{2(1 + 2\tau_m)^2(1 + \tau_r)\pi_2 - \tau_r \pi_1} & , \quad 2C \geq D, \\
0, & , \quad 2C < D \\
\end{cases} \]

where \(C = (1 + 2\tau_m)(1 + \tau_m)((1 + \tau_r)\pi_2 - \tau_r \pi_1)/(1 + \tau_m)\pi_2 - \tau_m \pi_2).\)

5. Comparison and analysis.

Corollary 1. The relationship between related parameters under decentralized scenario with fairness concern is shown in Table 3.

Note: “+” indicates positive correlation; “−” indicates negative correlation; “×” indicates irrelevant.

Corollary 1 shows: (1) When both the manufacturer and retailer are fairness concern, with the increase in its own marginal revenue, the manufacturer’s investment in emission reduction and the manufacturer’s investment in low-carbon promotion will also continue to increase, while with the other side’s marginal revenue and its own intensity of fairness concern continuously increasing, the manufacturer’s investment in emission reduction and the retailer’s investment in low-carbon promotion will continue to decrease, which will seriously damage low-carbon goodwill and negatively affect product demand. Therefore, when the supply chain members’ fairness concern intensity is certain, in order to further weaken negative effects of fairness concern behavior, the supply chain members should start from their own point of view and increase their own marginal profits through a variety of ways, thereby...
reducing the negative impact of supply chain members’ fairness concern behavior on the entire supply chain.

(2) The manufacturer’s investment in emission reduction and retailer’s investment in low-carbon promotion will decrease as their own fairness concern intensity continues to increase, while having nothing to do with the other party’s fairness concern intensity. This means that within the reasonable scope of their own fairness concern intensity, supply chain members showing a higher intensity of fairness concern to the other party will seriously damage the emission reduction cooperation between the two parties, which is not only harmful to their own profits, but also bring products with higher carbon level and lower low-carbon goodwill to consumers, weaken the market competitiveness of the overall supply chain and cause serious damage to the entire supply chain.

(3) With the increasing impact of the reference low-carbon effect and emission reduction level on product demand, manufacturers’ investment in emission reduction and consumer’s reference low-carbon level will continue to increase. With the increasing impact of the low-carbon promotion level and low-carbon goodwill on product demand, retailers’ investment in low-carbon promotion and product low-carbon goodwill will continue to increase. With the increasing impact of the low-carbon promotion level on product low-carbon goodwill, retailers’ investment in low-carbon promotion and product low-carbon goodwill will also continue to increase. This shows that facing the market environment under the influence of many factors, supply chain members will always be able to adjust their measures accordingly to maximize their own profits.

(4) As the memory parameter continues to increase, manufacturers’ investment in emission reduction and consumer’s reference low-carbon level will continue to decrease, while retailers’ investment in low-carbon promotion and the low-carbon goodwill will not be affected. This means that when consumers are inclined to short-term memory of the emission reduction level of the product, they judging the low-carbon level of products based on the low-carbon level during a short time will weaken manufacturers’ enthusiasm to invest in emissions reduction, and finally affect the low-carbon level of products they purchase.

(5) As the discount rate continues to increase, manufacturers’ investment in emission reduction and consumer’s reference low-carbon level will continue to increase, while retailers’ investment in low-carbon promotion and low-carbon goodwill will continue to decrease. This is because the higher the discount rate, the more the company cares about short-term profits. At this time, the manufacturer’s emission reduction investment can be perceived by the market in a short time due to the reference low-carbon effect, while the retailer’s low-carbon promotion investment is difficult to be perceived by the market in a short time, so the higher discount at this time will enhance the enthusiasm of manufacturers to invest in emissions reduction, while will weaken the enthusiasm of retailers to invest in low-carbon promotion.

Corollary 2. \[ E^c > E^n > E^f, A^c > A^n > A^f, R^c_\infty > R^n_\infty > R^f_\infty, G^c_\infty > G^n_\infty > G^f_\infty, E^{fb} > E^f, A^{fb} > A^f, R^{fb}_\infty > R^f_\infty, G^{fb}_\infty > G^f_\infty. \]

It can be seen from Corollary 2 that under centralized scenario, the manufacturer’s emission reduction investment and the retailer’s low-carbon promotion investment are both the largest. The fairness concern behavior of the manufacturer and the retailer can seriously cause both parties to reduce emission reduction investment, make the emission reduction investment of both parties less than that
when they are fully fairness neutral. Retailers sharing emission reduction costs for manufacturers can effectively encourage manufacturers to increase emission reduction investment, but the increased emission reduction investment of manufacturers still cannot reach the level of centralized scenario. Similarly, manufacturers sharing low-carbon promotion costs for retailers can effectively encourage retailers to increase low-carbon promotion investment, but the increased low-carbon promotion investment of retailers still cannot reach the level of centralized scenario. In addition, the relationship of the steady-state low-carbon goodwill and consumer’s reference low-carbon level under these scenarios is consistent with the conclusion of the retailer’s investment in low-carbon promotion and manufacturer’s investment in emission reduction.

**Corollary 3.** \( \frac{∂(R^n_∞ - R^f_∞)}{∂τ_m} = \frac{∂(R^n(τ) - R^f(τ))}{∂τ_m} > 0, \frac{∂(R^n_∞ - R^f_∞)}{∂τ_m} = \frac{∂(R^n(τ) - R^f(τ))}{∂τ_m} > 0; \) when \( R_0 < R^f_∞ < R^n_∞ < R^n_∞ \), there is \( \frac{∂(R^n(τ))}{∂τ} > \frac{∂(R^n(τ))}{∂τ} > \frac{∂(R^f(τ))}{∂τ} > 0; \) when \( R_0 > R^f_∞ > R^n_∞ > R^f_∞ \), there is \( \frac{∂(R^n(τ))}{∂τ} = 0; \) when \( R_0 = R^f_∞ \), there is \( \frac{∂(R^n(τ))}{∂τ} = 0; \) when \( R_0 = R^n_∞ \), there is \( \frac{∂(R^n(τ))}{∂τ} = 0. \)

It can be seen from Corollary 3 that as the intensity of the fairness concern behavior of manufacturers continues to increase, the difference between the steady-state reference low-carbon level under centralized scenario and the steady-state reference low-carbon level under decentralized scenario with fairness concern will continue to expand, which again verifies that the fairness concern behavior of the manufacturer will severely cause it to decrease its own emission reduction investment. If the initial consumer’s reference low-carbon level of the product is less than the steady-state reference low-carbon level under each decision scenario, consumer’s reference low-carbon level of the product will continue to rise over time, otherwise, consumer’s reference low-carbon level of the product will continue to decrease over time.

**Corollary 4.** \( \frac{∂(G^n_∞ - G^f_∞)}{∂τ_m} = \frac{∂(G^n(τ) - G^f(τ))}{∂τ_m} > 0, \frac{∂(G^n_∞ - G^f_∞)}{∂τ_m} = \frac{∂(G^n(τ) - G^f(τ))}{∂τ_m} > 0; \) when \( G_0 < G^n_∞ < G^n_∞ < G^n_∞ \), there is \( \frac{∂(G^n(τ))}{∂τ} > \frac{∂(G^n(τ))}{∂τ} > \frac{∂(G^f(τ))}{∂τ} > 0; \) when \( G_0 > G^n_∞ > G^n_∞ > G^n_∞ \), there is \( \frac{∂(G^n(τ))}{∂τ} = 0; \) when \( G_0 = G^f_∞ \), there is \( \frac{∂(G^n(τ))}{∂τ} = 0; \) when \( G_0 = G^n_∞ \), there is \( \frac{∂(G^n(τ))}{∂τ} = 0. \)

It can be seen from Corollary 4 that as the intensity of the retailer’s fairness concern behavior continues to increase, the difference between the steady-state low-carbon goodwill under centralized scenario and the steady-state low-carbon goodwill under decentralized scenario with fairness concern will continue to expand, which also again verifies that the fairness concern behavior of the retailer will severely cause it to decrease its own low-carbon promotion investment. If the initial low-carbon goodwill of the product is less than the steady-state low-carbon goodwill under each decision scenario, the low-carbon goodwill of the product will continue to rise over time, otherwise, the low-carbon goodwill of the product will continue to decrease over time.

**Corollary 5.** \( \frac{∂φ_n}{∂τ_m} < 0, \frac{∂φ_n}{∂τ_2} > 0, \frac{∂φ_n}{∂τ_2} > 0, \frac{∂φ_n}{∂τ_2} < 0, \frac{∂φ_n}{∂τ_7} < 0, \frac{∂φ_n}{∂τ_7} > 0, \frac{∂φ_n}{∂τ_2} > 0, \frac{∂φ_n}{∂τ_7} < 0, \frac{∂φ_n}{∂τ_2} < 0, \frac{∂φ_n}{∂τ_7} < 0, \frac{∂φ_n}{∂τ_2} < 0. \)
It can be seen from Corollary 5 that the cost-sharing ratio of low-carbon promotion provided by the manufacturer to the retailer will decrease with the increase in the intensity of its fairness concern behavior and the retailer’s marginal revenue, and will increase with the increase in its own marginal revenue and the retailer’s intensity of fairness concern. Similarly, the cost-sharing ratio of emission reduction provided by the retailer to the manufacturer will decrease with the increase in the intensity of its fairness concern behavior and the manufacturer’s marginal revenue, and will increase with the increase in its own marginal revenue and the manufacturer’s intensity of fairness concern. This is consistent with the reality. When the manufacturer or retailer are fairness concern, they will pay more attention to the other party’s profit and when the other party’s profit exceeds its own profit, it will cause negative utility, therefore, it is not difficult to understand that in order to maximize its own utility at this time, the manufacturer or retailer will reduce the cost-sharing ratio of the other party’s emission reduction investment. But regardless of whether the manufacturer or retailer is fairness concern, as their own marginal revenue increases, they will naturally strengthen their incentives for the other party to invest in emission reduction. On the contrary, when the other party’s marginal revenue increases, it is not difficult to understand that at this time the other party has a strong economic power to invest in emission reduction, so the manufacturer or retailer will reduce its economic support for the other party’s emission reduction investment. In addition, the manufacturer’s profit will decrease as its and the retailer’s intensity of the fairness concern behavior increases, and the retailer’s profit will also decrease as its and the manufacturer’s intensity of the fairness concern behavior increases. This indicates that the fairness concern behavior of both parties will cause serious damage to their own profits and the profit of the other party.

**Corollary 6.** $\frac{\partial^2 E_f}{\partial \epsilon^2} > 0$, $\frac{\partial^2 E_f}{\partial \epsilon \partial \pi^1_m} < 0$, $\frac{\partial^2 E_f}{\partial \epsilon \partial \tau^m} > 0$, $\frac{\partial^2 E_f}{\partial \epsilon \partial \alpha} < 0$.

It can be seen from Corollary 6 that as the memory parameter continues to increase, the rate of decline of the manufacturer’s emission reduction investment with the increase of memory parameter will be lower. Similarly, as the intensity of the manufacturer’s fairness concern behavior continues to increase, the rate of decline of the manufacturer’s emission reduction investment with the increase of the memory parameter will also be lower. As the consumers’ reference low-carbon effect coefficient continues to increase, the rate of decline of the manufacturer’s emission reduction investment with the increase of the memory parameter will also be higher. While as the manufacturer’s marginal revenue continues to increase, the rate of decline of the manufacturer’s emission reduction investment with the increase of the memory parameter will be higher.

**Corollary 7.** $\pi_{nm}^n(t) \geq \pi_{nm}^n(t), \pi_{nr}^n(t) \geq \pi_{nr}^n(t), \pi_{mb}^b(t) > \pi_{mb}^b(t), \pi_{fb}^b(t) > \pi_{fb}^b(t), \pi_{nm}^n(t) + \pi_{nr}^n(t) < \pi_{nc}(t), \pi_{nm}^b(t) + \pi_{fb}^b(t) < \pi_{nc}(t)$.

It can be seen from Corollary 7 that compared with the scenario when both parties do not have fairness concern behavior, the fairness concern behavior of the manufacturer and the retailer will cause the decrease in the profits of both parties. When the manufacturer and the retailer choose to share the emission reduction costs with each other, it can further improve the profit level of both parties. In addition, the overall profit of the supply chain under centralized scenario is the greatest, under decentralized scenario with fairness concern, even if both parties share the emission reduction costs with each other, the overall profit of the supply chain at this time still cannot reach the level of centralized decision-making scenario.
6. Supply chain coordination with fairness concern. Through the analysis in the previous section, a simple bilateral cost-sharing contract cannot achieve perfect coordination in the supply chain. Therefore, we will coordinate the supply chain by designing a bilateral cost sharing-revenue sharing hybrid contract in this section. The main content of the hybrid contract is: both parties will adopt the optimal decisions under the centralized decision scenario. At the same time, the manufacturer will provide the retailer with a reasonable low-carbon promotion cost-sharing ratio $\phi_c (0 < \phi_c < 1)$, and the retailer will also provide the manufacturer with a reasonable emission reduction cost-sharing ratio $\gamma_c (0 < \gamma_c < 1)$, the revenue-sharing coefficient is $\theta (0 < \theta < 1)$, which means the proportion of the manufacturer benefiting from selling low-carbon products is $\theta$, the proportion of the retailer benefiting from selling low-carbon products is $1 - \theta$.

At this time, the objective functions of the manufacturer and retailer are as follows:

$$J^{fc}_{m}(R, G, t) = \max_{E} \int_{0}^{\infty} e^{-\rho t} [(1 + \tau_m)[\theta(\pi_1 + \pi_2)]((\alpha + \beta)E + \mu G + kA - \alpha R] - \frac{\eta_m(1 - \gamma_c)^2}{2} - \frac{\eta_c \phi_c A^2}{2}] - \tau_m[1 - \theta(\pi_1 + \pi_2)][(\alpha + \beta)E + \mu G + kA - \alpha R] - \frac{\eta_c (1 - \phi_c) A^2}{2} - \frac{\eta_m \gamma_c E^2}{2}] dt$$  \hspace{1cm} (13)

$$J^{fc}_{r}(R, G, t) = \max_{A} \int_{0}^{\infty} e^{-\rho t} [(1 + \tau_r)[(1 - \theta)(\pi_1 + \pi_2)]((\alpha + \beta)E + \mu G + kA - \alpha R] - \frac{\eta_r (1 - \phi_c) A^2}{2}] - \tau_r[\theta(\pi_1 + \pi_2)][(\alpha + \beta)E + \mu G + kA - \alpha R] - \frac{\eta_r (1 - \phi_c) A^2}{2}] dt$$  \hspace{1cm} (14)

According to the solution method of the optimal control problem, we can get the retailer’s optimal low-carbon promotion investment at this time:

$$A^{fc} = \frac{[(1 + \tau_r)(1 - \theta) - \tau_r \theta(\pi_1 + \pi_2)[\lambda \mu + k(\rho + \sigma)]}{\eta_r [(1 + \tau_r) - (1 + 2\tau_r) \phi_c](\rho + \sigma)}$$

Similarly, we can get the manufacturer’s optimal emission reduction investment at this time:

$$E^{fc} = \frac{[(1 + \tau_m) \theta - \tau_m(1 - \theta)](\pi_1 + \pi_2)[\rho \alpha + \beta(\rho + \epsilon)]}{\eta_m [(1 + \tau_m) - (1 + 2\tau_m) \gamma_c](\rho + \epsilon)}$$

Here, we let $E^{fc} = E^c, A^{fc} = A^c$, then we can obtain: $\gamma_c = 1 - \theta, \phi_c = \theta$, further we can get $\pi^{fc}_{m} = \theta \pi^{sc}_{m}, \pi^{fc}_{r} = (1 - \theta) \pi^{sc}_{c}$.

In order to make both the manufacturer and the retailer to accept this contract, it is necessary to ensure that the profits of the manufacturer and the retailer under the contract is greater than the profits under the decentralized scenario with fairness
concern, that is $\theta \pi_{sc}^c > \pi_m^f (1 - \theta) \pi_{sc}^c > \pi_r^f$, therefore, we can obtain $\frac{\pi_m^f}{\pi_{sc}^c} < \theta < 1 - \frac{\pi_r^f}{\pi_{sc}^c}$, that is, the upper limit of $\theta$ is $\theta_U = 1 - \frac{\pi_m^f}{\pi_{sc}^c}$, the lower limit of $\theta$ is $\theta_L = \frac{\pi_m^f}{\pi_{sc}^c}$.

**Theorem 6.1.** When the manufacturer’s low-carbon promotion cost-sharing ratio for the retailer meets $\phi_c = \theta$, the retailer’s emission reduction cost-sharing ratio for the manufacturer meets $\gamma_c = 1 - \theta$, and the revenue-sharing coefficient meets $\frac{\pi_m^f}{\pi_{sc}^c} < \theta < 1 - \frac{\pi_r^f}{\pi_{sc}^c}$, this bilateral cost sharing-revenue sharing hybrid contract can achieve supply chain coordination, and the value of the revenue-sharing coefficient $\theta$, depends on the bargaining power of the manufacturer and retailer.

7. **Numerical analysis.** Although the previous section has compared and analyzed the relevant equilibrium solutions, it is difficult to visually display the relevant conclusions considering the complexity of the solutions, this section will present numerical analysis to test the conclusions. Based on the related researches and the specific research hypothesis of this paper, the parameters involved in this paper are set as follows: $\pi_1 = 1, \pi_2 = 0.5, \eta_m = 1, \eta_r = 1, \rho = 0.1, \epsilon = 0.3, \lambda = 0.1, \alpha = 0.1, \beta = 0.8, \sigma = 1, k = 0.4, \mu = 0.1, R_0 = 0, G_0 = 0, \tau_m = 0.5, \tau_r = 0.5$.

(1) Impact of the bilateral cost sharing-revenue sharing hybrid contract

![Figure 1](image)

(a) the effect of $\tau_m$ and $\tau_r$ on $\theta$. (b) the effect of $\theta$ on both parties’ profits.

It can be seen from figure 1(b) that as the revenue-sharing coefficient $\theta$ (low-carbon promotion cost-sharing ratio $\phi_c$) increases, the manufacturer’s profit gap between these two scenarios will increase, while the retailer’s profit gap between these
two scenarios will decrease. When the revenue-sharing coefficient $\theta$ (low-carbon promotion cost-sharing ratio $\phi_c$) meets $\theta \in (0.37, 1)$, the manufacturer’s profit with the bilateral cost sharing-revenue sharing hybrid contract will be higher than that under the decentralized scenario with fairness concern. When the revenue-sharing coefficient $\theta$ (low-carbon promotion cost-sharing ratio $\phi_c$) meets $\theta \in (0, 0.68)$, the retailer’s profit with the bilateral cost sharing-revenue sharing hybrid contract will be higher than that under the decentralized scenario with fairness concern. In short, When the revenue-sharing coefficient $\theta$ meets $\theta \in (0.37, 0.68)$, which is, the low-carbon promotion cost-sharing ratio provided by the manufacturer satisfies $\phi_c \in (0.37, 0.68)$, the emission reduction cost-sharing ratio provided by the retailer satisfies $\gamma_c \in (0.32, 0.63)$, the profits of both parties with the bilateral cost sharing-revenue sharing hybrid contract will be higher than that under the decentralized scenario with fairness concern, and the bilateral cost sharing-revenue sharing hybrid contract can effectively coordinate the supply chain when the manufacturer and the retailer are both fairness concern.

It can be seen from figure 1 (a) that the upper limit of value of the revenue-sharing coefficient $\theta_U$ (the upper limit of value of the low-carbon promotion cost-sharing ratio $\phi_c$) will increase as the intensity of the manufacturer’s and retailer’s fairness concern increases, the lower limit of value of the revenue-sharing coefficient $\theta_L$ (the lower limit of value of the low-carbon promotion cost-sharing ratio $\phi_c$) will decrease as the intensity of the manufacturer’s and retailer’s fairness concern increases. The above phenomenon shows from the side that both parties’ fairness concern is not conducive to the improvement of their own profits.

(2) Impact of Time $t$

\[ G(t), R(t) \]

\[ G(t), R(t) \]

**Figure 2.** (a) The evolution path of low-carbon goodwill $G(t)$. (b) The evolution path of reference low-carbon level $R(t)$. 
Figure 2 shows that under the four decision scenarios, product low-carbon goodwill and reference low-carbon level all have a time-stabilizing trend, showing that they tend to a certain stable value when time tends to infinity. In addition, it can be seen that since the initial product low-carbon goodwill and reference low-carbon level are both assumed to be 0 at this time, which is less than the stable value, the product low-carbon goodwill and reference low-carbon level both show a monotonous increasing trend over time. At the same moment, each state quantity under centralized decision scenario is the highest, and it is much larger than that under each decentralized decision scenario. Each state quantity under decentralized decision scenario with fairness concern is lower than that under decentralized decision scenario without fairness concern. When both parties share the emission reduction cost with each other, each state quantity will be further improved. The above phenomenon shows that the fairness concern behavior of manufacturers and retailers will seriously reduce product low-carbon goodwill and reference low-carbon level, and when manufacturers and retailers both share the emission reduction cost with each other, it will help further improve product low-carbon goodwill and reference low-carbon level in a certain degree so as to alleviate the negative effects of both parties’ fairness concern behavior.

It can be seen from Figure 3 (a), (b) and (c) that as time goes by, the profits of the manufacturer, the retailer and the overall supply chain under each decision scenario continue to decrease, and eventually tend to a certain stable value. Moreover, when both parties have fairness concern behavior, the profits of both parties will decrease compared with when they do not have fairness concern behavior. In addition, when both parties share the emission reduction cost with each other, the profits of both parties have been further improved. From Figure 3(c), it can be seen that the overall profit of the supply chain under centralized decision scenario is much greater than that under each decentralized decision scenario. The overall profit of the supply chain under decentralized decision scenario without fairness concern is the second, while the overall profit of the supply chain under decentralized decision scenario with fairness concern without a bilateral cost-sharing contract is the lowest. From Figure 3 (d) and (e), it can be seen that both parties’ fairness utilities continue to decrease over time, and eventually tend to a certain stable value. This indicates that from a long-term perspective, if both the manufacturer and the retailer hold a fairness concern attitude towards each other, it will not only seriously damage the sustained and stable growth of the both parties’ profits, but also produce lasting and negative social impact. From Figure 3(f), it can be seen that the difference between the utilities of the manufacturer and the retailer under the two decision scenarios with fairness concern will decrease over time, and eventually tends to a certain stable value. This means that when the manufacturer and the retailer both have fairness concern behavior, if both parties share the emission reduction cost with each other, the utilities of both parties will be further improved.

(3) Impact of Fairness Concern

It can be seen from Figure 4 (a) that with the increase in the intensity of the manufacturer’s fairness concern, the low-carbon promotion cost-sharing ratio provided by the manufacturer will decrease, while it will increase with the increase in the intensity of the retailer’s fairness concern. It can also be seen from Figure 4 (b) that with the increase in the intensity of the manufacturer’s fairness concern, the emission reduction cost-sharing ratio provided by the retailer will increase, while it will decrease with the increase in the intensity of the retailer’s fairness concern.
The above phenomenon is consistent with Corollary 5. The above phenomenon indicates that when both parties are fairness concern, if they choose to share emission reduction cost with each other, the manufacturer’s higher level of fairness concern will reduce its motivation to share the low-carbon promotion cost for the retailer, while the retailer’s higher level of fairness concern will force the manufacturer to share a higher proportion of low-carbon promotion cost for itself. It is not difficult to understand that this is because when the manufacturer pays too much attention to fairness, in order to avoid the other party’s profit surpassing its own profit, it is unwilling to share the emission reduction cost for the other party. While the more the retailer pays attention to fairness, in order to maximize its own utility, it will adopt a series of measures to force the manufacturer to share the emission reduction cost for itself. This is also true when retailers share the emission reduction cost for manufacturers.

From Figure 4 (c) and (d), it can be seen that the manufacturer’s emission reduction investment will decrease as its fairness concern intensity increases, and it has nothing to do with the retailer’s fairness concern intensity. The retailer sharing
Figure 4. (a) The impact of $\tau_m$ and $\tau_r$ on the low-carbon promotion cost-sharing ratio. (b) The impact of $\tau_m$ and $\tau_r$ on the emission reduction cost-sharing ratio. (c) The impact of $\tau_m$ and $\tau_r$ on the manufacturer’s emission reduction investment. (d) The impact of $\tau_m$ and $\tau_r$ on the retailer’s low-carbon promotion investment. (e) The impact of $\tau_m$ and $\tau_r$ on the manufacturer’s profit $\pi_m^f$. (f) The impact of $\tau_m$ and $\tau_r$ on the retailer’s profit $\pi_r^f$.

Emission reduction cost for the manufacturer can further encourage the manufacturer to increase emission reduction investment. Similarly, the retailer’s low-carbon promotion investment will decrease as its fairness concern intensity increases, and it has nothing to do with the manufacturer’s fairness concern intensity. The manufacturer sharing low-carbon promotion cost for the retailer can further encourage the retailer to increase low-carbon promotion investment. The above phenomenon indicates that when both parties are fairness concern, they will both reduce their emission reduction investment, which is not good for the sustainability of supply chain. If the two parties can share the emission reduction cost at this time, it can weaken the negative impact of their fairness concern behavior on their emission reduction investment to a certain extent.

From Figure 4(e), it can be seen that the profit of the manufacturer decreases as its fairness concern intensity increases, and it will also decrease as the retailer’s fairness concern intensity increases. From Figure 4(f), it can also be seen that the profit of the retailer decreases with the increase of its fairness concern intensity, and
it will also decrease with the increase of the manufacturer's fairness concern intensity. The above phenomenon shows that even if the decisions made by both parties based on fairness concern can maximize their own utilities, the manufacturer’s and retailer’s fairness concern will seriously do harm to the profits of its own and the other party, and ultimately seriously affect the overall profit of the supply chain and weaken the market competitiveness of the entire supply chain. The more both parties are concerned about fairness, the greater the intensity of fairness concern, and the decisions made by both parties based on fairness concern will have a more serious negative impact on both parties’ profits.

(4) Impact of Reference Low-Carbon Effect

Combining Figure 5 (a) and (b), it can be seen that the manufacturer’s emission reduction investment will decrease as the memory parameter $\epsilon$ increases, while it will increase with the increase in $\alpha$. Besides, we can see that as $\alpha$ is becoming larger and larger, the emission reduction investment’s rate of decline with the increase in the $\epsilon$ is also becoming greater and greater. However, when $\epsilon$ is becoming larger and larger, the emission reduction investment’s rate of increase with the increase in $\alpha$ is becoming smaller and smaller. This indicates that when consumers have a long-term memory of the product’s low-carbon level, and they are very concerned about reference low-carbon effect, at this time, it can significantly stimulate the increase in the manufacturer’s emission reduction investment. On the contrary, when consumers have a short-term memory of the product’s low-carbon level, and they are not sensitive to reference low-carbon effect, at this time, it will weaken manufacturers’ enthusiasm to conduct emission reduction.

It can be seen from Figure 5 (c) that as the intensity of the manufacturer’s fairness concern $\tau_m$ increases, the manufacturer’s emission reduction investment will decrease, as the memory parameter $\epsilon$ increases, the manufacturer’s emission reduction investment will also decrease. Besides, it can be clearly seen that as $\tau_m$ is becoming smaller and smaller, the rate of decline of the manufacturer’s emission reduction investment with the increase in the memory parameter $\epsilon$ is becoming greater and greater. While when $\epsilon$ is becoming smaller and smaller, the rate of increase of the manufacturer’s emission reduction investment with the decrease in $\tau_m$ is becoming larger and larger. It can be seen from Figure 5 (d) that as the intensity of the manufacturer’s fairness concern $\tau_m$ increases, the manufacturer’s emission reduction investment will decrease, while as $\alpha$ increases, the manufacturer’s emission reduction investment will increase. The above phenomenon indicates that when consumers in the market are more sensitive to reference low-carbon effect, and they tend to have a long-term memory of the product’s low-carbon level, this will effectively weaken the negative impact of the manufacturer’s fairness concern on its emission reduction investment to a certain extent.

It can be seen from Figure 5(e) and (f) that as the reference low-carbon effect $\alpha$ increases, both parties’ profits will continue to decrease, with the increase of the memory parameter $\epsilon$, both parties’ profits will continue to increase. Particularly, when the reference low-carbon effect reaches its maximum and the memory parameter reaches its minimum, both parties’ profits will reach a minimum level. The above phenomenon indicates that when consumers in the market are not sensitive to reference low-carbon effect, and they tend to have a long-term memory of the product’s low-carbon level, it can significantly improve both parties’ profits.
Figure 5. (a) The impact of $\epsilon$ on the manufacturer’s emission reduction investment. (b) The impact of $\alpha$ and $\epsilon$ on the manufacturer’s emission reduction investment. (c) The impact of $\tau_m$ and $\epsilon$ on the manufacturer’s emission reduction investment. (d) The impact of $\tau_m$ and $\alpha$ on the manufacturer’s emission reduction investment. (e) The impact of $\alpha$ and $\epsilon$ on the manufacturer’s profit $\pi^f_m$. (f) The impact of $\alpha$ and $\epsilon$ on the retailer’s profit $\pi^f_r$. (g) The impact of initial reference low-carbon level $R_0$ on the manufacturer’s profit. (h) The impact of initial reference low-carbon level $R_0$ on the retailer’s profit.

Figure 5(g) and (h) shows that as the initial reference low-carbon level increases, both parties’ profits will decrease. This indicates that a higher initial reference low-carbon level of the product will have a significantly negative effect on both parties’ profits. The reason is when the initial reference low-carbon level of consumers in the market is high, which means that consumers in the market have higher expectation...
or requirements for the emission reduction level of the product at this time, the manufacturer can not meet or will find it difficult to meet consumers' requirements and expectation through the emission reduction investment at present, therefore, it will inevitably cause a negative impact on the product demand, and will finally cause the decrease in both parties' profits.

8. Conclusions and discussion. In the context of the low-carbon economy, this paper introduces consumers’ reference low-carbon effect and the supply chain members’ fairness concern behavior into the joint emission reduction issue of a supply chain, and respectively constructs decision-making models under four decision scenarios: centralized scenario, decentralized scenario without fairness concern, decentralized scenario with fairness concern and decentralized scenario with fairness concern and a bilateral cost-sharing contract. Then this paper uses Stackelberg differential game theory and Bellman continuous dynamic programming theory to solve the equilibrium solutions under the four decision scenarios in turn, and discusses the impact of the supply chain members' fairness concern behavior, consumers' reference low-carbon effect, bilateral cost-sharing contract on supply chain members' equilibrium strategies and performance from a long-term perspective. Finally, in order to effectively coordinate the supply chain when supply chain members are fairness concern under decentralized scenario, this paper designs a bilateral cost sharing-revenue sharing hybrid contract. After mathematical derivation and numerical analysis, the following conclusions can be obtained.

Compared with both parties not having fairness concern behavior, manufacturers’ emission reduction investment, retailers' low-carbon promotion investment, steady-state low-carbon goodwill level, steady-state reference low-carbon level and both parties’ profits will decrease when both parties have fairness concern behavior. When both parties have fairness concern behavior and choose to share emission reduction costs with each other, both parties' profits and utilities can be further improved compared with no bilateral cost-sharing contract.

Under decentralized scenario with fairness concern and a bilateral cost-sharing contract, both parties sharing emission reduction cost with each other can effectively help promote manufacturers to increase emission reduction investment, promote retailers to increase low-carbon promotion investment. As the two cost-sharing ratios increase, manufacturers’ emission reduction investment and retailer’s low-carbon promotion investment will both continue to increase. The optimal emission reduction cost-sharing ratio provided by the retailer to the manufacturer is positively related to its own marginal revenue and the manufacturer's fairness concern intensity, while is negatively related to its own fairness concern intensity. Similarly, the optimal low-carbon promotion cost-sharing ratio provided by the manufacturer to the retailer is positively related to its own marginal revenue and the retailer's fairness concern intensity, while is negatively related to its own fairness concern intensity.

When the initial reference low-carbon level is high, the reference low-carbon effect is harmful to both parties. At this time, the manufacturer should try to reduce emission reduction investment to the greatest extent, but the retailer should increase low-carbon promotion investment to weaken the negative impact on product demand because of the manufacturer's emissions reduction investment reduction of the manufacturer. Consumers’ reference low-carbon effect will seriously reduce the profits of both parties and force manufacturers to reduce emission reduction
investment, which will directly do harm to product low-carbon level and eventually adversely affect the low-carbon product market.

The fairness concern behavior of manufacturers and retailers can dampen the manufacturer’s enthusiasm to invest in emission reduction, lower the retailer’s low-carbon promotion investment level, thereby reducing low-carbon goodwill and consumer demand. At the same time, it will also aggravate the adverse effects of consumers’ reference low-carbon effect and do harm to the profits of both parties, increase the double marginal effect of the supply chain, and the degree of damage will increase with the increase in the intensity of both parties’ fairness concern.

When the low-carbon promotion cost-sharing ratio provided by the manufacturer, the emission reduction cost-sharing ratio provided by the retailer, and the revenue-sharing coefficient between the two parties meet a certain relationship, and both parties adopt the equilibrium strategies under the centralized decision scenario, then the supply chain system when both parties are fairness concern can reach coordination at this time, and both parties’ profits can achieve Pareto improvement. The upper limit of value of the revenue-sharing coefficient is positively related to the intensity of the manufacturer’s and retailer’s fairness concern; while the lower limit of value of the revenue-sharing coefficient is negatively related to the intensity of the manufacturer’s and retailer’s fairness concern.

Based on the above conclusions, in order to provide more references for supply chain companies to make suitable emission reduction decisions, we give the following management insights.

Both the government and supply chain enterprises should strengthen the propaganda of the low-carbon economy through a variety of ways, and advocate a low-carbon culture, so that it can raise the public’s awareness of environmental protection and promote low-carbon consumption. In addition, the government should establish a scientific low-carbon product certification system and increase the supervision of low-carbon certified products, so that it can strengthen consumers’ belief in low-carbon products. At the same time, supply chain enterprises should strengthen communication with potential consumers, and stimulate potential consumers through various information such as promotion information, technological progress information, quality information, etc., and strengthen their memory of the enterprises’ emission reduction efforts, reduce the negative impact of consumers’ reference low-carbon effect and maintain a good low-carbon product market to a certain extent.

In the context of the low-carbon economy, in order to maintain continuous market competitiveness and achieve sustainable development, supply chain enterprises should abandon fairness concern awareness when conducting joint emission reduction activities, and should actively cooperate by sharing emission reduction costs with each other, because a cost-sharing contract can effectively increase the profits of both parties. At the same time, since the cost-sharing ratio is proportional to supply chain members’ own marginal revenue and fairness concern intensity, in order to further enhance the cooperation level between the two parties, manufacturers and retailers should pay more attention to their own marginal revenue and fairness concern intensity to ensure that more profit and utility increments can be obtained. In addition, due to the long-term and dynamic characteristics of emission reduction activities, supply chain enterprises should also focus on making emission reduction decisions from a long-term perspective and shouldn’t be constrained to short-term interests at the same time.
This paper still has some shortcomings that need to be explored in the future. First, this paper does not consider the influence of government intervention policies (carbon tax, carbon trading, etc.), future research can combine government intervention policies and supply chain member behavior factors for discussion. Second, this paper considers the deterministic demand model, future research can introduce uncertain demand into long-term dynamic decision-making issue. Third, this paper only considers supply chain members’ fairness concern behavior, but in real life, supply chain members may be affected by multiple behaviors at the same time due to the impact of multiple factors. Therefore, future studies can explore the influence of other behavioral factors on the joint emission reduction decisions of supply chain members from a long-term perspective. Finally, this paper does not consider the influence of price factors when constructing the demand function model, and assumes that the marginal revenue of manufacturers and retailers is constant. Therefore, future studies can explore how consumers’ reference low-carbon effect and supply chain members’ fairness concern behavior affect their decisions and performance when the price factors are considered.

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