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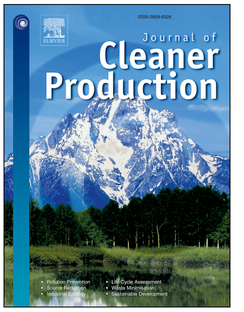

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Green Supply Chain Game Model and Analysis under Revenue-sharing Contract

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Abstract： A revenue-sharing contract can play an important role in coordinating the distribution of benefits among the upstream and downstream members of a green supply chain and improving its overall performance. However, there are few quantitative studies on revenue-sharing contracts in green supply chains. To this end, we first establish a green supply chain game model with two kinds of revenue-sharing contracts, and then compare the results with the common centralized control game model and the decentralized decision game model's results. By comparing the model's results, we can quantitatively analyze the impact of the contracts on the internal membership decision variables and the overall performance of the supply chain. Our study also takes consumer sensitivity towards green products into account to make a better sense of its impacts on the relative variables. Finally, we propose that a revenue-sharing contract can effectively improve the greening level of the products and the overall profitability of the supply chain. In particular, the retail-led revenue-sharing contract leads to higher greening level compared with the decentralized control condition. In addition, under this case, both the manufacturer and the retailer get higher profits, which is of great significance to green supply chain's establishment and cooperation. In addition, the bargaining revenue sharing contract can make both product's greening level and supply chain's overall profit even higher than that under the manufacturer-led revenue sharing contract.

Key words： green supply chain; revenue-sharing contract; game model; green sensitive

1. Introduction

The great development of economic globalization requires companies to establish a global supply chain instead of the traditional limited supply chain. The global supply chain aims to ensure the timely availability of material as well as minimizing the cost of manufacturing, service and performance (Almaktoom et al., 2016). However, with the expansion of the global supply chain, resource consumption and environmental pollution problems have aroused people's attention(Zhu and Sarkis,2004). Therefore, improving the global supply chain's resource utilization efficiency and reducing the impact of manufacturing on the environment have become a hot topic(Seuring ,2016). Under this circumstance, the green supply chain concept came into being.

A green supply chain is a modern management idea with the goal of minimizing environmental impacts and maximizing resource efficiency from material acquisition, processing, packaging, storage, transportation, use, to final scrapping (Srivastava,2007). Establishing green supply chains to raise the utilization efficiency of resources and reduce the impact of the manufacturing on the environment has attracted the attention of various countries and organizations. Hundreds of countries have put energy conservation and environmental protection into their development strategies, and continued to strengthen and improve relevant legislation(Mathiyazhagan et al., 2015). For example, the "Restrictions on the Use of Certain Hazardous Substances Directive in Electrical and Electronic Equipment" promulgated by the European Union in 2006(EU-Directive, 2003) prompted manufacturers to attach great importance to toxic and hazardous substances in products. Since 2009, China has strengthened environmental protection legislation and supervision, and has begun to implement environmental protection and reduce energy consumption in the process of business management. Implementing green supply chain has become an important goal(Luo et al., 2015) .To motivate the companies to participate in the green supply chain, the government has provided subsides for remanufacturers(Albared, 2008). Increasingly stringent laws and regulations as well as rising public environmental awareness have forced the world's leading business giants to work with upstream and downstream companies to build green supply chains (Sancha et al., 2016). As early as 2001, Volkswagen and Ford, two major global automakers, announced the implementation of green supply chain management which required suppliers and business partners to be ISO14001 certified by July 2003 and December 2002(Kushwaha et al., 2016). Adidas, a leading manufacturer of athletic wear, uses MMVEA and Eco-Grip technology to reduce harmful substances from materials used in manufacturing to minimize the manufacturing impact on environment. It can be seen that the establishment of collaboration between upstream and downstream enterprises by implementing green supply chains is an irreversible trend.

The green supply chain is not only a hot topic in political cycle, but also captures keen scientific attention. Studies on green supply chain analysis have continued for several decades. Current green supply chain research has mainly focused on case studies, questionnaires, and other means of qualitative analysis, and has been less involved in quantitative research. In recent years, scholars are advancing that research to establish green supply chain game models to quantitatively analyze decision rules for green supply chain members and promote cooperation among them. Ghosh and Shah (2012) studied a secondary supply chain consisting of a manufacturer and a retailer. And they explored the effect of decentralized decision-making and negotiation while bargaining on the greening level of products, and then further proposed a contractual coordination mechanism. Zhang et al.(2016) set a dynamic model with learning and operational inefficiency effects, and obtained forward-looking and myopic equilibria. They found that the efficiency of both the forward-looking and the myopic supply chain is lower than the static one, and they also proposed that competition can make supply chain efficiency and manufacturer's profit proportion improved. Kannan et al.(2015) proposed a fuzzy criteria approach to help manufactures to select the best green supplier and provided a numerical application to demonstrate the effectiveness of the proposed approach. Nagarajan and Sosic(2008) discussed mechanisms of collaboration when two firms develop new products and face technical uncertainty. They analyzed and surveyed several models, and used cooperative bargaining models to find how supply chain partners allocate their profit.

By summing up the previous quantitative research literature, we can find that, in general, the basic dynamic game model commonly used in the study of green supply chains includes two categories: the decentralized decision-making game model and the centralized control game model. In the decentralized decision game model, manufacturers and retailers make decisions based on their own costs to maximize their own interests; in the centralized control game model, manufacturers and retailers no longer make individual decisions based on their own interests, but make collective decisions to maximize the overall profitability of the supply chain. These two models have significant meaning for understanding the decision-making process of supply chain members and promoting the realization of the optimal decision values. At the same time, these two models have some problems. In the decentralized decision game model, independent decisions of suppliers and retailers lead to low supply chain efficiency, which is a common problem in supply chains. And the centralized control game model requires a decision-maker who controls the supply chain and masters all information to maximize the overall profitability of the supply chain by centralized decision-making, which is difficult to achieve in reality.

Because both the centralized control model and the decentralized decision-making model have many shortcomings in solving the green supply chain's profit distribution problems and promoting the cooperation between manufacturers and retailers. The integration of supply chain contract coordination mechanism provides an important way to further optimize the green supply chain game model and ensure green supply chain's stable operation. The supply chain contract refers to the provision set between buyers and sellers by providing appropriate information and incentives to ensure their coordination and optimize the sales channel performance (Cachon,2003). It includes Buy Back or Return Contract, Wholesale Price Contract, Quantity Flexibility Contract, Revenue Sharing Contract and so on(Sluis and

Giovanni,2016). In particular, the revenue-sharing contract can more effectively coordinate profit distribution and improve performance compared with the traditional coordination mechanism (Veen, Venugopal, 2005). Under the revenue sharing contract, retailers share a certain percentage of sales with suppliers to obtain a lower wholesale price, and achieve a fair distribution of internal profits eventually.

Current research on revenue-sharing contracts in green supply chains focuses more on qualitative analysis than quantitative research. In recent years, researchers begin to study the impact of revenue-sharing contract on green supply chains quantitatively. Qian and Guo(2014) developed a revenue-sharing bargaining model between Energy Service Company and an Energy-Using Organization to analyze the impact on energy prices, risk-adjusted discount rates and accidents on the ESCO's bargaining strategies. Hsueh(2014) integrated corporate social responsibility (CSR) into supply chain coordination, and established a new revenue sharing contract embedding corporate social responsibility to coordinate a two-tier supply chain. The research found that the contract could not only improve both the CSR performance and the total supply chain profits, but also ensure that each partner could benefit from that. Arani and Rabbani(2016) introduced a novel mixed revenue-sharing option contract to coordinate the supply chain and modeled that through a game theoretic approach to obtain the order quantity of the retailer and the production quantity of the manufacturer.

Moreover, green supply chains differ from general supply chains, because green supply chain coordination objects not only include the manufacturers and retailers in traditional supply chains, but also include consumers. Meeting consumer demand for green products is one of the main purpose of green supply chain participants implementing green innovations (Vachon,Klassen,2008).Consumer sensitivity to green product affects the greening level of products and the size of sales directly, which in turn affect the profitability of manufacturers and retailers.

By taking all above factors into consideration, this paper tries to apply the revenue sharing contract to the green supply chain. We study revenue sharing contract's influence on the decision variables of the green supply chain members. The aim is to explore whether revenue sharing contract could coordinate the green supply chain members' interest conflicts or promote the green supply chain's establishment. At the same time, in order to better explore the impact of consumer consumption preference on the green supply chain, we also take the consumer sensitivity towards green products into account. To better study the influence of the revenue-sharing contract on green supply chain coordination, we establish two revenue-sharing contract game models: a retailer-led revenue-sharing contract game model and a bargaining revenue-sharing contract game model. The first model represents the situation that the revenue sharing contract is determined by the retailor who dominates the green supply chain, while the manufacturer incurs the whole R&D costs and can't participate in making the contract. The second model represents the situation where the manufacturer refuses the revenue sharing contract proposed by the retailer, while instead, the manufacturer bargains with the retailer to establish a new revenue sharing contract. Then we compare the results of the two models with the results of the centralized control game model and the decentralized decision game model. The purpose is to find out how revenue sharing contract affects the product's greening level and the green supply chain' profit. Finally, we hope to provide a reference for green supply chain's establishment and management.

2. The Models

2.1 Model Hypotheses

We examined a secondary supply chain model consisting of a manufacturer who sells green products to a retailer directly at wholesale prices and a retailer who sells products to consumers at retail prices. General products and green products can replace each other completely in the market. Consumers are sensitive to green products, and need to consider both the product price and the greening level when buying products (Ghosh, Shah, 2015). We make the following assumptions, and the parameters and meanings are listed in table 1:

Table 1: Parameters and its Meaning

Parameter	Meaning
a	The total market potential
b	Consumer sensitivity to price
α	Consumer sensitivity to greening level improvement
c	The cost of producing green products
q	The actual demand of market
m	Retailer's margins

w	The wholesale price of products

(1) The retail price of green products is p, greening level is θ, the consumer sensitivity to green improvements is α. The greater θ is, the higher the environmental protection of the products will be; the greater α is, the more sensitive consumers are to green products will be. Referring to Savaskan's approach (Savaskan, 2004), we assume that the market's total potential demand for green products is a, and the actual market demand is q. The actual market demand changes with the product's greening level and retail price. When product's greening level improved or retail price decreased, the actual market demand q will be higher than the market's total potential demand a.The market demand q is a linear function of product price and greening level, i.e., $q(p,\theta) = a - bp + \alpha\theta$. Consumer demand for green products is proportional to α and θ, and inversely proportional to p. In other words, consumers prefer inexpensive products, and when the product price is lower and the greening level are higher, product sales are greater.

(2) To improve the greening level of products, manufacturers need to invest funds for new product research and development (R&D). With reference to Banker's research (Banker et al., 1998), we assume R&D results investment have a quadratic relationship and that the costs of green product R&D are entirely borne by the manufacturers. In other words, green product R&D costs $I\theta^2$, where I is the green investment parameter.

(3) The manufacturer's cost of producing green products is c, the wholesale price to the retailer is w, and the retailer sells the product to consumers at the retail

price p, so that the gross profit per unit for the retailer is $m = p - w$. To encourage manufacturers to participate in the green supply chain, we assume the retailer shares a certain percentage income with the manufacturer.

Based on the above assumptions:

The profit function π for the manufacturer is:

$$\pi_M = (w - c)q - I\theta^2 \quad (1)$$

The profit function for the retailer is:

$$\pi_R = (p - w)q \quad (2)$$

The total profit function for the supply chain is:

$$\pi_{SC} = (p - c)q - I\theta^2 \quad (3)$$

2.2 Basic Game Models

To compare with the new revenue-sharing game models, we first introduce the decentralized decision game model and the centralized control game model.

2.2.1 Decentralized Decision Game Model

The core idea of the decentralized decision game model is that manufacturers and retailers make their own decisions based on their own costs to maximize their own interests, but the decision-making results are mutually influential. We examined the manufacturer-led Stackelberg game model, where suppliers take the initiative and retailers are passive. The dynamic game order is as follows: firstly, the manufacturer determines the product greening improvement level θ and the wholesale price w using the response function of the retailer; then the retailer reacts to determine the product's retail price p. The purpose of both the manufacturer and the retailer is the same that is to maximize their own profits. Given this structure, we get the equilibrium values that are shown in table 2. Vol (1991) establishes an approach for the centralized and decentralized channels, and we develop it here to motivate revenue-sharing contract analysis.

Using the inverse induction method, first we solve the profit function for the retailer from Eq. (2):

$$\pi_R(m) = (p - w)q = m(a - b(m + w) + \alpha\theta) \tag{4}$$

We obtain the first derivative and the second derivative of m, and set the first derivative equal to zero:

$$m(\theta, w) = \frac{a - bw + \alpha\theta}{2b} \tag{5}$$

Then we solve the profit function for the manufacturer, from Eq. (1):

$$\pi_M(w, \theta) = (w - c)q - I\theta^2 = (w - c)(a - b(m + w) + \alpha\theta) - I\theta^2 \tag{6}$$

We put the results of Eq. (5) into Eq. (6), and obtain the first and second partial derivative of w, θ. Then we find that when $2bI - \frac{\alpha^2}{4} > 0$, π_M is a strictly concave function of w and θ.

Next, we set the first derivatives of w and θ equal to zero, and get the optimal product greening level and the best wholesale price for the manufacturer:

$$\theta_M^* = \frac{\alpha(a - bc)}{8bI - \alpha^2} \tag{7}$$

$$w_M^* = \frac{4I(a - bc)}{8Ib - \alpha^2} + c \tag{8}$$

We put the values of θ_M^* and w_M^* into Eq. (5), and get the maximum gross profit margin for the retailer:

$$m_M^* = \frac{2I(a-bc)}{8bI-\alpha^2} \tag{9}$$

And the optimal retail price for the products:

$$p_M^* = m_M^* + w_M^* = \frac{6I(a-bc)}{8bI-\alpha^2} + c \tag{10}$$

Finally we put the values of θ_M^*, w_M^*, and p_M^* into Eqs. (1) to (3), and get the maximum profits for the manufacturer, retailer and supply chain:

$$\pi_M^* = \frac{I(a-bc)^2}{8Ib-\alpha^2}$$

$$\pi_R^* = \frac{4bI^2(a-bc)^2}{(8Ib-\alpha^2)^2}$$

$$\pi_{Msc}^* = \frac{I(a-bc)^2(12Ib-\alpha^2)}{(8Ib-\alpha^2)^2}$$

2.2.2 Centralized Control Game Model

The centralized control game model, known as the vertical integration game model, is the ideal state for supply chain management. This game model treats the supply chain as a whole, and manufacturers and retailers no longer make individual decisions based on their own interests, but rather make collective decisions to maximize overall profitability of the supply chain.

At this point, the profit of the supply chain is:

$$\pi_{SC}(p,\theta) = (p-c)q - I\theta^2 = (p-c)(a-bp+\alpha\theta) - I\theta^2 \tag{11}$$

We obtain the first and second partial derivatives of m and θ, and find that when $\frac{\partial^2}{\partial\theta^2}\pi_{sc} * \frac{\partial^2}{\partial p^2}\pi_{sc} - (\frac{\partial^2}{\partial\theta\partial p}\pi_{sc})^2 > 0$, which is $4Ib - \alpha^2 > 0$, π_{sc} is a strictly concave function of p and θ.

Next, we set the first derivatives of m and θ equal to zero, and get the optimal retail price and the optimal product greening level:

$$p^* = \frac{2I(a-bc)}{4Ib-\alpha^2} + c \tag{12}$$

$$\theta^* = \frac{\alpha(a-bc)}{4Ib-\alpha^2} \tag{13}$$

At this point, the gross profit for the products is:

$$m^* = p^* - c = \frac{2I(a-bc)}{4Ib-\alpha^2}$$

Finally, we put Eq. (12) and Eq. (13) into Eq. (11) and find that the profit for the supply chain is:

$$\pi_{sc}^* = \frac{I(a-bc)^2}{4Ib-\alpha^2}$$

2.3 Revenue-sharing Game Models

To achieve integrated management, promote upstream and downstream business cooperation, and ultimately obtain high overall performance are the goals for building a green supply chain. Here, we establish a retailer-led revenue-sharing contract game model and a bargaining revenue-sharing contract game model. The core idea is that retailers will share part of their sales with manufacturers to reduce the burden of green product development costs and coordinate the distribution of profits, thus encouraging manufacturers to participate in the green supply chain.

2.3.1 Retailer-led Revenue-sharing Contract Game Model

Because the costs of green product R&D are higher, when manufacturers are responsible for all R&D costs, they incur high economic risk. Therefore, to encourage manufacturers to participate in green supply chain, retailers and manufacturers establish a revenue-sharing contract. Because of the asymmetry of information, downstream retailers know more about market demand than upstream manufacturers, and have obvious advantages in the game. Based on these two points, we establish the retailer-led revenue-sharing contract model, in which retailers determine the proportion of income sharing under the premise of ensuring their own interests to maximize profits. The order and rules of the game are as follows: the manufacturer first determines the wholesale price w and the product greening level θ. On this basis, the retailer determines the selling price p of the products under the premise of ensuring their own interests to maximize profits, and provides the revenue-sharing ratio λ $(0 < \lambda < 1)$, indicating that the percentage of retailer income from final sales is λ and the remaining $1 - \lambda$ is shared with the manufacturer.

At this point, the profit for the manufacturer and the profit for the retailer are as follows：

$$\pi_R = \lambda(p - w)q \tag{14}$$

$$\pi_M = (w - c)q - I\theta^2 + (1 - \lambda)(p - w)q \tag{15}$$

First we get the profit of the retailer:

$$\pi_R = \lambda(p - w)q = \lambda(p - w)(a - bp + \alpha\theta) \tag{16}$$

We obtain the first and second derivatives of p and set the first derivative equal to zero, to get:

$$p(w, \theta) = \frac{a + \alpha\theta + bw}{2b} \tag{17}$$

Next we get the profit of the manufacturer:

$$\pi_M = (w - c)(a - bp + \alpha\theta) - I\theta^2 + (1 - \lambda)(p - w)(a - bp + \alpha\theta) \tag{18}$$

We put Eq. (17) into Eq. (18), and obtain the first and second partial derivatives of w and θ. Then we get that when $\frac{\partial^2}{\partial w^2}\pi_M * \frac{\partial^2}{\partial \theta^2}\pi_M - \left(\frac{\partial^2}{\partial w \partial \theta}\right)^2 > 0$, which is $-\alpha^2\lambda^2 - \alpha^2 + 4bI\lambda + 4bI > 0$, π_M is a strictly concave function of w and θ. We set the first derivatives of w and θ equal to zero:

$$w(\theta)=\frac{bc+\lambda(a+\alpha\theta)}{(1+\lambda)b} \tag{19}$$

$$\theta(w)=\frac{\alpha(a-bc-\lambda a+\lambda bw)}{-\alpha^2+4bI(1+\lambda)} \tag{20}$$

According to Eq. (19) and Eq. (20), we can get:

$$w(\lambda)=\frac{4I(\lambda a+bc)-\alpha^2 c}{-\alpha^2+4bI(1+\lambda)} \tag{21}$$

$$\theta(\lambda)=\frac{\alpha(a-bc)}{-\alpha^2+4bI(1+\lambda)} \tag{22}$$

Therefore, the optimal retail price is:

$$p(\lambda)=\frac{2I(2a\lambda+bc+a)-\alpha^2 c}{-\alpha^2+4bI(1+\lambda)} \tag{23}$$

We put Eqs. (21), (22), and (23) into Eq. (18), and obtain the first derivative of λ:

$$\frac{\partial}{\partial\lambda}\pi_R=-\frac{4bI^2(a-bc)^2(h^2-4bI+4\lambda bI)}{(4bI+4\lambda bI-\alpha^2)^3} \tag{24}$$

Next we obtain the second derivative of λ:

$$\frac{\partial^2}{\partial\lambda^2}\pi_R=\frac{64b^2I^3(a-bc)^2(\alpha^2-4bI+2\lambda bI)}{(4bI+4\lambda bI-\alpha^2)^4} \tag{25}$$

So, when $\alpha^2-4bI+2\lambda bI<0$, π_R is a strictly concave function of λ.

We set the first derivative equal to zero:

$$\lambda^{opt}=\frac{4bI-\alpha^2}{4bI} \tag{26}$$

Finally we substituting the value of λ^{opt}in the above expressions, we get : w^{opt}, θ^{opt}, p^{opt}, m^{opt}, π_M^{opt}, π_R^{opt} and π_{SC}^{opt}. Specific values are listed in Table 2.

2.3.2 Bargaining Revenue-sharing Contract Game Model

Compared with traditional supply chains, green supply chain is very different. A key factor in success of green supply chains is to value information sharing and co-operation among upstream and downstream enterprises. Therefore, in this model, we assume that manufacturers and suppliers have good communication. The revenue-sharing ratio λ is no longer determined by the retailer, but collectively determined by the manufacturers and retailers through bargaining. Using the Nash bargaining game (Nash, 1950-1953), we simulate the bargaining process between manufacturers and retailers by establishing the model in the function $MAX\pi_B(\lambda) = \pi_M\pi_R$. When π_B reaches the maximum value, the corresponding λ is the optimal benefit ratio for the game model.

We put Eqs. (21) to (23) into Eq. (15) and Eq. (16):

$$\pi_M(\lambda) = \frac{I(a-bc)^2}{4bI+4\lambda bI-\alpha^2} \tag{27}$$

$$\pi_R(\lambda) = \frac{4\lambda bI^2(a-bc)^2}{(4bI+4\lambda bI-\alpha^2)^2} \tag{28}$$

Therefore,

$$\mathrm{MAX}\pi_B(\lambda) = \pi_M\pi_R = \frac{4\lambda bI^3(a-bc)^4}{(4bI+4\lambda bI-\alpha^2)^3} \tag{29}$$

We obtain the first and second derivatives of λ, and set the first derivative equal to zero:

$$\lambda^b = \frac{4bI-\alpha^2}{8bI} \tag{30}$$

Finally we take λ^b back into the above expressions, we get : w^b, θ^b, p^b, m^b, π_M^b, π_R^b, π_{SC}^b, and the specific values are in Table 2.

3 Model Comparison

A summary of the variables corresponding to optimal decision-making under the four models is shown in Table 2.

Table 2: Comparison of Equilibrium Values for Four Game Types

Variable	Centralized	Decentralized	Retailer-led revenue-sharing	Revenue-sharing through bargaining
λ	--	--	$\frac{4bI-\alpha^2}{4bI}$	$\frac{4bI-\alpha^2}{8bI}$
θ^*	$\frac{\alpha(a-bc)}{4bI-\alpha^2}$	$\frac{\alpha(a-bc)}{8bI-\alpha^2}$	$\frac{\alpha(a-bc)}{2(4bI-\alpha^2)}$	$\frac{2\alpha(a-bc)}{3(4bI-\alpha^2)}$
w^*	--	$\frac{4I(a-bc)}{8bI-\alpha^2} + c$	$\frac{a+bc}{2b}$	$\frac{a+2bc}{3b}$
p^*	$\frac{2I(a-bc)}{4bI-\alpha^2} + c$	$\frac{6I(a-bc)}{8bI-\alpha^2} + c$	$\frac{a}{2b}+\frac{c}{2} + \frac{I(a-bc)}{4bI-\alpha^2}$	$\frac{a}{3b}+\frac{c}{3} + \frac{4I(a-bc)}{3(4bI-\alpha^2)}$
m^*	$\frac{2I(a-bc)}{4bI-\alpha^2}$	$\frac{2I(a-bc)}{8bI-\alpha^2}$	$\frac{(a-bc)I}{4bI-\alpha^2}$	$\frac{4(a-bc)I}{3(4bI-\alpha^2)}$
π_M^*	--	$\frac{I(a-bc)^2}{8bI-\alpha^2}$	$\frac{I(a-bc)^2}{2(4bI-\alpha^2)}$	$\frac{2I(a-bc)^2}{3(4bI-\alpha^2)}$
π_R^*	--	$\frac{4bI^2(a-bc)^2}{(8bI-\alpha^2)^2}$	$\frac{I(a-bc)^2}{4(4bI-\alpha^2)}$	$\frac{2I(a-bc)^2}{9(4bI-\alpha^2)}$
π_{SC}^*	$\frac{I(a-bc)^2}{4bI-\alpha^2}$	$\frac{I(a-bc)^2(12Ib}{(8bI-\alpha^2)}$	$\frac{3I(a-bc)^2}{4(4bI-\alpha^2)}$	$\frac{8I(a-bc)^2}{9(4bI-\alpha^2)}$

On the basis of the above four models, the optimal decision variables are compared and analyzed, and the following five properties are proposed:

3.1 The optimal revenue-sharing ratio meets the condition $\lambda^b < \lambda^{opt}$, and is inversely proportional to consumer sensitivity to green improvements, α

Under a bargaining revenue-sharing contract, the proportion of the profit $(1-\lambda)$ shared by the retailer with the manufacturer is greater than the proportion under a retailer-led revenue-sharing contract. And the higher the α, the smaller the proportion of revenue-sharing.

3.2 The optimal greening level of a product under different conditions meet the condition that $\boldsymbol{\theta^* > \theta^b > \theta^{opt} > \theta_M^*}$

The greening level of products are highest under the centralized control condition, and lowest under the decentralized decision condition. Greening level of the product under the bargaining revenue-sharing contract is higher than that under the retailer-led revenue-sharing contract. Revenue-sharing contracts are conducive to improving the greening level of products and effective communication will further improve these attributes in a green supply chain.

Proof: $\frac{\theta^*}{\theta^b} = \frac{3}{2} > 1, \ \therefore \theta^* > \theta^b$

$\frac{\theta^b}{\theta^{opt}} = \frac{4}{3} > 1, \ \therefore \theta^b > \theta^{opt}$

$8bI - \alpha^2 > 2(4bI - \alpha^2), \ \therefore \theta^{opt} > \theta_M^*$

In summary, $\theta^* > \theta^b > \theta^{opt} > \theta_M^*$

3.3 The optimal wholesale price of a green product meets the condition that $\boldsymbol{w_M^* > w^{opt} > w^b}$

The wholesale price of a green product is the highest in a decentralized decision-making contract, followed by the retailer-led revenue-sharing contract, while it is the lowest under the bargaining revenue-sharing contract. The two kinds of revenue-sharing contracts are conducive to reducing the wholesale price of green products, especially the bargaining revenue-sharing contract.

Proof: $\because \ \theta^* = \frac{\alpha(a-bc)}{4bI-\alpha^2} > 0, \ \therefore (a - bc) > 0$

By the initial constraint $4Ib - \alpha^2 > 0, \ \therefore 8bI - \alpha^2 > 0$

$\therefore w_M^* - w^{opt} = \frac{\alpha^2(a-bc)}{2b(8bI-\alpha^2)} > 0$

$$w^{opt} - w^b = \frac{a-bc}{6b} > 0$$

$\therefore w^{opt} > w^b$

In summary, $w_M^* > w^{opt} > w^b$

3.4 The optimal retail price of the green product meets the conditions that $\boldsymbol{p_M^* > p^{opt} > p^b > p^*}$

The retail price of green products is highest under the decentralized decision-making condition, and lowest under the centralized control condition. The retail price of green products is higher under the retailer-led revenue-sharing contract than under the bargaining revenue-sharing contract, which is the inverse of the pattern for greening level of products mentioned in the section 3.2. A revenue-sharing contract can make green products meet consumer's demand to be inexpensive.

Proof: By the initial constraint $\alpha^2 - 4bI + 2\lambda bI < 0$

$\therefore \alpha^2 - 4bI + 2\lambda bI = \alpha^2 - 2bI - 2bI(1-\lambda) > \alpha^2 - 2bI$

$\therefore \alpha^2 - 2bI < \alpha^2 - 4bI + 2\lambda bI < 0$

So,

$$\alpha^2 < 2bI \tag{31}$$

$$p_M^* - p^{opt} = \frac{\alpha^2(2bI-\alpha^2)(a-bc)}{2b(4bI-\alpha^2)(8bI-\alpha^2)} > 0$$

$\therefore p_M^* > p^{opt}$

$$p^{opt} - p^b = \frac{(2bI-\alpha^2)(a-bc)}{6b(4bI-\alpha^2)} > 0$$

$\therefore p^{opt} > p^b$

$$p^b - p^* = \frac{(2bI-\alpha^2)(a-bc)}{3b(4bI-\alpha^2)} > 0$$

$\therefore p^b > p^*$

In summary, $p_M^* > p^{opt} > p^b > p^*$

3.5 The total profit of the green supply chain meets the conditions that $\boldsymbol{\pi_{sc}^* > \pi_{sc}^b > \pi_{sc}^{opt} > \pi_{Msc}^*}$

The total profit of the green supply chain is largest under centralized control conditions and smallest under decentralized decision-making conditions. Profitability under the two revenue-sharing contracts is between the two extremes, with profit under the bargaining condition higher than under the retailer-led condition. Revenue-sharing contracts are conducive to improving green supply chain profitability, and effective communication will make the supply chain more profitable.

Proof:

$$\frac{\pi_{sc}^*}{\pi_{sc}^b} = \frac{9}{8} > 1$$

$\therefore \pi_{sc}^* > \pi_{sc}^b$

$$\frac{\pi_{sc}^b}{\pi_{sc}^{opt}} = \frac{32}{27} > 1$$

$\therefore \pi_{sc}^b > \pi_{sc}^{opt}$

$$\pi_{sc}^{opt} - \pi_{Msc}^* = \frac{I(a-bc)^2(16bI-\alpha^2)\alpha^2}{4(4bI-\alpha^2)(8bI-\alpha^2)^2} > 0$$

$\therefore \pi_{sc}^{opt} > \pi_{Msc}^*$

In summary, $\pi_{sc}^* > \pi_{sc}^b > \pi_{sc}^{opt} > \pi_{Msc}^*$

4. Numerical analysis

Through the results obtained above, we get five decision variables that is the greening level and price of the product, the profit of retailer and manufacturer, and the overall profit of the green supply chain. To prove the validity of the five decision variables, we took consumer sensitivity to green improvements α as the independent variable, and the five decision-making variables as the dependent variables.

The reasons why we choose consumer sensitivity to green improvements α as independent variable are as follows: firstly, the consumers' sensitivity to green products can determine the greening level of green products directly. If consumers are sensitive to green products, the products of high greening level are usually more popular in the market. Therefore, the manufacturer will make efforts to develop high greening level products to increase its market share. Secondly, products of high greening level usually means expensive R&D inputs and costs. Thus, manufacturers and retailers will adjust the price to make new profit maximization for themselves. And the green supply chain's total profit will be changed correspondingly. Based on the above two points, we choose consumer sensitivity towards greening improvements α as the independent variable to explore its influence on the relevant decision variables. In order to ensure our study within the feasibility region, we refer to Ghosh and Shan's research and assign values to parameters, which are shown in Table 3. We use Matlab to simulate the variables in different situations, and the results are shown in Figure 1 through Figure 5. Because the Centralized Control game model aims to make the overall profit of the supply chain maximal and doesn't focus on how to distribute the profits between manufacturer and retailer, so we can't draw the profit of the manufacturer or the retailer. That's the reason why in Figure 3 and Figure 4, it isn't taken into consideration.

Table 3 Parameter Assignment

parameter	a	b	c	I
value	1000	50	6	40

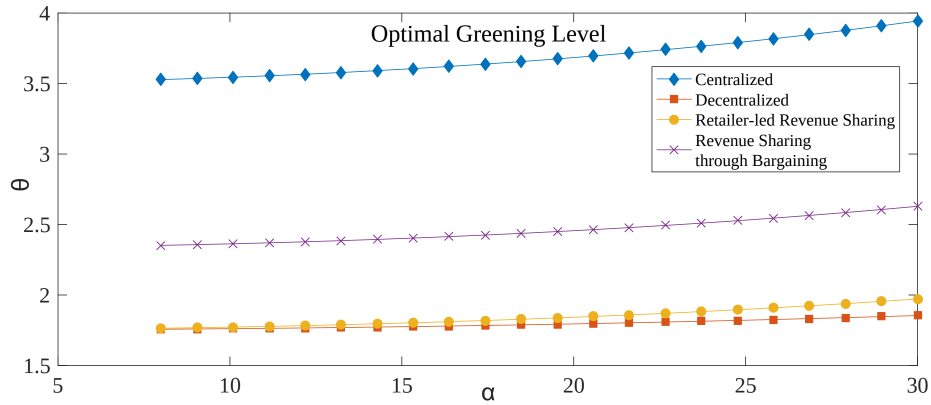

Figure 1 Optimal greening level vs α

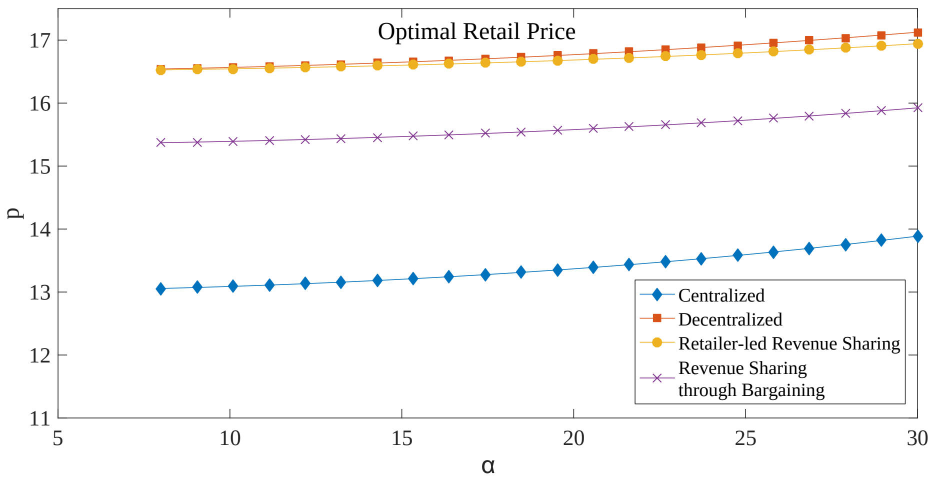

Figure 2 Optimal retail price vs α

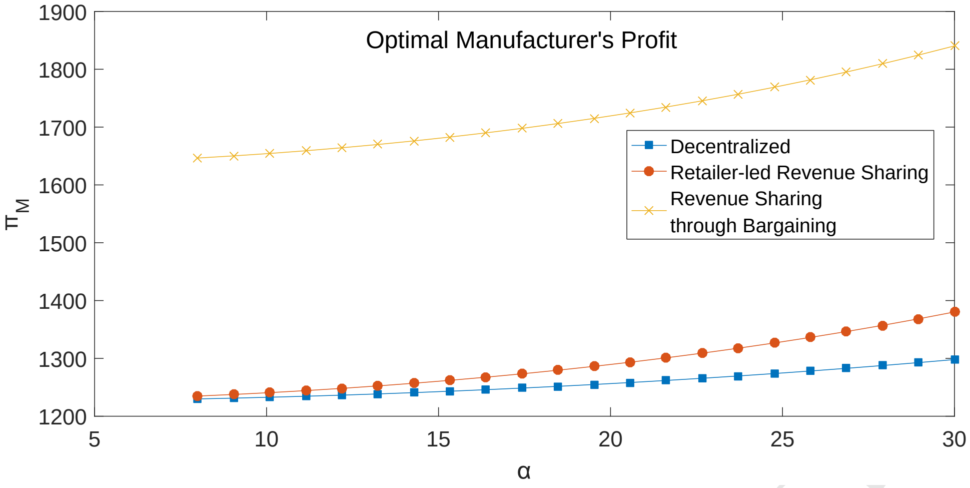

Figure 3 Optimal manufacturer's profits vs α

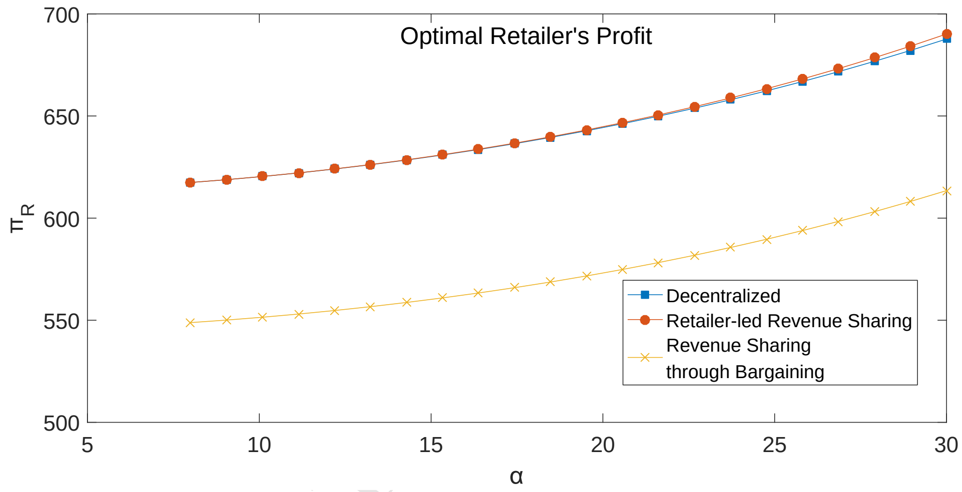

Figure 4 Optimal retailers' profits vs α

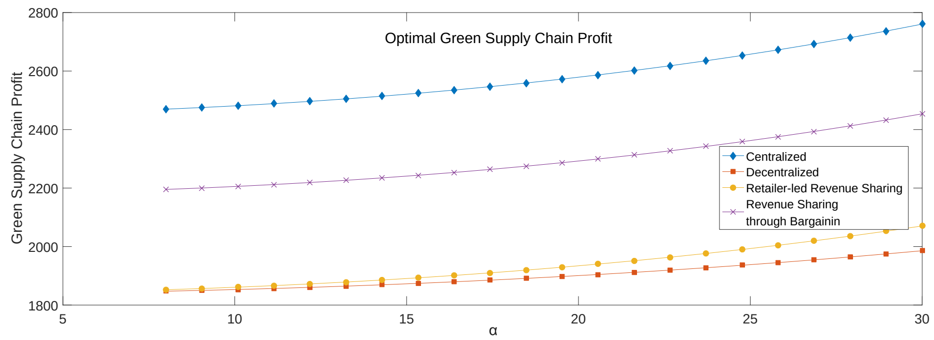

Figure 5 Optimal green supply chain profits vs α

From Figures 1–5, it can be seen that consumer sensitivity to green improvements is proportional to the greening level of the products, the retail price, the manufacturer's profits, the retailer's profits, and the total profits of the supply chain. Consumers tend to buy products with high-greening level in markets in which consumers have high sensitivity to green improvements(Figure1), so green supply chain participants will increase the R&D to increase sales. While the development of new products will lead to higher production costs, profits of manufacturers and retailers will rise(Figure 3 and 4) due to high retail prices (Figure 2) and high sales volume green products in these markets. The market can induce better implementation of green technology innovation platforms for green supply chain participants.

By comparing variables under the two kinds of revenue-sharing contracts with variables under the decentralized decision condition, we can see that the revenue-sharing contracts play an important role in improving the greening level of products, resolving profit conflicts of the participants, and improving the overall profit of the green supply chain. From the consumer perspective, both revenue-sharing contracts not only improve the greening level of products compared with the decentralized decision-making condition(Figure 1), but also lower the price(Figure 2). Therefore, green supply chains based on the two kinds of revenue-sharing contracts are of great benefit to consumers. From the perspective of green supply chain participants, manufacturer profits are higher under the revenue-sharing contracts than under the decentralized decision-making condition(Figure 3). Therefore, manufacturers will accept a revenue-sharing contract and participate in a green supply chain. In addition, when manufacturers are more powerful, they will bargain with retailers and require the reallocation of profits to maximize their own profits. For retailers, increased sales income due to improved greening level of products cannot offset the cost of increasing the share of profits to manufacturers, because the revenue-sharing ratio in the bargaining revenue-sharing contract is lower compared with the retailer-led revenue-sharing contract(Figure 4). To encourage retailers to accept a bargaining revenue-sharing contract, adding new incentives or appropriately increasing the retailer revenue-sharing ratio to ensure that retailer's profits are not less than that under a retailer-led revenue-sharing contract is necessary. It is interesting that a retailer-led revenue-sharing contract increases overall profits of manufacturers, retailers, and the supply chain, which is of great practical significance to the establishment of the green supply chain(Figure 3 4 and 5). From the overall supply chain point of view, both the revenue-sharing contracts increase the total profit level compared with the decentralized decision-making condition, and the bargaining revenue sharing contract can make the overall profit level even closer to that under the centralized control condition(Figure 5). So the bargaining revenue sharing contract is more conducive to achieving the optimal state of the green supply chain because the contract mechanism improves total profitability and operational efficiency.

When comparing the results of the two revenue sharing contract game models, we find that the proportion that the retailer gains from final sales is $\frac{4bI-\alpha^2}{8bI}$ under bargaining revenue sharing contract. It's half of the proportion under retailer-led revenue sharing contract. Since the manufacturer can get more income through the bargaining revenue sharing contract, the manufacturer can put more money into green product R&D process. Consequently, the product's greening level reaches $\frac{2\alpha(a-bc)}{3(4bI-\alpha^2)}$, improved by nearly 33% compared with the retailer-led revenue sharing contract. It's interesting to find that although the greening level of the product is raised, the retail price of the product is even lower. It can be seen that the bargaining revenue sharing contract makes the product more "inexpensive". Therefore, the total market demand will be significantly improved. And the total profit of the supply chain increased to $\frac{8I(a-bc)^2}{9(4bI-\alpha^2)}$ correspondingly, which improved by nearly 19% compared with retailer-led revenue sharing contract result. Though the retailer-led revenue sharing contract has several advantages, it also has an obvious deficiency that the retailer's profit under this condition is even lower than the profit under the decentralized condition. That's because the retailer shares higher proportion of the income to the manufacturer. It's obvious that the retailer would refuse the bargaining revenue sharing contract. How to solve the problem has become the key to establish a green supply chain bargaining contract coordination mechanism.

In summary, a revenue sharing contract improves the greening level of products compared with the decentralized decision condition, and reduces retail prices significantly. This is especially true for the retailer-led revenue-sharing contract, which improves profits of the manufacturers, retailers, and the overall supply chains. Therefore, revenue-sharing contracts are of great significance for establishing green supply chains and improving their operational efficiency.

5. Conclusion

Based on cooperation among manufacturers and retailers in green supply chains, a retailer-led revenue-sharing contract game model and a bargaining revenue-sharing contract game model are established. We discussed the impact of the two revenue-sharing models on green supply chain’s product greening levels, prices and profits. To better understand the results, we further explored and discussed the impact of consumer sensitivity to green improvements on the above variables.

From the results, we can see that revenue-sharing contract can improve the greening level of products, and increase the total profit of manufacturer and supply chain. Thus we draw a conclusion that revenue-sharing contract is an important way to promote the cooperation establishment among green supply chain members. In particular, the retail-led revenue-sharing contract makes the profits of the manufacturer, the retailer, and the supply chain all higher than the profits under the decentralized control condition. It is of great significance to the establishment and cooperation of the green supply chain. As for the bargaining revenue sharing contract, it can make the total profit of the green supply chain more favorable than the retailer-led revenue-sharing contract. However, the retailer's profit is less than that under the decentralized model result. Therefore, taking appropriate measures to make up for the retailer's profit loss is of vital importance to bargaining revenue sharing contract’s successful establishment.

Implementing green supply chain and establishing cooperation among upstream and downstream enterprises are not only the requirement of the economic development, but also the needs for supply chain enterprises to further develop. To strengthen the revenue sharing contract's effect on coordinating green supply chains and achieve win-win situation among upstream and downstream enterprises, there are several aspects needing improvement. Firstly, enterprises should strengthen the consciousness of coordination. Business managers should not focus only on improving their own profit level. They should strive to promote the overall performance of the supply chain and make decisions from the long-term interests of enterprises. Secondly, the supply chain members should change the previous idea that they should depend on suppliers completely to research and design products. They should start to work with its suppliers and give the enterprises appropriate incentives to promote and ensure the development of green products to be successful. Lastly, the effective contract coordination mechanism is based on the high quality of information sharing among enterprises. Therefore, enterprises should strengthen the information construction and improve information sharing level. With sustained efforts like this, they are able to ensure the validity of the contract and maximize the profits of the green supply chain.

Though our study makes several innovations, there are still several shortcomings and deficiencies remaining in the models. In this study, we don't take greening level's impact on production and sales costs into consideration. In addition, we regard the general demand of the market as a simple linear function of product price and greening level, which makes the adaptability of the models have some limitations. The models are also limited to a two-tier green supply chain consisting of a single manufacturer and a single retailer. In the further work, we will consider a green supply chain composed of several manufacturers and retailers, and account for the impact of greening level on production and sales costs. As can be seen from the results, the proportion that retailer shares with the manufacturer is much higher under bargaining revenue sharing contract than that under the retailer-led revenue sharing contract. In order to compensate for the profit loss, the retailer can further negotiate with the manufacturer to seek a new profit sharing ratio. The future research can study on this issue and try to solve the question.

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Highlights

- Two green supply chain game models are given under the revenue-sharing contract
- Quantitative analysis of the performance of green supply chains are conducted
- The revenue-sharing contract can improve the greening level of the products

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