RAIRO-Oper. Res. 55 (2021) S2487–S2508
https://doi.org/10.1051/ro/2020098

RAIRO Operations Research
www.rairo-ro.org

WITHDRAWN: OPTIMAL CAP SETTING AND PRICING IN SUPPLY CHAINS UNDER VERTICAL-HORIZONTAL COOPERATION AND CAP-AND-TRADE REGULATION

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Abstract. This article has been withdrawn at the request of the authors, who did not approve the publication in a supplementary issue. The Publisher apologizes for the inconvenience this is causing.

Mathematics Subject Classification. 90B05.

Received April 25, 2020. Accepted September 7, 2020.

1. Introduction

In recent decades, global attention has been paid to carbon emissions, and various international government organizations have made efforts to curb carbon emissions. From the international perspective, the Paris agreement has officially entered into force, which has made clear the global "2 °C temperature rise target" and the medium and long-term emission control target of all countries. Green and low-carbon development has become the global trend. In China, the carbon intensity in 2020 will be 18% lower than that in 2015 is a core goal of China's low carbon development during the 13th Five Year Plan period. It is proposed in the 13th Five Year Plan for controlling greenhouse gas emissions. The co-ordination mechanism is an important factor in the supply chain operation. As revenue sharing contract, cost sharing contract and wholesale price contract etc. are widely adopted in academic researchers [13, 17, 18, 21, 35].

Keywords. Cooperation, cap-and-trade, supply chain, government decision.

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Article published by EDP Sciences

However, carbon emissions regulations, including a cap-and-trade regulation, will increase the production costs of the manufacturing enterprises to some extent and affect other enterprises in the supply chain; in order to cope with the pressure from carbon policies, enterprises have attempted to adjust their operational decisions. The implementation of the carbon cap-and-trade policy comes from Kyoto Protocol, which realizes the goal of energy conservation and emission reduction through government regulation and market regulation. The implementation of this policy makes the greenhouse gas emission right become a kind of scarce resource with liquidity, and promotes the carbon emission trading market by carbon dioxide. The cap-trade policy is a way of emission reduction which combines direct regulation and economic incentives on the basis of carbon emission cap. Montgomery [20] made a forward-looking conception and introduction to the concept of emissions trading earlier.

With the development of market economy, the enterprises' competition was changed to the competition of cross industry industrial chain. Martin Christopher who is a supply chain management expert of British, pointed out that the competition is no longer the competition between enterprises, but the competition between supply chain and supply chain in the 21st century. It has become an urgent research topic for the development of enterprises in the new situation that all enterprises in the supply chain cooperate in order to achieve the overall optimization.

The cooperation between enterprises in the supply chain has two types: the structural cooperation and contractual cooperation. The structural cooperation means that the members adopt the collaboration without the assistance of a cooperation contract. Contract design is an important topic in the supply chain operations management literature. In the study of supply chain coordination mechanism, common cooperation contracts include the cost sharing contract, revenue sharing contract, and wholesale price contract. In this paper, the wholesale price contract is introduced through a special solution method [13]. The solution method means that the manufacturer as a leader of Stackelbeg game in a supply chain sets the retailer price to maximize its profit.

The remainder of this paper is organized as follows. Section 2 reviews the literature and Section 3 introduces the formulation and notation of the models. Section 4 describes the six different models and analyzes the optimal solution of them. Section 5 provides numerical examples and Section 6 expound some relevant conclusions. The Appendices A and B provides all the proofs.

2. Literature review

There are four main streams of research that closely relate to our work. The first stream focuses on the influence of cap-trade regulation on the supply chain decision. The second stream is related to the government decision under the cap-and-trade regulation. The third stream concentrates on the competitive decision of low-carbon supply chains. The last stream is about the coordination of the supply chain (the wholesale price contract and Nash bargaining).

In the first research stream, the environmental problems in the supply chain are concerned by many researchers as governments' environmental policies tighten. For the cap-and-trade regulation, the carbon emission cap is an exogenous parameter in some research literatures. Under the low-carbon environment, Wang *et al.* [26] focus on a dyadic supply chain with a manufacturer and a retailer to develop a game model for studying the issues of carbon emission reduction within the retailer dominant and the power balanced cases, respectively. Ji *et al.* [12] analyze a detailed model which incorporates both cap-and-trade regulation and consumers' low-carbon preference. Taleizadeh *et al.* [23] expand a two-echelon supply chain consisting of the cap-and-trade regulation, and analyzed the supply chain in both cooperative and non-cooperative forms. Based on the cap-and-trade regulation, Yang *et al.* [38] construct two models with and without remanufacturing to obtain the optimal levels of carbon emission reduction and pricing strategies. Xia *et al.* [30] investigate the pricing and emission reduction policies of a supply chain in a social environment and a cap-and-trade system. Xia *et al.* [31] incorporate social preferences, which are divided into relationship preferences and status preferences, as well as consumer low-carbon awareness into a supply chain with one manufacturer and one retailer under the cap-and-trade system. Yang *et al.* [39] examine the manufacturer's channel selection and emission reduction decisions when considering carbon emission constraints, and explore a two-echelon supply chain consisting of one manufacturer and one retailer under the cap-and-trade regulation. Taleizadeh *et al.* [24] think that two possibilities in the forward flow, including the technologies investment and the cap-and-trade are employed in line with reducing carbon emission. Tong *et al.* [25] consider a scenario with a model economy under the effects of a cap-and-trade policy, with consumers who prefer low-carbon products, and develops an evolutionary game model to examine the evolution of behaviors for powerful retailers and manufacturers in a retailer-led supply chain.

For the decision system of the supply chain, the cap-and-trade regulation is adjusted by carbon trading market as an exogenous factor, and is not decided by the government through maximizing social welfare. This certain has been concerned by some scholars.

In the second research stream, the carbon emission cap is established by the government based on the maximization of social welfare. Many countries have implemented various policies to reduce carbon emissions, which has affected the operational decisions of enterprises in the supply chain since most carbon is emitted during the production process [27]. Du *et al.* [6] focus on a so-called emission-dependent supply chain consisting of one single emission dependent manufacturer and one single emission permit supplier in the cap-and-trade system, where emission permit becomes requisite for production. Xu *et al.* [33] study the joint production and pricing problem of a manufacturing firm with multiple products under cap-and-trade and carbon tax regulations, as well as compares the effects of the two regulations on the total carbon emissions, the firm's profit, and social welfare. Cao *et al.* [3] investigate the impacts of the cap-and-trade policy and low carbon subsidy policy on the production and carbon emission reduction level of a manufacturer, and explore which policy is better for society. He *et al.* [9] investigate the optimal production decisions of a self-pricing manufacturer and the optimal cap-setting decisions of a regulator under the cap-and-trade regulation. Ji *et al.* [13] use a two-stage Stackelberg game to explore the production decision as well as the government cap setting with wholesale price and revenue sharing contracts under cap-and-trade regulation. Considering the cap-and-trade regulation, Zhang *et al.* [41] develop game models to investigate the manufacturer's production and emission abatement decisions as well as the governmental emission cap regulation in a supply chain with three power structures.

In the above literatures, the carbon emission cap decision by the government is not considered in the competition of two supply chains. Besides, the carbon trading price is an exogenous parameter, and is not affected by the carbon emission cap.

In the third research stream, the behavior of industry competition is changing from competition among independent enterprises to competition among supply chains [32]. There are some studies that have concentrated on competition of two supply chains. Hafezalkotob [8] develop price-energy-saving competition and cooperation models for two green supply chains under government financial intervention. Yang *et al.* [37] consider two competitive supply chains under the cap-and-trade scheme, each of which consists of one manufacturer and one retailer. The chain-to-chain competition is analyzed in three scenarios, one of which is a horizontal Nash game, as well as the others are traditional supply chain Stackelberg game and the low-carbon supply chain Stackelberg game [15]. Considering the role of the consumers' low-carbon preference in the cooperation for low-carbon production, Pu *et al.* [22] construct four scenarios to investigate the effects of consumers' low-carbon preference on the market equilibrium of supply chains' product selection strategy. Wang *et al.* [28] investigate a fresh food supply chain comprising a large-scale supplier and multiple small-scale retailers under a carbon cap-and-trade policy.

There are some deficiencies in above literatures. The government policy to restrict carbon emission is not the cap-and-trade regulation [22]. The cap-and-trade regulation is not introduced to control the carbon emission in supply chains [8]. Besides, the carbon emission cap and the carbon trading price are just the parameters, not the decision variable of government [15, 28, 37].

In the last research stream, the wholesale price contract is widely considered to coordinate the operation of the low-carbon supply chain. It is divided into three types according to the determination method of the wholesale price contract. First, the retailer persuades the manufacturer to produce products without increase of wholesale price using a rate, which satisfy customer's willingness, and consequently, enhance demand of market and profit of the supply chain [23, 26]. Second, by the inverse function of the retailer's response function, the manufacturer as a leader of Stackelbeg game in a supply chain sets the retailer price to maximize its profit. By analyzing the wholesale price contract to coordinate the supply chain, Xu *et al.* [34] find that, although the wholesale price is equal to the total cost, the manufacturer can still obtain profit because he can sell emission credits to the carbon trading market. By comparative analyzing the coordination effect of wholesale price and revenue sharing contracts, Ji *et al.* [13] research the production decisions and cap setting in low-carbon supply chain. Third, it is other type. Yang *et al.* [36] present coordination mechanisms with all-unit wholesale quantity (price) discount contract in different low-carbon policies.

The Nash bargaining is considered a cooperative policy in supply chain operation management. The Nash bargaining model can be divided into the symmetric structure and asymmetrical structure. In cooperation of low-carbon supply chain, it is considered "level of greening" decision as a function of the symmetric Nash bargaining between the collaborating firms [7]. Zand *et al.* [40] study the profit division of the members considering their risk attitude and bargaining power through asymmetrical Nash bargaining in the apparel supply chain. Extending from the basic model, Li *et al.* [14] further discuss the equilibrium solutions under asymmetrical Nash bargaining model, in which the retailer and the manufacturer bargain on a cost-sharing rate or a revenue-sharing rate. Wu and Kung [29] find that if the government wants to publish some preferential policies to encourage the adoption of green technology in the supply chain, it should choose the party with higher bargaining power. Matsui [19] finds that the manufacturer achieves its highest profit by bargaining the wholesale price earlier than determining the direct price.

In recent decades, global attention has been paid to carbon emissions, and various international government organizations have made efforts to curb carbon emissions. From the international perspective, the Paris agreement has officially entered into force, which has made clear the global "2 °C temperature rise target" and the medium and long-term emission control target of all countries. Green and low-carbon development has become the global trend. In China, the carbon intensity in 2020 will be 18% lower than that in 2015 is a core goal of China's low carbon development during the 13th Five Year Plan period. It is proposed in the 13th Five Year Plan for controlling greenhouse gas emissions. The co-ordination mechanism is an important factor in the supply chain operation. As revenue sharing contract, cost sharing contract and wholesale price contract etc are widely adopted in academic researchers

This paper contribution is threefold. The comparison between this article and prior research, as well as the summary of our contribution also derives from Table 1. In the cooperation of two supply chains, our first contribution is in carbon trading price which is a function of carbon emission cap. The second contribution is to give optimal carbon emission cap based on maximizing social welfare, and find the optimal distribution proportion of the cap through Nash bargaining between supply chains. Lastly, the wholesale price contract is introduced to coordinate the manufacturer and retailer as a vertical cooperation of the supply chain, as well as compare contractual cooperation and structural cooperation. Specifically, this study answers to the following research queries:

(1) What are the optimal decisions for the supply chain members and government under different cooperation structures?
(2) In each supply chain, what is the bargaining power of distribution proportion in asymmetric competition, and whether the distribution proportion still is 0.5?
(3) How do various factors such as unit carbon emission, environmental damage coefficient, price sensitivity of carbon emission cap and competitive sensitivity parameter impact the distribution proportion of cap setting, pricing and profit of supply chains and social welfare?

3. Model formulation and notation

In this paper, it considers two competitive supply chains named chain 1 and 2. Each of the two chains consists of one manufacturer (M) and one retailer (R). In such a supply chain, the manufacturer selling its products to the consumers through the retailer, so shown in Figure 1, so the decision of the supply chain is the pricing decision

TABLE 1. Comparison between this article and prior research.

paper	Supply chains' competition	Cap-and-trade regulation	Government decision	Portion of cap	Vertical contract
Du *et al.* [6]	No	Yes	Yes	No	No
Wang *et al.* [26]	No	Yes	No	No	Yes
Ji *et al.* [12]	No	Yes	No	No	No
He *et al.* [9]	No	Yes	Yes	No	No
Hafezalkotob [8]	Yes	No	Yes	No	No
Yang *et al.* [37]	Yes	Yes	No	No	No
Taleizadeh *et al.* [23]	No	Yes	No	No	Yes
Yang *et al.* [38]	No	Yes	No	No	No
Xia *et al.* [30]	No	Yes	No	No	No
Xia *et al.* [31]	No	Yes	No	No	Yes
Yang *et al.* [39]	No	Yes	No	No	No
Lou and Ma [15]	Yes	Yes	No	No	No
Pu *et al.* [22]	Yes	No	No	No	No
Taleizadeh *et al.* [24]	No	Yes	No	No	No
Tong *et al.* [25]	No	Yes	No	No	No
Zhang *et al.* [41]	No	Yes	Yes	No	No
Wang *et al.* [28]	Yes	Yes	No	No	No
Ji *et al.* [13]	No	Yes	Yes	No	Yes
This paper	Yes	Yes	Yes	Yes	Yes

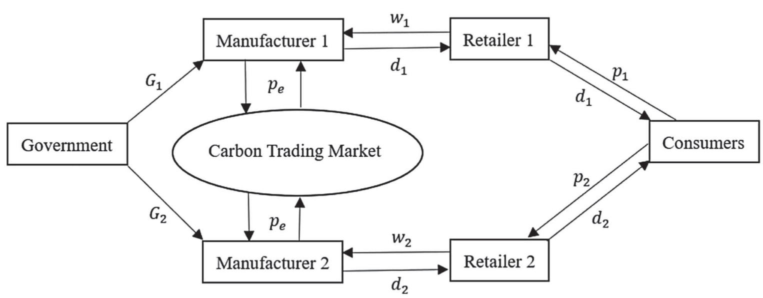

FIGURE 1. The two supply chains with cap-and-trade regulation structure.

of the manufacturer and the retailer. Under cap-and-trade regulation, the government (G) constraints on supply chains' total carbon emission by setting a cap of carbon emission. Besides, the vertical-horizontal cooperation of two supply chains is considered, as well as the wholesale price contract as a non-cooperative contract between the manufacturer and the retailer, such as the double decentralized scenario (Model-DD), the two manufacturers cooperation scenario (Model-MM), the single centralized, single decentralized scenario (Model-CD), the double centralized scenario (Model-CC), the single contract, single decentralized scenario (Model-SD), and the double contract scenario (Model-SS) (see the Fig. 2).

A three-stage Stackelberg game model is constructed, where the government plays as the leader in government-supply chain game and the manufacturer is the leader in manufacturer-retailer game. In the first stage, the government firstly set the optimal emission cap based on the maximization of social welfare. Then, manufacturers separately decide the distribution proportion of the cap by seeking the maximization of the supply chain's profits

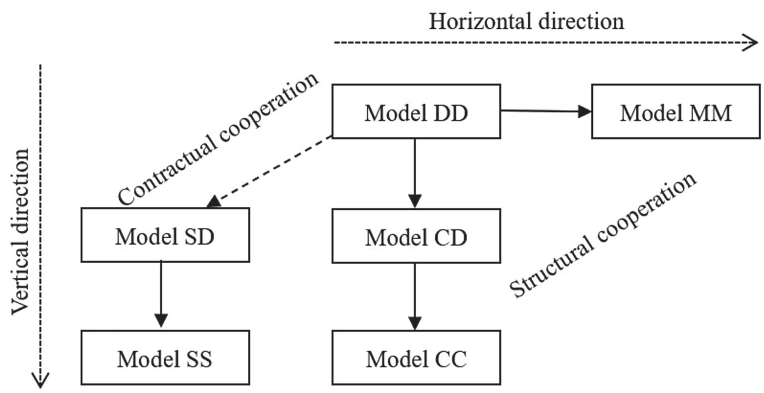

FIGURE 2. Organization order of the models.

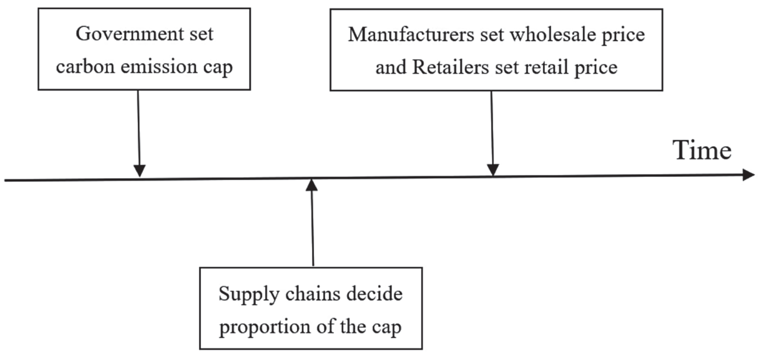

FIGURE 3. The sequence of events in the game.

in the second stage. Last, the third stage is the comm pricing stage of the supply chain, and chain-and-chain strategy with Nash bargaining game (see the Fig. 3).

The following notations are used to develop the proposed model (Table 2).

In this paper, the competition of the supply chains focuses on the price competition. It is assumed that price-dependent demands with imperfect product substitutability, as well as the market demand is decreasing in self-freight price and increasing in competitor's price. Thus, the demand is specified as a linear function [5,42]:

$$d_x = \alpha - p_x + \beta p_{3-x} \quad \text{for } x = 1, 2 \tag{3.1}$$

where $\alpha > 0$, denote the potential market, and β denote the competitive sensitivity parameter $0 < \beta \leq 1$. It is creasing, the competition of chain-and-chain is strengthening.

Carbon trading is also known as cap-and-trade. The government initially set a free quantity of carbon emission credits to supply chain system, *i.e.* carbon emission cap G. The manufacturer x is allocated the cap of the supply chain x, *i.e.* the manufacturer 1 is allocated the cap of ηG, and the manufacturer 2 is allocated the cap of $(1-\eta)G$. $\eta (0 < \eta \leq 1)$ denotes the distribution proportion of the cap. The manufacturer needs to buy more carbon emission credits from the carbon trading market when the total emission exceeds the carbon cap. By contrary, the manufacturer can sell the surplus carbon emission credits to the carbon trading market.

Similar to previous literatures [11, 13]. It is assumed that the carbon trading price is increasing in the cap setting of the government. Thus, the linear function of the carbon trading price as follows:

$$p_e = a - \lambda G \tag{3.2}$$

TABLE 2. The major parameters and notations.

Parameters	Definition
d_x	The demand of the supply chain $x = 1, 2$
α	The potential market $\alpha > 0$
β	The competitive sensitivity parameter $0 < \beta < 1$
p_x	Retail price set by the retailer $x = 1, 2$ (decision variable)
w_x	Wholesale price set by the manufacturer $x = 1, 2$ (decision variable)
p_e	The carbon trading price $p_e > 0$
G	Carbon emission cap set by the government (decision variable)
a	The maximal price of the carbon emission credits $a > 0$
λ	The price sensitivity of the cap $\lambda > 0$
E	The environmental damage cost
V	The environmental damage coefficient $0 < V \leq 1$
e	The carbon emission incurred unit product $0 < e \leq 1$
η	The distribution proportion of the cap setting by supply chain power (decision variable)
c	The unit production cost
π_{Mx}^{C}	The profit of the manufacturer x in model i
π_{Rx}^{i}	The profit of the retailer x in model i
π_{Tx}^{i}	The profit of the supply chain x in model i
SW^{i}	The social welfare in model i

$a > 0$ denotes the maximal price of the carbon emission credits, and $\lambda > 0$ denotes the price sensitivity of the cap. Besides, $G < \frac{a}{\lambda}$ due to $p_e > 0$.

The emission intensity is denoted by the parameter e which refers to the carbon emission incurred by per unit of product. Let V is environmental damage coefficient that translates a unit carbon emission into a monetary unit. The environmental damage cost E is assumed as a relationship between total emission and product quantity [1,3,4]. In addition, it is assumed the product quantity equals the market demand. Thus, the formulation of the environmental damage cost is

$$E = V\left(e\sum_{x=1}^{2} d_x\right)^2. \tag{3.3}$$

The government always concern about the carbon emission of manufacturing industry, and enact various stringent rules and regulations day by day on carbon emission by manufacturers for the welfare of the society, *i.e.* carbon cap-and-trade regulation. In this regulation, the government's purpose is to implement the optimal emission cap G^* to maximize the total social welfare, which consists of the sum of the supply chains' profit, the consumer surplus, and the environmental damage cost [7,10,13]. Consequently, the total social welfare function SW under a given cap G is given by

$$\text{SW}(G) = \sum_{X=1}^{2} \pi_{Tx} + \frac{1}{2}\sum_{X=1}^{2} d_x^2 - E \tag{3.4}$$

where the part $\sum_{X=1}^{2} \pi_{Tx}$ as the supply chains' profit, the part $\frac{1}{2}\sum_{X=1}^{2} d_x^2$ denotes the consumer surplus, and the VE^2 measures the environmental damage cost.

As these literatures [7, 14], the optimal distribution proportion η of the cap is got through the symmetric Nash bargaining structure. Two supply chains bargain on the sharing distribution proportion to be achieved by the bargaining structure. Thus, when the supply chains participate in the bargaining process, it is solved (Tab. 2).

$$\max_{\eta} \left(\pi_{T1}\pi_{T2}\right). \tag{3.5}$$

$i \in \{\text{DD}, \text{MM}, \text{CD}, \text{CC}, \text{SD}, \text{SS}\}$ signifies the scenarios from model DD to model SS.

4. Optimal decisions and analysis of models

In this section, it is divided into six subsections based on the scenarios (DD ∼ SS) mentioned above. Each subsection contains the optimal decisions of the supply chain's members and the government in each scenario.

4.1. The double decentralized scenario (Model-DD)

The model-DD is the scenario of the supply chain's members with non-cooperation. The manufacturer and retailer make their decisions independently to maximize their own profit in each supply chain. For each supply chain, first, the manufacturer decides the wholesale price. Then, the retailer decides the retail price. Accordingly, the decision problem of the manufacturers is formulated as

$$\max \pi_{M_1}^{\mathrm{DD}}(w_1) = (w_1 - c)(\alpha - p_1 + \beta p_2) - (a - \lambda G)\left[e(\alpha - p_1 + \beta p_2) - \eta G\right] \tag{4.1}$$

$$\max \pi_{M_2}^{\mathrm{DD}}(w_2) = (w_2 - c)(\alpha - p_2 + \beta p_1) - (a - \lambda G)\left[e(\alpha - p_2 + \beta p_1) - (1-\eta) G\right]. \tag{4.2}$$

The decision problem of the retailers is defined as

$$\max \pi_{Rx}^{\mathrm{DD}}(p_x) = (p_x - w_x)(\alpha - p_x + \beta p_{3-x}) \quad \text{for } x = 1, 2. \tag{4.3}$$

Theorem 4.1. *The following optimal decision variables of Model-DD, Nash Bargaining model and the total social welfare function SW are achieved through the backward solution. See Appendix A for proof.*

$$\begin{aligned}
G^{\mathrm{DD}^*} &= \frac{a(64 - 96\beta - 12\beta^2 + 68\beta^3 - 15\beta^4 - 12\beta^5 + 4\beta^6)}{U_1} \\
&\quad - \frac{ae^2\lambda\left(56 - 112\beta + 96\beta^3 - 38\beta^4 - 20\beta^5 + 10\beta^6 + 8\beta^2\right)}{U_1} \\
&\quad + \frac{V[8ae^4\lambda\left(4 - 8\beta + 8\beta^3 - 3\beta^4 - 2\beta^5 + \beta^6\right)]}{U_1} \\
&\quad - \frac{8e^3V[\alpha - c(1-\beta)]\left(2 - \beta^2\right)\left(2 - 2\beta - \beta^2 + \beta^3\right)\lambda}{U_1} \\
&\quad + \frac{2e\left(14 - 5\beta^2\right)(\alpha - c(1-\beta))\left(2 - 2\beta - \beta^2 + \beta^3\right)\lambda}{U_1} \\
\eta^{\mathrm{DD}^*} &= \frac{1}{2} \\
w_1^{\mathrm{DD}^*} &= w_2^{\mathrm{DD}^*} = \frac{\left[c + \left(a - \lambda G^{\mathrm{DD}^*}\right)e\right]\left(2 - \beta^2\right) + \alpha(2+\beta)}{4 - \beta - 2\beta^2} \\
p_1^{\mathrm{DD}^*} &= p_2^{\mathrm{DD}^*} = \frac{\left[c + \left(a - \lambda G^{\mathrm{DD}^*}\right)e\right]\left(2 - \beta^2\right) + 2\alpha\left(3 - \beta^2\right)}{(2-\beta)\left(4 - \beta - 2\beta^2\right)}
\end{aligned}$$

where

$$\begin{aligned}
U_1 = 2\lambda\big[&e^4\lambda V\left(16 - 32\beta + 32\beta^3 - 12\beta^4 - 8\beta^5 + 4\beta^6\right) \\
&- e^2\lambda\left(28 - 56\beta + 4\beta^2 + 48\beta^3 - 19\beta^4 - 10\beta^5 + 5\beta^6\right) \\
&+ \left(64 - 96\beta - 12\beta^2 + 68\beta^3 - 15\beta^4 - 12\beta^5 + 4\beta^6\right)\big].
\end{aligned}$$

Finally, By Substituting the values $w_1^{\mathrm{DD}^*}$, $w_2^{\mathrm{DD}^*}$, $p_1^{\mathrm{DD}^*}$, and $p_2^{\mathrm{DD}^*}$ into function (4.1) to (4.3), as well as it gets the $\pi_{M1}^{\mathrm{DD}^*} = \pi_{M2}^{\mathrm{DD}^*}$, $\pi_{R1}^{\mathrm{DD}^*} = \pi_{R2}^{\mathrm{DD}^*}$, and $\mathrm{SW}^{\mathrm{DD}^*}$.

The model-DD is one of scenarios with the symmetrical competition in the supply chains. In this model, the pricing decisions of two supply chains are the same, and the distribution proportion of the cap is equal to 1/2. If the cap is an exogenous parameter, the pricing of the members is decreasing as the government raising the cap, as well as it is increasing with the competition intensity of supply chains with the cap being given. It means that a higher emission cap and a strong price competition make the market demand depressed.

To measure the impact of eliminating competition on the pricing decisions of supply chains and kinds of index (profits and social welfare), the two kinds of cooperation scenarios are explored as follow: (i) the vertical-horizontal cooperation of supply chain (no contract); (ii) the cooperation with the wholesale price contract.

4.2. The two manufacturers cooperation scenario (Model-MM)

In this subsection, the purpose of cooperation between two manufacturers is to maximize the profit of cooperation. But, the retailer of each supply chain still independent. The problems faced by manufacturer and retailer at stage 3 are to determine their optimal prices with the Stackelberg game of the manufacturer as leader, which can be formulated as

$$\begin{aligned}\max \pi_M^{\mathrm{MM}}(w_1,w_2) = \ & (w_1-c)(\alpha-p_1+\beta p_2) \\ & + (w_2-c)(\alpha-p_2+\beta p_1) - (a-\lambda G)[e(\alpha-p_1+\beta p_2) \\ & + e(\alpha-p_2+\beta p_1) - G] \qquad (4.4)\\ \max \pi_{Rx}^{\mathrm{MM}}(p_x) = \ & (p_x-w_x)(\alpha-p_x+\beta p_{3-x}) \quad \text{for } x=1,2. \qquad (4.5)\end{aligned}$$

Theorem 4.2. *Through the backward solution, there exists an optimal level of emission cap, the distribution proportion of the cap and enterprises pricing,* G^{MM^*}, η^{MM^*}, $w_1^{\mathrm{MM}^*}$, $w_2^{\mathrm{MM}^*}$, $p_1^{\mathrm{MM}^*}$, *and* $p_2^{\mathrm{DD}^*}$, *respectively, such that the enterprises' profit and the total social welfare are maximized, as well as they are as follows:*

$$\begin{aligned} G^{\mathrm{MM}^*} &= \frac{e[\alpha-c(1-\beta)][7-4e^2V(1-\beta)-5\beta]\lambda}{\lambda\{4Ve^4\lambda(1-\beta)^2+[4(2-\beta)^2-e^2\lambda(7-12\beta+5\beta^2)]\}} \\ &\quad + \frac{a[4e^4\lambda V(1-\beta)^2-e^2\lambda(7-12\beta+5\beta^2)+2(4-4\beta+\beta^2)]}{\lambda\{4Ve^4\lambda(1-\beta)^2+[4(2-\beta)^2-e^2\lambda(7-12\beta+5\beta^2)]\}} \\ \eta^{\mathrm{MM}^*} &= \frac{1}{2} \\ w_1^{\mathrm{MM}^*} &= w_2^{\mathrm{MM}^*} = \frac{\alpha+(1-\beta)\left[c+e\left(a-\lambda G^{\mathrm{MM}^*}\right)\right]}{2(1-\beta)} \\ p_1^{\mathrm{MM}^*} &= p_2^{\mathrm{MM}^*} = \frac{3\alpha-2\alpha\beta+(1-\beta)\left[c+e\left(a-\lambda G^{\mathrm{MM}^*}\right)\right]}{2(2-\beta)(1-\beta)}. \end{aligned}$$

The optimal profits of the enterprises and the total social welfare, $\pi_M^{\mathrm{MM}^*}$, $\pi_{Rx}^{\mathrm{MM}^*}$, $\mathrm{SW}^{\mathrm{MM}^*}$ *are given respectively by* G^{MM^*}, $w_1^{\mathrm{MM}^*}$, $w_2^{\mathrm{MM}^*}$, $p_1^{\mathrm{MM}^*}$, $p_2^{\mathrm{MM}^*}$, *and* η^{MM^*}. *See Appendix A for proof.*

Similar to the model-DD, the model-MM is a scenario with the symmetrical competition in the supply chains. Besides, it is a scenario of horizontal cooperation of the supply chain structure. Notice that the optimal decision solutions of two retailers cooperation scenario (Model-RR) are the same with model-MM, but the order and way of the decision making for them are different. To simplify the content of this paper, the model-RR is not analyzed in a further section.

4.3. The single centralized and single decentralized scenario (Model-CD)

As a benchmark, the manufacturer and the retailer of supply chain 1 cooperate to maximize their common profit. In the supply chain 2, the manufacturer and the retailer make their decisions independently to maximize their own profit. The formulation of the profits as follows:

$$\max \pi_{T1}^{\mathrm{CD}}(w_1) = (p_1 - c)(\alpha - p_1 + \beta p_2) - (a - \lambda G)[e(\alpha - p_1 + \beta p_2) - \eta G] \tag{4.6}$$

$$\max \pi_{\mathrm{M2}}^{\mathrm{CD}}(w_2) = (w_2 - c)(\alpha - p_2 + \beta p_1) - (a - \lambda G)[e(\alpha - p_2 + \beta p_1) - (1-\eta)G] \tag{4.7}$$

$$\pi_{\mathrm{R2}}^{\mathrm{CD}}(p_2) = (p_2 - w_2)(\alpha - p_2 + \beta p_1). \tag{4.8}$$

Theorem 4.3. *In the model-CD, the optimal cap setting of the government G^{CD^*} in the stage 1, the optimal distribution proportion of the supply chains η^{CD^*} in the stage 2, and the optimal pricing of the manufacturer and retailer $w_1^{\mathrm{CD}^*}$, $w_2^{\mathrm{CD}^*}$, $p_1^{\mathrm{CD}^*}$, and $p_2^{\mathrm{CD}^*}$ in the stage 3 are given, respectively.*

$$\begin{aligned}
G^{\mathrm{CD}^*} &= \frac{U_2}{U_3}\\
\eta^{\mathrm{CD}^*} &= \frac{U_4}{8G(2-\beta)(2-\beta^2)^2(a - G^{\mathrm{CD}^*}\lambda)}\\
w_2^{\mathrm{CD}^*} &= \frac{\alpha(2+\beta) + (2+\beta-\beta^2)(c + ae - e\lambda G^{\mathrm{CD}^*})}{2(2-\beta^2)}\\
p_1^{\mathrm{CD}^*} &= \frac{\alpha(4 - 2\beta^2 + \beta) + (4 - \beta - \beta^2)(c + ae - e\lambda G^{\mathrm{CD}^*})}{2(2-\beta)(2-\beta^2)}\\
P_2^{\mathrm{CD}^*} &= \frac{3\alpha - \alpha\beta^2 + (1+\beta-\beta^2)(c + ae - e\lambda G^{\mathrm{CD}^*})}{(2-\beta)(2-\beta^2)}
\end{aligned}$$

where

$$\begin{aligned}
U_2 = a\,&\big[e^4\lambda V(72 - 120\beta - 46\beta^2 + 152\beta^3 - 28\beta^4 - 48\beta^5 + 18\beta^6)\\
&- e^2\lambda(76 - 128\beta - 41\beta^2 + 150\beta^3 - 28\beta^4 - 46\beta^5 + 17\beta^6)\\
&+ 4(16 - 16\beta - 12\beta^2 + 16\beta^3 - 4\beta^5 + \beta^6)\big]\\
&- e[\alpha - c(1-\beta)](1-\beta)[2e^2V(6 + \beta - 3\beta^2)^2\\
&- (76 + 24\beta - 69\beta^2 - 12\beta^3 + 17\beta^4)]\lambda\\
U_3 = \lambda&[e^4\lambda V(72 - 120\beta - 46\beta^2 + 152\beta^3 - 28\beta^4 - 48\beta^5 + 18\beta^6)\\
&- e^2\lambda(76 - 128\beta - 41\beta^2 + 150\beta^3 - 28\beta^4 - 46\beta^5 + 17\beta^6)\\
&+ 8(16 - 16\beta - 12\beta^2 + 16\beta^3 - 4\beta^5 + \beta^6)]\\
U_4 = 2&(2 + 3\beta - 5\beta^2 - 2\beta^3 + 2\beta^4)\Big\{e\alpha\Big(a - \lambda G^{\mathrm{CD}^*}\Big)\\
&+ c\Big[\alpha - e(1-\beta)\Big(a - \lambda G^{\mathrm{CD}^*}\Big)\Big]\Big\}\\
&+ 4G^{\mathrm{CD}^*}(8 - 4\beta - 8\beta^2 + 4\beta^3 + 2\beta^4 - \beta^5)\Big(a - \lambda G^{\mathrm{CD}^*}\Big)\\
&+ e^2\lambda G^{\mathrm{CD}^*}(2 + \beta - 8\beta^2 + 3\beta^3 + 4\beta^4 - 2\beta^5)\Big(2a - \lambda G^{\mathrm{CD}^*}\Big)\\
&- \big[\alpha^2 + (c^2 + a^2e^2)(1-\beta)^2\big](2 + 5\beta - 2\beta^3).
\end{aligned}$$

According to the above optimal decisions, it can find the optimal profit of the supply chain 1 $\pi_{T1}^{\mathrm{CD}^*}$, the optimal profits of the manufacturer and retailer in supply chain 2 $\pi_{M2}^{\mathrm{CD}^*}$, $\pi_{R2}^{\mathrm{CD}^*}$, and the optimal social welfare $\mathrm{SW}^{\mathrm{CD}^*}$. See Appendix A for proof.

The model-CD is one of scenarios with the asymmetric competition in the supply chains, as well as a scenario of the single horizontal cooperation of the supply chain structure. The retail price $p_1^{\mathrm{CD}^*}$ in supply chain 1 adopting the horizontal cooperation is less than the retail price $p_2^{\mathrm{CD}^*}$ in the supply chain 2 with no-cooperation. The optimal distribution proportion is not equal to 1/2, because the supply chain is in an asymmetric competitive environment. This distribution proportion is influenced by kinds of the parameters. How it changes with the parameters will be discussed in a further section.

4.4. The double centralized scenario (Model-CC)

The model-CC characterizes the following: the manufacturer and retailer in each supply chain cooperatively set the retail price in order to attain their total profit maximization. The supply chains' profits are:

$$\max \pi_{T1}^{\mathrm{CC}}(p_1) = (p_1 - c)(\alpha - p_1 + \beta p_2) - (a - \lambda G)\left[e(\alpha - p_1 + \beta p_2) - \eta G\right] \tag{4.9}$$
$$\max \pi_{T2}^{\mathrm{CC}}(p_2) = (p_2 - c)(\alpha - p_2 + \beta p_1) - (a - \lambda G)\left[e(\alpha - p_2 + \beta p_1) - (1-\eta) G\right]. \tag{4.10}$$

Theorem 4.4. *In the situation of the double centralized, the optimal decisions of the government and supply chains are respectively*

$$\begin{aligned} G^{\mathrm{CC}^*} &= \frac{a\left[8e^4\lambda V(1-\beta)^2 - 6e^2\lambda(1-\beta)^2 + (2-\beta)^2\right]}{2\lambda\left[4e^4\lambda V(1-\beta)^2 - 3e^2\lambda(1-\beta)^2 + (2-\beta)^2\right]} \\ &\quad - \frac{2e\left(4e^2V-3\right)\left[\alpha - c(1-\beta)\right](1-\beta)\lambda}{2\lambda\left[4e^4\lambda V(1-\beta)^2 - 3e^2\lambda(1-\beta)^2 + (2-\beta)^2\right]} \\ \eta^{\mathrm{CC}^*} &= \frac{1}{2} \\ p_1^{\mathrm{CC}^*} &= p_2^{\mathrm{CC}^*} = \frac{C + ae + \alpha - e\lambda G^{\mathrm{CC}^*}}{2-\beta}. \end{aligned}$$

Similar to above models, it can find the supply chains' optimal profits $\pi_{T1}^{\mathrm{CC}^*}$ and $\pi_{T2}^{\mathrm{CC}^*}$ ($\pi_{T1}^{\mathrm{CC}^*} = \pi_{T2}^{\mathrm{CC}^*}$) as well as the optimal social welfare $\mathrm{SW}^{\mathrm{CC}^*}$ by the optimal decisions in this model. See Appendix A for proof.

The model-CC is a scenario of complete cooperation, as well as a scenario of the double horizontal cooperation of the supply chain structure. Normally, for other models, the retail price is lowest and the market demand is most in this model.

4.5. The single contract and single decentralized scenario (Model-SD)

In the traditional supply chain, wholesale price contract cannot coordinate the supply chain due to double marginalization [2]. Although wholesale price contract can coordinate the supply chain, it sacrifices the manufacturer's profit [34]. Under the wholesale price contract, the difficulty of implementing cap-and-trade regulation is increased when the government's over-allocated carbon credits. When the middle environmental concern parameter increases, the government should keep the optimal cap unchanged under the low or high environmental concern parameter, and decrease the cap [13].

In this scenario, the wholesale price contract was adopted in the supply chain 1, and the supply chain 2 still executes decentralized decision. The additional parameter is not introduced in this contract. Conventionally, the manufacturer firstly decisions a wholesale price w_x^{SD} to the retailer. After knowing the wholesale price, retailers set the retail price p_x^{SD}. But, the step of solving the game is different from the general step in this contract [13]. Denote by π_{Mx}^{SD} and π_{Rx}^{SD} the manufacturers and the retailers' profits with a wholesale price contract, respectively. The profit functions of the manufacturers and retailers are similar as the model-DD.

Theorem 4.5. *The single contract and single decentralized scenario with wholesale price contract, the decision results as follows:*

$$
\begin{aligned}
G^{\mathrm{SD}^*} &= \frac{U_5}{\lambda U_6}\\
\eta^{\mathrm{SD}^*} &= \frac{U_7}{8G\left(16-15\beta^2+3\beta^4\right)^2\left(a-G^{\mathrm{SD}^*}\lambda\right)}\\
w_1^{\mathrm{SD}^*} &= \frac{\alpha\left(16+12\beta-4\beta^2-3\beta^3\right)}{2\left(16-15\beta^2+3\beta^4\right)}\\
&\quad+\frac{\left(16+4\beta-14\beta^2-\beta^3+3\beta^4\right)\left[c+e\left(a-\lambda G^{\mathrm{SD}^*}\right)\right]}{2\left(16-15\beta^2+3\beta^4\right)}\\
w_2^{\mathrm{SD}^*} &= \frac{\alpha\left(8+6\beta-3\beta^2-2\beta^3\right)+\left(8+2\beta-6\beta^2-\beta^3+\beta^4\right)\left[c+e\left(a-\lambda G^{\mathrm{SD}^*}\right)\right]}{16-15\beta^2+3\beta^4}\\
p_1^{\mathrm{SD}^*} &= \frac{\alpha\left(12+9\beta-4\beta^2-3\beta^3\right)+\left(4+3\beta-2\beta^2-\beta^3\right)\left[c+e\left(a-\lambda G^{\mathrm{SD}^*}\right)\right]}{16-15\beta^2+3\beta^4}\\
p_2^{\mathrm{SD}^*} &= \frac{3\alpha\left(8+6\beta-3\beta^2-2\beta^3\right)+\left(8+6\beta-3\beta^2-3\beta^3\right)\left[c+e\left(a-\lambda G^{\mathrm{SD}^*}\right)\right]}{2\left(16-15\beta^2+3\beta^4\right)}
\end{aligned}
$$

where

$$
\begin{aligned}
U_5 = a\,&\big[e^4\lambda V\left(512-256\beta-1184\beta^2+432\beta^3+1010\beta^4-232\beta^5-372\beta^6\right.\\
&\left.+\,40\beta^7+50\beta^8\right)-e^2\lambda(896-448\beta-2008\beta^2+724\beta^3+1647\beta^4-366\beta^5\\
&-576\beta^6+58\beta^7+73\beta^8)+(1024-1920\beta^2+1284\beta^4-360\beta^6+36\beta^8)\big]\\
&-e[\alpha-c(1-\beta)](1-\beta)[2e^2V\left(16+12\beta-7\beta^2-5\beta^3\right)^2-(896+1344\beta\\
&-216\beta^2-1052\beta^3-241\beta^4+204\beta^5+73\beta^6)]\lambda\\
U_6 = e^4&\lambda V(512-256\beta-1184\beta^2+432\beta^3+1010\beta^4-232\beta^5-372\beta^6\\
&+40\beta^7+50\beta^8)-e^2\lambda(896-448\beta-2008\beta^2+724\beta^3+1647\beta^4-366\beta^5\\
&-576\beta^6+58\beta^7+73\beta^8)+(2048-3840\beta^2+2568\beta^4-720\beta^6+72\beta^8)\\
U_7 = \alpha^2&\beta^2\left(16+36\beta+13\beta^2-12\beta^3-6\beta^4\right)+\left[c^2+e^2\left(a-\lambda G^{\mathrm{SD}^*}\right)^2\right]\beta^2\\
&\left(16+4\beta-43\beta^2-2\beta^3+31\beta^4-6\beta^6\right)+2\left(a-\lambda G^{\mathrm{SD}^*}\right)G^{\mathrm{SD}^*}(512\\
&-960\beta^2+642\beta^4-180\beta^6+18\beta^8)-2\beta^2\left[e\left(\alpha-c(1-\beta)\right)\left(a-\lambda G^{\mathrm{SD}^*}\right)\right.\\
&\left.+\,\alpha c\right]\left(16+20\beta-23\beta^2-25\beta^3+6\beta^4+6\beta^5\right).
\end{aligned}
$$

Based on decision results of stage 1–stage 3, it has the optimal profits of the enterprises ($\pi_{Mx}^{\mathrm{SD}^*}$ and $\pi_{Rx}^{\mathrm{SD}^*}$) as well as the optimal social welfare $\mathrm{SW}^{\mathrm{SD}^*}$. See Appendix A for proof.

For the model-CD, the similarities are that it is a scenario with the asymmetric competition in the supply chains, pricing of the enterprises are not equal, as well as the optimal distribution proportion is not equal to 1/2; but, the difference is that a scenario of the single vertical cooperation with the contract in the model-SD.

Comprehensiveness about problem setting, the single contract, and single centralized scenario (Model-SC) should be established. But, the optimal decisions of the model-SC are the same as that of the model-CD. Thus, the model-SC is not analyzed in a further section similar as the model-RR.

4.6. The double contract scenario (Model-SS)

Different from the model-SD, the wholesale price contract was adopted by two supply chains in this scenario. The profit functions of this model are similar as the model-DD.

Theorem 4.6. *Under this scenario, there are the optimal value for the emission cap, the distribution proportion, and the enterprises' pricing level as follow:*

$$\begin{aligned} G^{\mathrm{SS}^*} &= \frac{a\left[8e^4\lambda V(1-\beta)^2 - 14e^2\lambda(1-\beta)^2 + \left(16-24\beta+9\beta^2\right)\right]}{2\lambda\left[4e^4\lambda V(1-\beta)^2 - 7e^2\lambda(1-\beta)^2 + (16-24\beta+9\beta^2)\right]} \\ &\quad - \frac{2e\left(4e^2V-7\right)[\alpha - c(1-\beta)](1-\beta)\lambda}{2\lambda\left[4e^4\lambda V(1-\beta)^2 - 7e^2\lambda(1-\beta)^2 + (16-24\beta+9\beta^2)\right]} \\ \eta^{\mathrm{SS}^*} &= \frac{1}{2} \\ w_1^{\mathrm{SS}^*} = w_2^{\mathrm{SS}^*} &= \frac{2\alpha + (2-\beta)\left[c + e\left(a - \lambda G^{\mathrm{SS}^*}\right)\right]}{4-3\beta} \\ p_1^{\mathrm{SS}^*} = p_2^{\mathrm{SS}^*} &= \frac{3\alpha + c + e\left(a - \lambda G^{\mathrm{SS}^*}\right)}{4-3\beta}. \end{aligned}$$

Similar to the above models, it can get the manufacturers' profit $\pi_{Mx}^{\mathrm{SS}^*}$*, the retailers' profit* $\pi_{Rx}^{\mathrm{SS}^*}$*, and the total social welfare* $\mathrm{SW}^{\mathrm{SS}^*}$*. See Appendix A for proof.*

In the model-SS, the supply chains adopt the symmetrical competition, as well as the competition is weakened by the double vertical cooperation with the contract.

4.7. Impacts of the environmental damage cost on optimal decisions

The environmental damage cost V is that the total emission should have a macro environmental of V impact on external environment. As well as, it is higher which means that carbon emission makes the society worse off.

Proposition 4.7. *Under different models, the optimal emission caps are decreasing in the environmental damage cost, but, the optimal pricing of enterprises increasing in that. See Appendix B for proof.*

The government set a lower emission cap and the market demand is cut by the enterprises setting higher pricing when the environmental damage cost is higher. For reduce carbon emission, these are the responses of the government and enterprises to the high damage cost.

5. Numerical examples

In this section, the numerical examples are used to characterize the six models concretely. To explore the influence of parameters on optimal decisions, profits of the supply chain system, and total social welfare, as well as how changes in parameters affect their relationship. To satisfy the thresholds in the model descriptions, the parameters should be defined as follows:

$$\alpha = 50, c = 5, a = 80, \begin{cases} e = 1 & \text{if it is given} \\ e \in (0,1) & \text{if it is changing} \end{cases}, \begin{cases} V = 0.7 & \text{if it is given} \\ V \in (0,1) & \text{if it is changing} \end{cases},$$

$$\begin{cases} \lambda = 0.9 & \text{if it is given} \\ \lambda \in (0.5, 1.5) & \text{if it is changing} \end{cases}, \begin{cases} \beta = 3/4 & \text{if it is given} \\ \beta \in (0,1) & \text{if it is changing} \end{cases}.$$

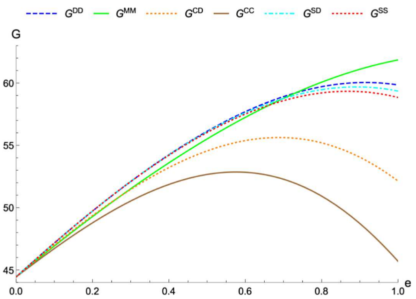

FIGURE 4. Impact of the parameter e on the G.

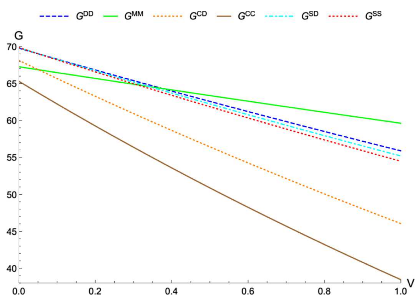

FIGURE 5. Impact of the parameter V on the G.

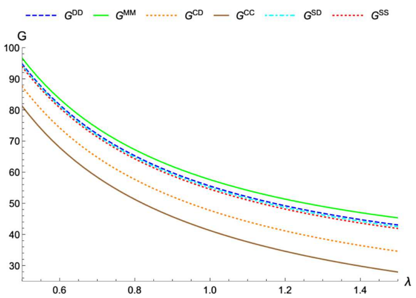

FIGURE 6. Impact of the parameter λ on the G.

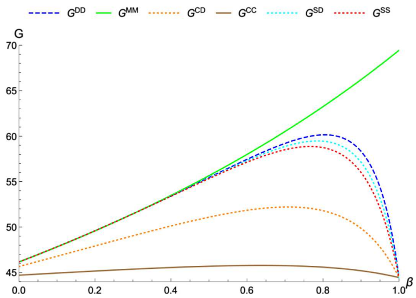

FIGURE 7. Impact of the parameter β on the G.

5.1. Analysis of cap setting

To clarify the relationship of the optimal cap setting in six models, the sensitivity analyses are conducted (shown in Figs. 4–7) by changing the value of four parameters.

Figures 4–7 demonstrate the variation tendencies of the optimal cap setting with parameters in the mentioned six models. The cap setting will reduce with the growth of V or λ. For changes in e or β rise, the cap setting in the model-MM will raise, and first increase then decrease in other models. The relationship of the optimal cap setting as $G^{\mathrm{MM}^*} > G^{\mathrm{DD}^*} > G^{\mathrm{SD}^*} > G^{\mathrm{SS}^*} > G^{\mathrm{CD}^*} > G^{\mathrm{CC}^*}$ with the change of λ or β, as well as it also appears when $e > 0.732$ or $V > 0.376$. Besides, the G^{MM^*} successively surpasses $G^{\mathrm{CD}^*}, G^{\mathrm{SS}^*}, G^{\mathrm{SD}^*}$, and G^{DD^*} when $e = 0.269, e = 0.664, e = 0.698$, and $e = 0.732$, separately, or when $V = 0.051, V = 0.308, V = 0.341$, and $V = 0.376$, correspondingly. On the whole, the optimal cap setting of the vertical cooperation models are lower than that of the cooperation with the wholesale price contract.

5.2. Analysis of pricing

For the critical parameters and pricing decisions of supply chain members, the surfaces and contours of above six models are depicted in Figures 8–15 respectively.

It is clear in Figures 8–15 that the relationship of the optimal wholesale price as $w_x^{\mathrm{MM}^*} > w_x^{\mathrm{DD}^*} > w_1^{\mathrm{SD}^*} > w_2^{\mathrm{SD}^*} > w_x^{\mathrm{SS}^*} > w_x^{\mathrm{CD}^*}$, and the relationship of the optimal retail price as $p_x^{\mathrm{MM}^*} > p_x^{\mathrm{DD}^*} > p_1^{\mathrm{SD}^*} > p_2^{\mathrm{SD}^*} > p_x^{\mathrm{SS}^*} > p_2^{\mathrm{CD}^*} > p_1^{\mathrm{CD}^*} > p_x^{\mathrm{CC}^*}$. The relationship of supply chain members' pricing is not affected by parameter changes. The pricing of supply chain members is decreasing with the increase in λ, and that is increasing with e, V, or β. The gap between the model-CD and model-DD is narrowing in growth of the parameters, but that between the other models and model-DD is not changing. For other parameters, the optimal pricing is a sharp rise in response to the growth of β, as well as that is more obvious in model-MM. In model-SD, the wholesale price

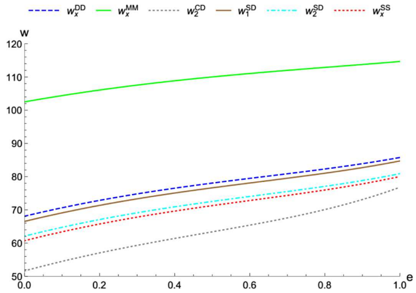

FIGURE 8. Impact of the parameter e on the w.

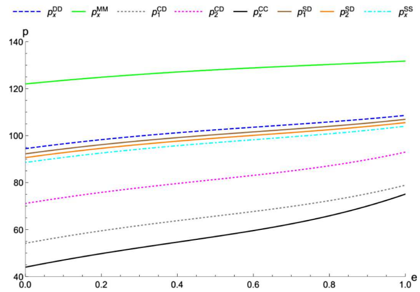

FIGURE 9. Impact of the parameter e on the p.

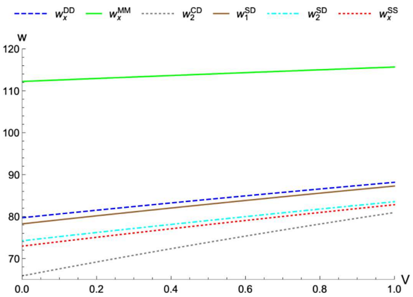

FIGURE 10. Impact of the parameter V on the w.

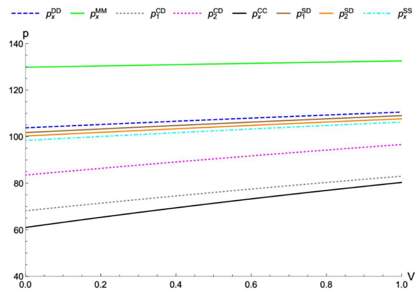

FIGURE 11. Impact of the parameter V on the p.

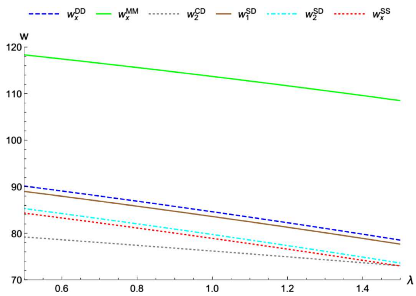

FIGURE 12. Impact of the parameter λ on the w.

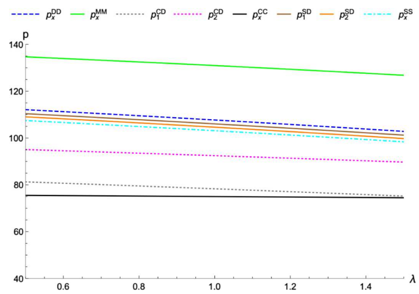

FIGURE 13. Impact of the parameter λ on the p.

and retail price in supply chain 1 both are higher than that in supply chain 2, but their margin in supply chain 1 is higher than that in supply chain 2. Thus, the wholesale price contract is beneficial for a unit profit of both manufacturers and retailers.

5.3. Analysis of distribution proportion

Figures 16–19 indicate the variation tendencies of the optimal pricing with e, V, λ, and β in the mentioned two models with asymmetric competition.

It is clear in Figures 16–19 that the optimal distribution proportion of cap setting in model-CD is less than, but that in model-SD is greater than 0.5. In other word, the bargaining power of the supply chain 1 is enhanced by adopting the wholesale price contract in model-SD, but that is diminished by vertical cooperation of structure.

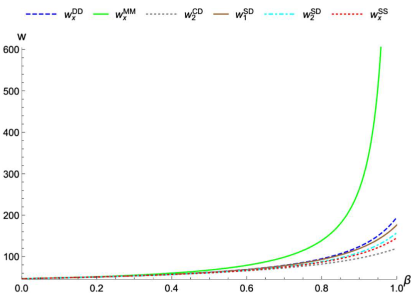

FIGURE 14. Impact of the parameter β on the w.

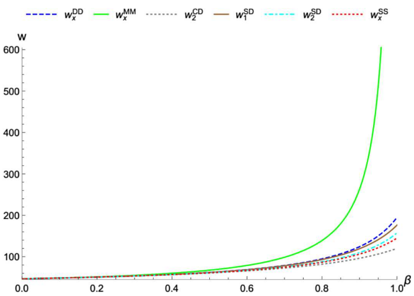

FIGURE 15. Impact of the parameter β on the p.

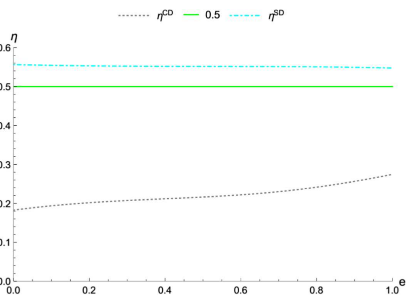

FIGURE 16. Impact of the parameter e on the η.

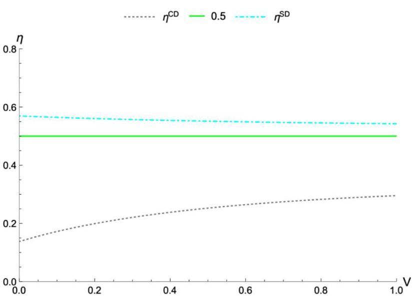

FIGURE 17. Impact of the parameter V on the η.

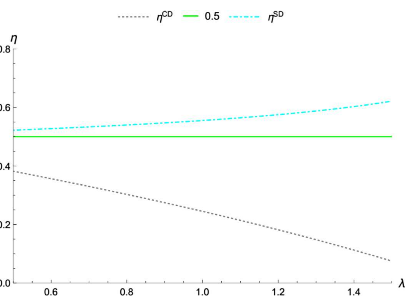

FIGURE 18. Impact of the parameter λ on the η.

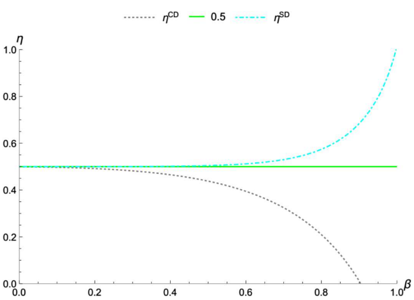

FIGURE 19. Impact of the parameter β on the η.

For the growth of e or V, the distribution proportion in mode-SD is decreasing and the distribution proportion in model-CD is increasing. For the growth of λ and β, the change trends of the distribution proportions are opposite to that before. For the critical parameters, the gap between η^{SD^*} and 0.5 is smaller than that between η^{SD^*} and 0.5.

5.4. Analysis of supply chains' profit and social welfare

It is challenging to analytically analyze supply chains' profit and social welfare due to their complex expressions. Hence, the numerical experiments are conducted to make sensitivity analysis and comparative analysis, as shown in Figures 20–27.

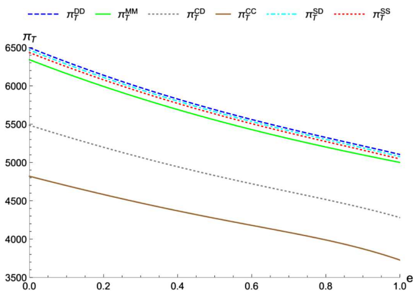

FIGURE 20. Impact of the parameter e on the π_T.

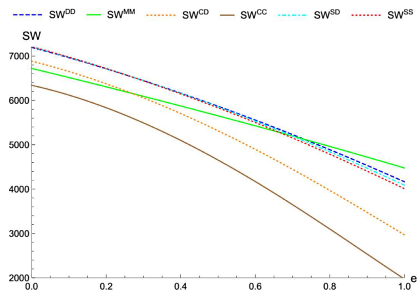

FIGURE 21. Impact of the parameter e on the SW.

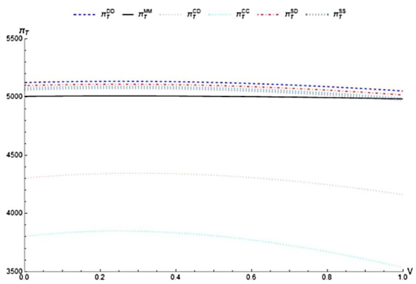

FIGURE 22. Impact of the parameter V on the π_T.

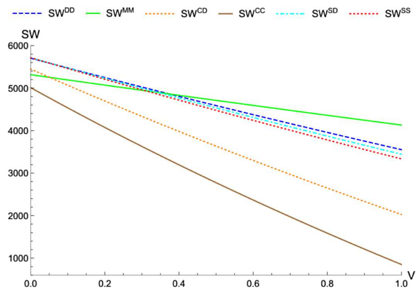

FIGURE 23. Impact of the parameter V on the SW.

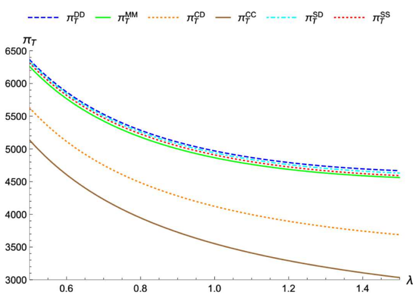

FIGURE 24. Impact of the parameter λ on the π_T.

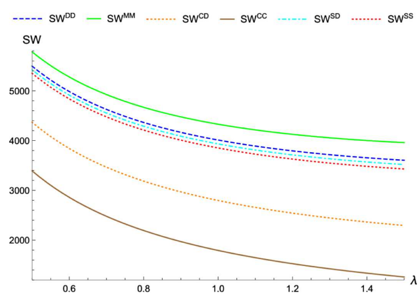

FIGURE 25. Impact of the parameter λ on the SW.

It is clear in Figures 20–27 that the supply chains' profit and social welfare both are reducing with e, V or λ, as well as that are increasing with β. The horizontal cooperation and wholesale price contract of supply chain has no obvious effect on the profit of supply chain system. For the social welfare, the influence of e or V is similar to that of e on cap setting. There's a relationship of the supply chain's profit like as $\pi_T^{\mathrm{DD}^*} > \pi_T^{\mathrm{SD}^*} > \pi_T^{\mathrm{SS}^*} > \pi_T^{\mathrm{MM}^*} > \pi_T^{\mathrm{CD}^*} > \pi_T^{\mathrm{CC}^*}$ in growth of e, V, or λ, as well as it also appears when $\beta > 0.790$. Besides, the $\pi_T^{\mathrm{MM}^*}$ successively surpasses $\pi_T^{\mathrm{CD}^*}, \pi_T^{\mathrm{SS}^*}, \pi_T^{\mathrm{SD}^*}$, and $\pi_T^{\mathrm{DD}^*}$ when $\beta = 0.484, \beta = 0.764, \beta = 0.777$, and $\beta = 0.792$, separately. The wholesale price as an internal parameter, it indirectly affects market demand. Moreover, the market demand is only affects by retail price. Thus, the relationship of the supply chains' profit is same as that of the wholesale price.

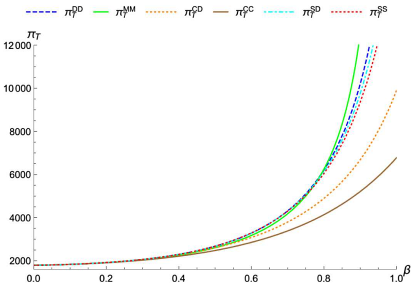

FIGURE 26. Impact of the parameter β on the π_T.

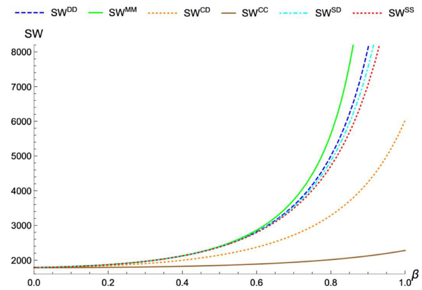

FIGURE 27. Impact of the parameter β on the SW.

Similarly, there's relationship of the social welfare like as $\mathrm{SW}^{\mathrm{MM}^*} > \mathrm{SW}^{\mathrm{DD}^*} > \mathrm{SW}^{\mathrm{SD}^*} > \mathrm{SW}^{\mathrm{SS}^*} > \mathrm{SW}^{\mathrm{CD}^*} > \mathrm{SW}^{\mathrm{CC}^*}$ in growth of λ or β, and it also appears when $e > 0.731$ or $V > 0.376$. Besides, the $\mathrm{SW}^{\mathrm{MM}^*}$ successively surpasses $\mathrm{SW}^{\mathrm{CD}^*}, \mathrm{SW}^{\mathrm{SS}^*}, \mathrm{SW}^{\mathrm{SD}^*}$, and $\mathrm{SW}^{\mathrm{DD}^*}$ when $e = 0.268, e = 0.664, e = 0.698$, and $e = 0.731$, separately, or when $V = 0.051, V = 0.307, V = 0.342$, and $V = 0.374$, correspondingly.

6. Conclusion

In this study, it attempts to investigate government's set the carbon emission cap as well as the product pricing behavior of supply chain members. It assumes that five cooperation scenario are available for two supply chains with competition based on the double decentralized scenario: (1) the two manufacturers cooperation scenario, (2) the single centralized and single decentralized scenario, (3) the double centralized scenario, (4) the single contract and single decentralized scenario, (5) the double contract scenario. Under each scenario, the cap setting, the distribution proportion, the wholesale price, and the retail price are optimized and analytically analyzed, which provide insights into the cap setting, cap distribution, and pricing strategies. On this basis, the optimal profit of the supply chain system and the optimal social welfare are identified and analyzed. The main conclusions are as following:

(1) The market demand being affected by the vertical cooperation is more than that by the horizontal cooperation, besides, the market demand being affected by the cooperation of the wholesale price contract is more than that by the structural cooperation.
(2) The asymmetric competition structure changes the bargaining power of the supply chains. The bargaining power in symmetrical competition models is the benchmark as 0.5, that of model-SD is larger than this benchmark, but, that of model-CD is lower than this benchmark.
(3) In the process of setting carbon emission cap, government should emphasize the influencing factors change of the cap, *i.e.* the structures with competition and cooperation of supply chain, unit emission, and environmental damage coefficient.
(4) For the members of the supply chain, they should pay attention to that the ability of bargaining power is enhanced by adopting the contractual cooperation in the competition of chain to chain.

In the paper, we also obtain some managerial insights. Researchers have developed different cooperation structures to convince the manufacturer and retailer to undertake cooperative decision-making to make the supply chain more profitable as a whole. But, in this work, the proposed model is supported for the same strategy under certain conditions. (1) The complete scheme of all members is not benefiting the conducive to the improvement of the members' profit and the social welfare. (2) Although the cooperation among manufacturers needing the government to invest much carbon emission cap, it can maximize the social welfare. (3) In low energy consumption and non-competitive industries, the members of low-carbon supply chain should adopt the non-cooperative mode to finish the production operation.

Although six models are considered in this paper to discuss the vertical-horizontal cooperation of supply chains in pricing and the cap setting of government, there are several limitations in our work, and some of them may serve as future research. First, the wholesale price contract is only considered in the horizontal cooperation. The cooperation by carbon trade and cap can be added to enrich contract cooperation structure in future research. Second, the market demand is affect only by the price competition. In practice, there are some other factors (carbon emission reduction level, service level, random factor etc.) to affect the market demand, which can be involved in future research. Third, it has not considered the emission reduction strategy needed to minimize the cost and environmental impact of the production process [16]. Fourth, these models are proposed only based on manufacturer dominant Stackelberg in single supply chain. Other dominant structures should be considered in a single supply chain, and Stackelberg game should be considered in the structure of the chain to chain. Finally, it is based on Stackelberg game and Nash game. Other games, such as repeated game should also be considered in an evolutionary game.

Appendix A.

The double decentralized scenario (Model-DD)

Step 1. The 2nd order partial differentiation w to p_1 and p_2 of the retailers' profit function given in equation (4.3) are $\frac{\partial^2 \pi_{\mathrm{R1}}}{\partial (p_1)^2} = \frac{\partial^2 \pi_{\mathrm{R2}}}{\partial (p_2)^2} = -2$. Therefore, the profit functions of the retailers are concave.

At extreme point, it has $\frac{\partial \pi_{\mathrm{R1}}}{\partial p_1} = 0$ and $\frac{\partial \pi_{\mathrm{R2}}}{\partial p_2} = 0$, as well as the retailers' reaction functions can be reached $p_1(w_1, w_2)$ and $p_2(w_1, w_2)$.

Step 2. Substituting $p_1(w_1, w_2)$ and $p_2(w_1, w_2)$ into equations (4.1) and (4.2) separately, and the 2nd order partial differentiation w_1 and w_2 of the manufacturers' profit functions given are $\frac{\partial^2 \pi_{M1}}{\partial (w_1)^2} = \frac{\partial^2 \pi_{\mathrm{M2}}}{\partial (w_2)^2} = -\frac{2(2-\beta^2)}{4-\beta^2}$. Therefore, the profit functions of the manufacturers are concave.

At extreme point, it has $\frac{\partial \pi_{\mathrm{M1}}}{\partial w_1} = 0$ and $\frac{\partial \pi_{\mathrm{M2}}}{\partial w_2} = 0$, as well as the manufacturers' reaction functions can be reached w_1^* and w_2^*. Based on this, it has p_1^* and p_2^*.

Step 3. Substituting w_1^*, w_2^*, p_1^*, and p_2^* into equation (3.5), it can find η^*.

Step 4. Substituting w_1^*, w_2^*, p_1^*, and p_2^* into equation (3.4), it can find G^*.

The two manufacturers cooperation scenario (Model-MM)

Step 1. Similar to model-DD, here it is omitted for brevity.

Step 2. Substituting $p_1(w_1, w_2)$ and $p_2(w_1, w_2)$ into equation (4.4), the Hessian matrix of the manufacturers' joint profit function, H is $\begin{pmatrix} -\frac{2(2-\beta^2)}{4-\beta^2} & \frac{2\beta}{4-\beta^2} \\ \frac{2\beta}{4-\beta^2} & -\frac{2(2-\beta^2)}{4-\beta^2} \end{pmatrix}$ and its determinate value $|H| = \frac{4(1-\beta^2)}{4-\beta^2} > 0$ as $0 < \beta < 1$. Therefore, the profit function of the manufacturer is concave.

At extreme point, it has $\frac{\partial \pi_{\mathrm{M}}}{\partial w_1} = 0$ and $\frac{\partial \pi_{\mathrm{M}}}{\partial w_2} = 0$ as well as the manufacturer' reaction function can be reached w_1^* and w_2^*. Based on this, it has p_1^* and p_2^*.

Steps 3 and 4. Similar to model-DD, here it is omitted for brevity.

The single centralized and single decentralized scenario (Model-CD)

Step 1. The 2nd order partial differentiation w, to p_1 and p_2 of the profit function of the retailer 2 and supply chain 1 given separately in equations (4.6) and (4.8) are $\frac{\partial^2 \pi_{T1}}{\partial (p_1)^2} = \frac{\partial^2 \pi_{\mathrm{R2}}}{\partial (p_2)^2} = -2$. Therefore, the profit functions of the retailer and supply chain 1 are concave, separately.

At extreme point, it has $\frac{\partial \pi_{T1}}{\partial p_1} = 0$ and $\frac{\partial \pi_{\mathrm{R2}}}{\partial p_2} = 0$, as well as the reaction functions of the retailer and supply chain 1 can be reached p_1^* and $p_2(w_2)$, separately.

Step 2. Substituting $p_1(w_2)$ and $p_2(w_2)$, into equation (4.7), and the 2nd order partial differentiation w_2 of the manufacturers' profit functions given is $\frac{\partial^2 \pi_{\mathrm{M2}}}{\partial (w_2)^2} = -\frac{2(2-\beta^2)}{4-\beta^2}$. Therefore, the profit function of the manufacturer is concave.

At extreme point, it has $\frac{\partial \pi_{\mathrm{M2}}}{\partial w_2} = 0$, as well as the manufacturer' reaction functions can be reached w_2^*. Based on this, it has p_1^* and p_2^*.

Steps 3 and 4. Similar to model-DD, here it is omitted for brevity.

The double centralized scenario (Model-CC)

Step 1. The 2nd order partial differentiation p_1 and p_2 of the supply chains' profit function given in equations (4.9) and (4.10) are $\frac{\partial^2 \pi_{T1}}{\partial (p_1)^2} = \frac{\partial^2 \pi_{T2}}{\partial (p_2)^2} = -2$. Therefore, the profit functions of the supply chains are concave.

At extreme point, it has $\frac{\partial \pi_{T1}}{\partial p_1} = 0$ and $\frac{\partial \pi_{T2}}{\partial p_2} = 0$, as well as the retailers' reaction functions can be reached p_1^* and p_2^*.

Steps 2 and 3. Similar to model-DD of Steps 3 and 4, here it is omitted for brevity.

The single contract and single decentralized scenario (Model-SD)

Step 1. The 2nd order partial differentiation w to p_1 and p_2 of the retailers' profit function given in equation (4.3) are $\frac{\partial^2 \pi_{\mathrm{R1}}}{\partial (p_1)^2} = \frac{\partial^2 \pi_{\mathrm{R2}}}{\partial (p_2)^2} = -2$. Therefore, the profit functions of the retailers are concave.

At extreme point, it has $\frac{\partial \pi_{\mathrm{R1}}}{\partial p_1} = 0$ and $\frac{\partial \pi_{\mathrm{R2}}}{\partial p_2} = 0$, as well as the retailers' reaction functions can be reached $p_1(w_1, w_2)$ and $p_2(w_1, w_2)$. Based on this, an inverse function of $p_1(w_1, w_2)$ is $w_1(p_1, w_2)$, which it can find. Thus, $p_2(w_1, w_2)$ is converted to $p_2(p_1, w_2)$ by $w_1(p_1, w_2)$.

Step 2. Substituting $w_1(p_1, w_2)$ and $p_2(p_1, w_2)$ into equations (4.1) and (4.2) separately, and the 2nd order partial differentiation p_1 and w_2 of the manufacturers' profit functions given are $\frac{\partial^2 \pi_{M1}}{\partial (p_1)^2} = -\frac{8-6\beta^2+\beta^4}{2}$ and $\frac{\partial^2 \pi_{\mathrm{M2}}}{\partial (w_2)^2} = -1$. Therefore, the profit functions of the manufacturers are concave.

At extreme point, it has $\frac{\partial \pi_{\mathrm{M1}}}{\partial p_1} = 0$ and $\frac{\partial \pi_{\mathrm{M2}}}{\partial w_2} = 0$, as well as the manufacturers' reaction functions can be reached p_1^* and w_2^*. Based on this, it has w_1^* and p_2^*.

Steps 3 and 4. Similar to model-DD, here it is omitted for brevity.

The double contract scenario (Model-SS)

Step 1. The 2nd order partial differentiation w to p_1 and p_2 of the retailers' profit function given in equation (4.3) are $\frac{\partial^2 \pi_{\mathrm{R1}}}{\partial (p_1)^2} = \frac{\partial^2 \pi_{\mathrm{R2}}}{\partial (p_2)^2} = -2$. Therefore, the profit functions of the retailers are concave.

At extreme point, we have $\frac{\partial \pi_{\mathrm{R1}}}{\partial p_1} = 0$ and $\frac{\partial \pi_{\mathrm{R2}}}{\partial p_2} = 0$, as well as the retailers' reaction functions can be reached $p_1(w_1, w_2)$ and $p_2(w_1, w_2)$. Based on this, the inverse functions of $p_1(w_1, w_2)$ and $p_2(w_1, w_2)$ are $w_1(p_1, p_2)$ and $w_2(p_1, p_2)$, which we can find.

Step 2. Substituting $w_1(p_1, p_2)$ and $w_2(p_1, p_2)$ into equations (4.1) and (4.2) separately, and the 2nd order partial differentiation p_1 and p_2 of the manufacturers' profit functions given are $\frac{\partial^2 \pi_{M1}}{\partial (p_1)^2} = \frac{\partial^2 \pi_{\mathrm{M2}}}{\partial (p_2)^2} = -4$. Therefore, the profit functions of the manufacturers are concave.

At extreme point, it has $\frac{\partial \pi_{\mathrm{M1}}}{\partial p_1} = 0$ and $\frac{\partial \pi_{\mathrm{M2}}}{\partial p_2} = 0$, as well as the manufacturers' reaction functions can be reached p_1^* and p_2^*. Based on this, it has w_1^* and w_2^*.

Steps 3 and 4. Similar to model-DD, here it is omitted for brevity.

Appendix B.

Proof of Proposition 4.7. It is easy to prove that $\frac{\partial G^{\mathrm{DD}^*}}{\partial V} < 0$, as well as the $w_x^{\mathrm{DD}^*}$ and $p_x^{\mathrm{DD}^*}$ are the strict decreasing function of G^{DD^*}. Then, the $w_x^{\mathrm{DD}^*}$ and $p_x^{\mathrm{DD}^*}$ are the strict increasing function of V. In other models, the process of proof be similar to model-DD, here it is omitted for brevity. □

Acknowledgements. It is sincerely thank the editor and anonymous reviewers for their kind and helpful comments on this paper. This work was supported by: (1) the National Natural Science Foundation of China [grant numbers 71561003, 71903043 and 71662005]; (2) the Humanities and Social Sciences Fund of Ministry of Education of China [grant number 19YJC790048]; (3) the Middle-aged and Young Teachers' Basic Ability Promotion Project of Guangxi [grant number 2020KY04036]; (4) the Training Plan for Young Key Teachers in Colleges and Universities in Henan Province [grant number 2020GGJS233]; (5) the Talent Introduction Research Project of Guangxi University for Nationalities [grant number 2018SKQD16]; (6) the Xiangsihu Young Scholars Innovation Team Project of Guangxi University for Nationalities [grant number 2018RSCXHQN06]. There are no conflicts of interest to this work.

References

[1] G.P. Cachon, Retail store density and the cost of greenhouse gas emissions. *Manage. Sci.* **60** (2014) 1907–1925.
[2] G.P. Cachon and A.G. Kök, Competing manufacturers in a retail supply chain: on contractual form and coordination. *Manage. Sci.* **56** (2010) 571–589.
[3] K. Cao, X. Xu, Q. Wu and Q. Zhang, Optimal production and carbon emission reduction level under cap-and-trade and low carbon subsidy policies. *J. Clean. Prod.* **167** (2017) 505–513.
[4] C. Chen and M. Akmalul' Ulya, Analyses of the reward-penalty mechanism in green closed-loop supply chains with product remanufacturing. *Int. J. Prod. Econ.* **210** (2019) 211–223.
[5] T.M. Choi, C. Ma, B. Shen and Q. Sun, Optimal pricing in mass customization supply chains with risk-averse agents and retail competition. *Omega* **88** (2019) 150–161.
[6] S. Du, L. Zhu, L. Liang and F. Ma, Emission-dependent supply chain and environment-policy-making in the "cap-and-trade" system. *Energ. Policy.* **57** (2013) 61–67.
[7] D. Ghosh and J. Shah, A comparative analysis of greening policies across supply chain structures. *Int. J. Prod. Econ.* **135** (2012) 568–583.
[8] A. Hafezalkotob, Competition, cooperation, and coopetition of green supply chains under regulations on energy saving levels. *Transp. Res. E-log.* **97** (2017) 228–250.
[9] P. He, G. Dou and W. Zhang, Optimal production planning and cap setting under cap-and-trade regulation. *J. Oper. Res. Soc.* **68** (2017) 1094–1105.
[10] P. He, Y. He and H. Xu, Channel structure and pricing in a dual-channel closed-loop supply chain with government subsidy. *Int. J. Prod. Econ.* **213** (2019) 108–123.
[11] G. Hua, T.E.C. Chen and S. Wang, Managing carbon footprints in inventory management. *Int. J. Prod. Econ.* **132** (2011) 178–185.
[12] J. Ji, Z. Zhang and Y. Lei, Carbon emission reduction decisions in the retail-/dual-channel supply chain with consumers' preference. *J. Clean. Prod.* **141** (2017) 852–867.
[13] T. Ji, X. Xu, X. Yan and Y. Yu, The production decisions and cap setting with wholesale price and revenue sharing contracts under cap-and-trade regulation. *Int. J. Prod. Res.* **58** (2020) 128–147.
[14] T. Li, R. Zhang, S. Zhao and B. Liu, Low carbon strategy analysis under revenue-sharing and cost-sharing contracts. *J. Clean. Prod.* **212** (2019) 1462–1477.
[15] W. Lou, and J. Ma, Complexity of sales effort and carbon emission reduction effort in a two-parallel household appliance supply chain model. *Appl. Math. Model.* **64** (2018) 398–425.
[16] A.I. Malik and B.S. Kim, A constrained production system involving production flexibility and carbon emissions. *Mathematics* **8** (2020) 275.
[17] A.I. Malik and B. Sarker, Coordinating supply-chain management under stochastic fuzzy environment and lead-time reduction. *Mathematics* **7** (2019) 480.
[18] A.I. Malik and B. Sarker, Coordination supply chain management under flexible manufacturing, stochastic lead time demand, and mixture of inventory. *Mathematics* **8** (2020) 911.
[19] K. Matsui, Optimal bargaining timing of a wholesale price for a manufacturer with a retailer in a dual-channel supply chain. *Eur. J. Oper. Res.* **287** (2020) 225–236.
[20] W.D. Montgomery, Markets in licenses and efficient pollution control programs. *J. Econ. Thero.* **5** (1972) 395–418.
[21] Q.Y. Peng, C.X. Wang and L. Xu, Emission abatement and procurement strategies in a low-carbon supply chain with option contracts under stochastic demand. *Comput. Ind. Eng.* **144** (2020) 106502.
[22] X. Pu, Z. Song and G. Han, Competition among supply chains and governmental policy: considering consumers' low-carbon preference. *Int. J. Env. Res. Pub. He.* **15** (2018) 1985.
[23] A.A. Taleizadeh, N. Alizadeh-Basban and N.R. Sarker, Coordinated contracts in a two-echelon green supply chain considering pricing strategy. *Comput. Ind. Eng.* **124** (2018) 249–275.
[24] A.A. Taleizadeh, N. Alizadeh-Basban and S.T.A. Niaki, A closed-loop supply chain considering carbon reduction, quality improvement effort, and return policy under two remanufacturing scenarios. *J. Clean. Prod.* **232** (2019) 1230–1250.
[25] W. Tong, D. Mu, F. Zhao, G.P. Mendis and J.W. Sutherland, The impact of cap-and-trade mechanism and consumers' environmental preferences on a retailer-led supply Chain. *Resour. Conserv. Recy.* **142** (2019) 88–100.
[26] Q. Wang, D. Zhao and L. He, Contracting emission reduction for supply chains considering market low-carbon preference. *J. Clean. Prod.* **120** (2016) 72–84.

[27] C. Wang, W. Wang and R. Huang, Supply chain enterprise operations and government carbon tax decisions considering carbon emissions. *J. Clean. Prod.* **152** (2017) 271–280.

[28] M. Wang, L. Zhao and M. Herty, Joint replenishment and carbon trading in fresh food supply chains. *Eur. J. Oper. Res.* **227** (2019) 561–573.

[29] T. Wu and C. Kung, Carbon emissions, technology upgradation and financing risk of the green supply chain competition. *Technol. Forecast. Soc.* **152** (2020) 119884.

[30] L. Xia, T. Guo, J. Qin, X. Yue and N. Zhu, Carbon emission reduction and pricing policies of a supply chain considering reciprocal preferences in cap-and-trade system. *Ann. Oper. Res.* **268** (2018) 149–175.

[31] L. Xia, W. Hao, J. Qin, F. Ji and X. Yue, Carbon emission reduction and promotion policies considering social preferences and consumers' low-carbon awareness in the cap-and-trade system. *J. Clean. Prod.* **195** (2018) 1105–1124.

[32] T. Xiao and D. Yang, Price and service competition of supply chains with risk-averse retailers under demand uncertainty. *Int. J. Prod. Econ.* **114** (2008) 187–200.

[33] X. Xu, X. Xu and P. He, Joint production and pricing decisions for multiple products with cap-and-trade and carbon tax regulations. *J. Clean. Prod.* **112** (2016) 4093–4106.

[34] X. Xu, P. He, H. Xu and Q. Zhang, Supply chain coordination with green technology under cap-and-trade regulation. *Int. J. Prod. Econ.* **183** (2017) 433–442.

[35] L. Xu, J. Shi and J.H. Chen, Pricing and collection rate for remanufacturing industry considering capacity constraint in recycling channels. *Complexity* **2020** (2020) 8391252.

[36] L. Yang, C. Zheng and M. Xu, Comparisons of low carbon policies in supply chain coordination. *J. Syst. Sci. Syst. Eng.* **23** (2014) 342–361.

[37] L. Yang, Q. Zhang and J. Ji, Pricing and carbon emission reduction decisions in supply chains with vertical and horizontal cooperation. *Int. J. Prod. Econ.* **191** (2017) 286–297.

[38] 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. *J. Clean. Prod.* **193** (2018) 506–523.

[39] L. Yang, G. Wang and C. Ke, Remanufacturing and promotion in dual-channel supply chains under cap-and-trade regulation. *J. Clean. Prod.* **204** (2018) 939–957.

[40] F. Zand, S. Yaghoubi and S. J. Sadjadi, Impacts of government direct limitation on pricing, greening activities and recycling management in an online to offline closed loop supply chain. *J. Clean. Prod.* **215** (2019) 1327–1340.

[41] S. Zhang, C. Wang, C. Yu and Y. Ren, Governmental cap regulation and manufacturer's low carbon strategy in a supply chain with different power structures. *Comput. Ind. Eng.* **134** (2019) 27–36.

[42] Y. Zheng, T. Shu, S. Wang, S. Chen, K. K. Lai and L. Gan, Analysis of product return rate and price competition in two supply chains. *Oper. Res.* **18** (2018) 469–496.