Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

Research on Green Supply Chain Game Models under Different Contracts

Baizhou Li, Xiuzi Hao*
School of Economics and Management, Harbin Engineering University, Harbin 150001, China
*Corresponding Author.

Abstract:

Faced with of increasingly severe environmental problems, consumers' green preference has become a key market drivers in promoting environmental sustainability of supply chains. This paper establishes a two-echelon supply chain model consisting of a manufacturer and a retailer, the impact of carbon tax and product greenness is considered. By introducing different contracts to study their impact on green supply chains, we resolve the revenue-sharing contract model, the decentralized decision-making model and the cost-sharing contract model respectively, followed by a further comparison of three game models. Since the centralized control model is difficult to be realized in practical application, we exclude the centralized control model from the research framework. The analytical results indicate that coordinating contracts, referring to the cost-sharing contract and the revenue-sharing contract, it can effectively raise the revenue of the entire green supply chain and the green level of products. Meanwhile, both the manufacturer and retailer can obtain higher revenue. Therefore, revenue-sharing contract is an optimization mechanism to increase the overall revenue of the green supply chain (GSC) and itsmembers involved. Additionally, both the cost-sharing contractand revenue-sharing contractare effective inpromoting cooperation of participants in the green supply chain. The results and findings in the paper provide significant implications for the implement and development of the green supply chain, which also contribute to further study on the contract design, revenue distribution and incentive mechanisms for the green supply chain management.

***Keywords**: Green supply chain, Game theory, Greenness of product, Revenue-sharing contract, Cost-sharing contract.*

I. INTRODUCTION

The increasing carbon emissions have currently incurred serious environmental problems in daily production and life. As far as the tense resource conditions and environmental pollution problems are concerned, the green and sustainable development issues have become increasingly important worldwide. Since the traditional supply chain focuses on the economic benefits of its participants, its negative effect on the environment and resources has been neglected. Therefore, the concept of a green supply chain has emerged in response to the resource consumption and environmental impact. GSC management targets at minimizing its impact on the environment and maximizing resource efficiency from the production process [1]. Driven by legislation, market pressure and social responsibility [2], it is an irreversible trend to establish collaboration among green supply chain participants.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

With the increasing low-carbon preference and environmental consciousness, consumers take the initiative to buy green products, which may cost more money, reducing the carbon emissions in an environmentally friendly way. According to the Carbon Trust surveys, it is indicated that approximately 20% of customers are tend to purchase higher pricegreen products. Regarding an investigation from Accenture, over 80% of interviewees take the products' greening level into account while conducting purchase decision [3]. Satisfying the consumers' demand for green products motivates the green supply chain members to conduct green innovations [4]. In this condition, the innovation cost and strategies of green supply chain enterprises are affected directly with the improvement of consumer awareness of low carbon. By introducing the consumers' sensitivity to green products, a two-echelon supply chain is established to reveal how the greening level of products and pricing strategies affect the supply chain participants' decisions, and further put forward the coordination mechanism of contracts. Liu et al. considered consumers' environmental preferences to investigate the decision strategy of retailersand manufacturers [5]. Zhang et al. discussed how the environmental awareness of consumers affects the quantity of orders and channel coordination in a secondary supply chain [6].

In addition, the cooperation among supply chain members can provide the whole supply chain with opportunities to integrate internal and external resources, thus improving the sustainable performance[7]. According to the previous research, it is found that the independent decisions made by green supply chain members to maximize their respective interests will lead to inefficiency of the green supply chain. However, it is difficult to realizethe centralized control model, since the green supply chain members are required to conduct decisions for the maximizing of overall benefits of the GSC. Under the circumstance, the integration of the contractual coordination mechanism is effective in solving the revenue distribution problem and promoting the cooperation among participants of the green supply chain. The supply chain contract refers to the agreement between sellers and buyers, which guarantees their coordination and optimizes the performance of sales channels by means of offering information and incentives properly. In terms of the environmental benefits and economic, the researches provide the guidance for cooperation between supply chain memberson the GSC's coordinated development with different contracts[8-10]. By establishing a two-echelon supply chain game model, Yang and Wang analyzed andcompared the carbon emission reduction and revenue of GSC under three different contracts. Cao et al. designed a revenue-sharing contract on the basis of different emission reduction policies, which can increase the GSC participants' revenue effectively [11-12]. The research results from Zhu and He indicated that neither the wholesale contracts nor cost-sharing contracts can fully coordinate supply chain profits. Hsueh constructed an advanced revenue-sharing contract with the corporate social responsibility embedded in the supply chain to improve the social responsibility performance of the corporate and the total profit of the supply chain [13]. In view of the cost-sharing problem, Li et al. determined the upstream and downstream sharing ratio from systematic perspective, and realized the supply chain coordination [14]. A cost-sharing contract was used to the research of ShahandGhosh on the green supply chain to maximize the profit of retailers, which stimulated a higher level of green industry [15]. Chakraborty et al. further introduced the cost-sharing contract into the innovation cooperation led by retailers, and the profits of supply chain and its participants involved have been raised.

Based on the existing literature, this paper introduces the cost-sharing contractsand revenue-sharing in

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

view of the above factors comprehensively, and studies the effect of cooperation contracts on the overall green supply chain as well as its participants involved. At the same time, we have incorporated the carbon taxandtheproduct greenness into analysis framework of green supply chain participants' decision-making strategies, since the impact of environmental regulations and consumer preferences should be considered. In this condition, this paper utilizes the game theory to construct a revenue-sharing contract model and a cost-sharing contract model. Thereinto, the revenue-sharing contract is dominated by the retailer, and the green technology innovation cost is fully undertaken by the manufacturer; the retailer takes the initiative to share the manufacturer's partial cost of green technology innovation in the cost-sharing contract. Since the centralized control model is difficult to realize in reality, the two models results under different contracts with that of the decentralized decision-making game model were compared. Both the cost-sharing contract and revenue-sharing contractare applied to study the collaborative innovation strategies of the manufacturer and retailer. We explore whether these two cooperation contracts can coordinate the green supply chain participants' revenue and promote the green supply chain's establishment and implementation, attempting to provide theoretical foundation and decision support for improving the green technological innovation and managing the green supply chain.

The remaining partof this work is organized as follows. We established the GSC model based on a description of the problem and some hypotheses. Then, the decentralized, cost-sharing and revenue-sharinggame models are all resolved by introducing contracts mechanism. We further compared and analyzed the results of the cost-sharing contract and revenue-sharing models in the decentralized model. In Section 5, the conclusions and implications are presented.

II. MODEL DESCRIPTION AND ESTABLISHMENT

This paper constructs a two-echelon GSC consisting of a manufacturer and a retailer. The green products produced by the manufacturersold to retailers at wholesale pricein the GSC,, then the consumers purchase the green products from retailers at retail prices. The green products compete with the general products for market share, since the general products can functionally replace the green products. In this condition, consumers with green preferences make purchasing decisions according to the price and greenness of products. In particular, the product greenness represents its emission reductions compared to the general products. Itis assumed that the manufacturer conducts green innovations by importing advanced technologies, purchasing new equipment, and transforming production processes, so as to reduce the carbon emissions during the process of production, thus improving the products' greening level in the supply chain.

In this GSC model, the manufacturersetwholesale price is w, and the retail price is p. In this condition, the gross revenue of the retailer is $m = p - w$ per unit. The greenness of products is assumed to be g, representing the emission reduction level, which is relevant to the effort level of green technology innovation. In other words, the manufacturer makes more effort to conduct green innovation in order to lower the emission, which will eventually contribute to the higher greening level of products. According to the research from Liu et al. [16] The cost of manufacturer's green innovation activities, as well as the cost of emission reduction is supposed to have a quadratic relationship with the product greenness, referring to

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

$\frac{1}{2}\mu g^2$, where μ is the coefficient of green innovation cost. Besides, the government intervention in emission reductions motivates the manufacturer to make green innovation. In this paper, the manufacturer is environmentally regulated by means of the carbon tax. We set t as carbon tax rate, and β as the amount of carbon emission of per unit of green products, thus the manufacturer's producing one unit of green products is charged for $t\beta$ as carbon tax. The manufacturing cost of green products is c.

The market demand is determined by the retail price and products' greenness, and the lower-priced products with relatively higher greening level are acclaimed by consumers in the market [17]. Since competition between the general and green products, there exist a gap between the potential market and actual market for green products. We donate q as the potential market demand, and a as the actual market demand for green products. The evaluations of consumers on products' functionality differs, but all the consumers are assumed to be environmentally conscious. θ is the consumer's preference for the product greenness. Under this circumstance, we assume that the market demand is linearly related to the retail price and product greenness, that is $q = a - bp + \theta g$.

On the basis of above assumptions, the profit functions of the manufacturer (π_M), retailer (π_R) and the green supply chain (π_{SC}) are, respectively:

$$\pi_M = (\omega - c - t\beta)q - \frac{1}{2}\mu g^2 \quad (1)$$

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

$$\pi_{SC} = (p - c - t\beta)q - \frac{1}{2}\mu g^2 \quad (3)$$

In the following, a cost-sharing contract and a revenue-sharing contractare incorporated to the research framework of GSC management. By comparing with the decentralized decision model, the influence of these two contracts on the manufacturer, the retailer and the overall green supply chain are further analyzed.

III. MATHEMATICAL FORMULATION AND ANALYSIS

3.1 Decentralized Decision Model

In the decentralized decision-making model, the manufacturer and retailer make respective decisions to maximize their own profits. In the green supply chain, the manufacturer produces the products with a certain greening level. The retailer purchases the green products from the manufacturer with the wholesale

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

price firstly, which are sold to consumers at the retail price afterwards. In this model, the green innovation cost is undertaken by the manufacturer entirely. Initially, we replace the market demand in Equation (1)-(3), then the profit functions become:

$$\pi_M = (\omega - c - t\beta)(a - bp - \theta g) - \frac{1}{2}\mu g^2 \quad (4)$$

$$\pi_R = (p - \omega)(a - bp - \theta g) \quad (5)$$

$$\pi_{SC} = (p - c - t\beta)(a - bp - \theta g) - \frac{1}{2}\mu g^2 \quad (6)$$

Through the inverse induction method, we can substitute p in Equation (2), since $m = p - w$. Therefore:

$$\pi_R = m\left[a - b(m + \omega) - \theta g\right] \quad (7)$$

We take first derivative of m, and set it to zero. In this condition:

$$a - b(m + \omega) + \theta g - bm = 0$$

$$m = \frac{a - b\omega + \theta g}{2b} \quad (8)$$

Substituting (8) into (4), obtainthe following equation:

$$\pi_M = (\omega - c - t\beta)\cdot\frac{(a - b\omega + \theta g)}{2} - \frac{1}{2}\mu g^2 \quad (9)$$

Then, the first-order and second-order partial derivative with respect to g and w are obtained, it is found that $\left(\frac{\partial^2 \pi_M}{\partial \omega^2}\right)\cdot\left(\frac{\partial^2 \pi_M}{\partial g^2}\right) - \left(\frac{\partial^2 \pi_M}{\partial \omega \partial g}\right)^2 = b\mu - \frac{\theta^2}{4} > 0$.

The first-order derivative of g and w in Equation (9) are set to be zero afterwards, thereby obtaining the optimal wholesale price and product greenness respectively:

$$\omega^* = \frac{2\mu(a - bc - t\beta b)}{4\mu b - \theta^2} + c + t\beta \quad (10)$$

$$g^* = \frac{\theta(a - bc - t\beta b)}{4\mu b - \theta^2} \quad (11)$$

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

We substitute the above w^* and g^* into Equation (8), we get the following value of m :

$$m^* = \frac{\mu(a - bc - t\beta b)}{4\mu b - \theta^2} \quad (12)$$

Accordingly, $p^* = m^* + \omega^* = \frac{3\mu(a - bc - t\beta b)}{4\mu b - \theta^2} + c + t\beta$.

By substituting w^*, g^* and p^* into Equation (4)-(6), the optimal profits for the retailer, manufacturer and green supply chain are calculated as follows:

$$\pi_R^* = \frac{\mu^2 b(a - bc - t\beta b)^2}{(4\mu b - \theta^2)^2} \quad (13)$$

$$\pi_M^* = \frac{\mu(a - bc - t\beta b)^2}{2(4\mu b - \theta^2)} \quad (14)$$

$$\pi_{SC}^* = \frac{\mu(a - bc - t\beta b)^2(6\mu b - \theta^2)}{2(4\mu b - \theta^2)^2} \quad (15)$$

The manufacturer and the retailer target at maximizing their own profitsin the decentralized decision-making model, which is unconduciveto the coordinated development of the GSC. Under this circumstance, the coordinating contracts are introduced to strengthen the cooperation between the manufacturer and the retailer, as well as the profitability of the GSC.

3.2 Revenue-Sharing Contract Game Model

In the revenue-sharing contract game model, the retailer will share a portion of sales revenue with the manufacturer, which can offset the partial green innovation costs of the manufacturer to some extent. According to the maximization of profits, revenue-sharing ratio λ, where $0 < \lambda < 1$, as well as the retail price are determined by the retailer. In this condition, the retailer retain λ of the sales revenue and share ($1 - \lambda$) with the manufacturer.

As a consequence, the profit functions of the retailer and manufacturer turn into the following equations:

$$\pi_R = \lambda(p - \omega)(a - bp + \theta g) \quad (16)$$

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

$$\pi_M = (\omega - c - t\beta)(a - bp + \theta g) - \frac{1}{2}\mu g^2 + (1-\lambda)(p-\omega)(a - bp + \theta g)$$
$$= \left[\lambda\omega + (1\text{-}\lambda)\, p - c - t\beta\right](a - bp + \theta g) - \frac{1}{2}\mu g^2 \qquad (17)$$

The first-order derivative of p in Equation (16) are set to be zero, thus the optimal retail price can be obtained:

$$\lambda(a - bp + \theta g) - \lambda b(p - \omega) = 0$$
$$p = \frac{a + b\omega + \theta g}{2b} \qquad (18)$$

We substitute Equation (18) into Equation (17) to get the following equation:

$$\pi_M = \left[\frac{(1+\lambda)\omega}{2} + \frac{(1-\lambda)\theta g}{2b} + \frac{(1-\lambda)a}{2b} - c - t\beta\right]\cdot\frac{(a - b\omega + \theta g)}{2} - \frac{1}{2}\mu g^2 \qquad (19)$$

Then, the first and second partial derivative of w and g are obtained, it is found that $\left(\frac{\partial^2\pi_M}{\partial\omega^2}\right)\cdot\left(\frac{\partial^2\pi_M}{\partial g^2}\right) - \left(\frac{\partial^2\pi_M}{\partial\omega\partial g}\right)^2 = \left[-\frac{(1+\lambda)}{2}\right]\cdot\left[-\mu + \frac{(1-\lambda)\theta^2}{2b}\right] - \frac{\lambda^2\theta^2}{4} > 0$, which means $2(1+\lambda)\mu b - \theta^2 > 0$.

$$g = \frac{\theta(a - bc - t\beta b)}{2(1+\lambda)\mu b - \theta^2} \qquad (20)$$

$$\omega = \frac{2\lambda\mu a + \left(2\mu b - \theta^2\right)(c + t\beta)}{2(1+\lambda)\mu b - \theta^2} \qquad (21)$$

$$p = \frac{(1+2\lambda)\mu a + \left(\mu b - \theta^2\right)(c + t\beta)}{2(1+\lambda)\mu b - \theta^2}\cdots \qquad (22)$$

We substitute Equation (20)-(22) into Equation (16):

$$\pi_R = \frac{\lambda b\mu^2\left[a - b(c + t\beta)\right]^2}{\left[2(1+\lambda)\mu b - \theta^2\right]^2} \qquad (23)$$

The first and second derivativeof λ , it is indicated that when

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

$\frac{8b^2\mu^3\left[a-b(c+t\beta)\right]^2\cdot\left[\theta^2-2\mu b+\lambda\mu b\right]}{\left[2(1+\lambda)\mu b-\theta^2\right]^4}<0$, that is $\theta^2-2\mu b+\lambda\mu b<0$, π_R is strictly concave function of λ. At this point, the first-order derivativewith respect to λ is set as zero, here:

$$\frac{b\mu^2\left[a-b(c+t\beta)\right]^2\cdot\left[-\theta^2+2\mu b-2\lambda\mu b\right]}{\left[2(1+\lambda)\mu b-\theta^2\right]^3}=0$$

$$-\theta^2+2\mu b-2\lambda\mu b=0$$

$$\lambda=\frac{-\theta^2+2\mu b}{2\mu b} \tag{24}$$

After replacing the value of λ in Equation (19)-(23), we have the results below:

The first derivative of w and g in Equation (19) are set to be zero afterwards, therefore

$$g^{**}=\frac{\theta(a-bc-t\beta b)}{2\left(2\mu b-\theta^2\right)} \tag{25}$$

$$\omega^{**}=\frac{a+b(c+t\beta)}{2b} \tag{26}$$

$$p^{**}=\frac{\left(3\mu b-\theta^2\right)a+\left(\mu b-\theta^2\right)(bc+t\beta b)}{2b\left(2\mu b-\theta^2\right)} \tag{27}$$

$$\pi_R^{**}=\frac{\mu(a-bc-t\beta b)^2}{4\left(2\mu b-\theta^2\right)} \tag{28}$$

$$\pi_M^{**}=\frac{\mu(a-bc-t\beta b)^2}{4\left(2\mu b-\theta^2\right)} \tag{29}$$

$$\pi_{SC}^{**}=\pi_R^{**}+\pi_M^{**}=\frac{\mu(a-bc-t\beta b)^2}{2\left(2\mu b-\theta^2\right)} \tag{30}$$

3.3 Cost-Sharing Contract Game Model

Due to the high cost and risk for the manufacturer's green innovation activities, the retailer chooses to share part of the green technological innovation cost directly. Therefore, the retailer and the manufacturer establish a cost-sharing contract in order to ease the burden of manufacturer's improving the products'

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

greening level. According to the strategy of manufacturer, the retailer determines the retail price and cost-sharing ratio ε , where $0 < \varepsilon < 1$.

Consequently, the profit functions of the retailer and manufacturer become:

$$\pi_R = (p - \omega)(a - bp + \theta g) - \frac{1}{2}\varepsilon\mu g^2 \quad (31)$$

$$\pi_M = (\omega - c - t\beta)(a - bp + \theta g) - \frac{1}{2}(1 - \varepsilon)\mu g^2 \quad (32)$$

The first derivative of p in Equation (31) are set to be zero, thus the optimal retail price can be obtained:

$$\lambda(a - bp + \theta g) - \lambda b(p - \omega) = 0$$

$$p = \frac{a + b\omega + \theta g}{2b} \quad (33)$$

We substitute Equation (33) into Equation (32) to get the following equation:

$$\pi_M = (\omega - c - t\beta)\cdot\frac{(a - b\omega + \theta g)}{2} - \frac{1}{2}(1 - \varepsilon)\mu g^2 \quad (34)$$

Then, the first-order and second-order partial derivative with respect to w and g are obtained, and $\left(\frac{\partial^2\pi_M}{\partial\omega^2}\right)\cdot\left(\frac{\partial^2\pi_M}{\partial g^2}\right) - \left(\frac{\partial^2\pi_M}{\partial\omega\partial g}\right)^2 = (-b)\cdot\left[-(1 - \varepsilon)\mu\right] - \frac{\theta^2}{4} > 0$, which implies that $4b(1 - \varepsilon)\mu - \theta^2 > 0$. Thus, π_M is a strictly concave function of w and g .

The first derivative of w and g in Equation (34) are set to be zero afterwards, therefore:

$$g = \frac{\theta(a - bc - t\beta b)}{4(1 - \varepsilon)\mu b - \theta^2} \quad (35)$$

$$\omega = \frac{4(1 - \varepsilon)\mu a + \left[4(1 - \varepsilon)\mu b - 2\theta^2\right](c + t\beta)}{2\left[4(1 - \varepsilon)\mu b - \theta^2\right]} \quad (36)$$

$$p = \frac{6(1 - \varepsilon)\mu a + 2\left[(1 - \varepsilon)\mu b - \theta^2\right](c + t\beta)}{2\left[4(1 - \varepsilon)\mu b - \theta^2\right]} \quad \ldots(37)$$

We substitute Equation (35)-(37) into Equation (31):

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

$$\pi_R = \frac{\mu\left[a-b(c+t\beta)\right]^2\cdot\left[2(1-\varepsilon)^2\mu b-\varepsilon\theta^2\right]}{2\left[4(1-\varepsilon)\mu b-\theta^2\right]^2} \quad (38)$$

The first and second derivative of ε , it is indicated that when $\frac{b\mu^2\theta^2\left[a-b(c+t\beta)\right]^2\cdot\left[13\theta^2-4\mu b+8\mu b\varepsilon\right]}{2\left[4(1-\varepsilon)\mu b-\theta^2\right]^4}<0$, referring to $13\theta^2-4\mu b+8\mu b\varepsilon<0$, π_R is strictly concave function of ε , here:

$$\frac{\mu\theta^2\left[a-b(c+t\beta)\right]^2\cdot\left(\theta^2-\varepsilon\mu b\right)}{2\left[4(1-\varepsilon)\mu b-\theta^2\right]^3}=0$$

$$\theta^2-\varepsilon\mu b=0$$

$$\varepsilon=\frac{\theta^2}{\mu b} \quad (39)$$

After replacing the value of ε in Equation (34)-(38), the values of different variables are illustrated below:

$$g^{***}=\frac{\theta(a-bc-t\beta b)}{4\mu b-5\theta^2} \quad (40)$$

$$\omega^{***}=\frac{2\left(\mu b-\theta^2\right)a+\left(2\mu b-3\theta^2\right)(bc+t\beta b)}{b\left(4\mu b-5\theta^2\right)} \quad (41)$$

$$p^{***}=\frac{3\left(\mu b-\theta^2\right)a+\left(\mu b-2\theta^2\right)(bc+t\beta b)}{b\left(4\mu b-5\theta^2\right)} \quad (42)$$

$$\pi_R^{***}=\frac{(a-bc-t\beta b)^2\cdot\left(2\mu^2b^2-4\mu b\theta^2+\theta^4\right)}{2b\left(4\mu b-5\theta^2\right)^2} \quad (43)$$

$$\pi_M^{***}=\frac{(a-bc-t\beta b)^2\cdot\left(4\mu^2b^2-9\mu b\theta^2+5\theta^4\right)}{2b\left(4\mu b-5\theta^2\right)^2} \quad (44)$$

$$\pi_{SC}^{***}=\frac{(a-bc-t\beta b)^2\cdot\left(6\mu^2b^2-13\mu b\theta^2+6\theta^4\right)}{2b\left(4\mu b-5\theta^2\right)^2} \quad (45)$$

IV. COMPARISON

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

Based on the decentralized revenue-sharing model, decision-making model and cost-sharing model, the following comparative analysis of optimal results are shown in different game scenarios.

Proposition 1. The optimal greening level of products satisfies the condition: $g^{***} > g^{**} > g^{*}$.

Proof: According to previous calculation, we get the optimal greening level of products in three models, namely $g^{*} = \frac{\theta(a - bc - t\beta b)}{4\mu b - \theta^{2}}$, $g^{**} = \frac{\theta(a - bc - t\beta b)}{2(2\mu b - \theta^{2})}$ and $g^{***} = \frac{\theta(a - bc - t\beta b)}{4\mu b - 5\theta^{2}}$.

Since $\frac{g^{***}}{g^{**}} = \frac{2(2\mu b - \theta^{2})}{4\mu b - 5\theta^{2}} = \frac{4\mu b - 5\theta^{2} + 3\theta^{2}}{4\mu b - 5\theta^{2}} = 1 + \frac{3\theta^{2}}{4\mu b - 5\theta^{2}} > 1$, $g^{***} > g^{**}$.

Since $\frac{g^{**}}{g^{*}} = \frac{4\mu b - \theta^{2}}{2(2\mu b - \theta^{2})} = \frac{4\mu b - 2\theta^{2} + \theta^{2}}{4\mu b - 2\theta^{2}} = 1 + \frac{\theta^{2}}{4\mu b - 5\theta^{2}} > 1$, $g^{**} > g^{*}$.

In this condition, $g^{***} > g^{**} > g^{*}$ is proved.

The product greening degree of the revenue sharing and cost sharing contract models are higher than the decentralized decision-making model, implying that the coordinating contracts can improve the product greenness. In particular, the cost-sharing contract is more beneficial to the improvement of product's greening level than the revenue-sharing contract.

Proposition 2. The optimal wholesale price of products satisfies the condition: $\omega^{*} > \omega^{***} > \omega^{**}$.

Proof: Based on the above results, the optimal wholesale price of products under three game scenarios are $\omega^{*} = \frac{2\mu(a - bc - t\beta b)}{4\mu b - \theta^{2}} + c + t\beta$, $\omega^{**} = \frac{a + b(c + t\beta)}{2b}$ and $\omega^{***} = \frac{2(\mu b - \theta^{2})a + (2\mu b - 3\theta^{2})(bc + t\beta b)}{b(4\mu b - 5\theta^{2})}$

.It is known that $(a - bc - t\beta b) > 0$, thus:

$$\omega^{*} - \omega^{**} = \frac{2\mu(a - bc - t\beta b)}{4\mu b - \theta^{2}} + c + t\beta - \frac{a + b(c + t\beta)}{2b}$$
$$= \frac{\theta^{2}(a - bc - t\beta b)}{2b(4\mu b - \theta^{2})} > 0$$

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

$$\omega^{***}-\omega^{**}=\frac{2\left(\mu b-\theta^2\right)a+\left(2\mu b-3\theta^2\right)\left(bc+t\beta b\right)}{b\left(4\mu b-5\theta^2\right)}-\frac{a+b\left(c+t\beta\right)}{2b}$$
$$=\frac{\theta^2\left(a-bc-t\beta b\right)}{2b\left(4\mu b-5\theta^2\right)}>0$$

$$\omega^{*}-\omega^{***}=\left(\omega^{*}-\omega^{**}\right)-\left(\omega^{***}-\omega^{**}\right)$$
$$=\frac{\theta^2\left(a-bc-t\beta b\right)}{2b\left(4\mu b-\theta^2\right)}-\frac{\theta^2\left(a-bc-t\beta b\right)}{2b\left(4\mu b-5\theta^2\right)}>0$$

$$\omega^{*}-\omega^{***}=\left(\omega^{*}-\omega^{**}\right)-\left(\omega^{***}-\omega^{**}\right)$$
$$=\frac{\theta^2\left(a-bc-t\beta b\right)}{2b\left(4\mu b-\theta^2\right)}-\frac{\theta^2\left(a-bc-t\beta b\right)}{2b\left(4\mu b-5\theta^2\right)}>0$$

In summary, $\omega^{*}>\omega^{***}>\omega^{**}$ is proved.

The wholesale price of green products in the decentralized decision model is the highest, the lowest under the revenue-sharing contract. Both the revenue-sharing contract and the cost-sharing cost can lower the wholesale price effectively.

Proposition 3. The optimal retail price of products satisfies the condition: $p^{***}>p^{*}>p^{**}$.

Proof: The optimal retail price of products in three models, referring to $p^{*}=\frac{3\mu\left(a-bc-t\beta b\right)}{4\mu b-\theta^2}+c+t\beta$, $p^{**}=\frac{\left(3\mu b-\theta^2\right)a+\left(\mu b-\theta^2\right)\left(bc+t\beta b\right)}{2b\left(2\mu b-\theta^2\right)}$ and $p^{***}=\frac{3\left(\mu b-\theta^2\right)a+\left(\mu b-2\theta^2\right)\left(bc+t\beta b\right)}{b\left(4\mu b-5\theta^2\right)}$ are obtained above.

$$p^{*}-p^{**}=\frac{3\mu\left(a-bc-t\beta b\right)}{4\mu b-\theta^2}+c+t\beta-\frac{\left(3\mu b-\theta^2\right)a+\left(\mu b-\theta^2\right)\left(bc+t\beta b\right)}{2b\left(2\mu b-\theta^2\right)}$$
$$=\frac{\theta^2\left(\mu b-\theta^2\right)\cdot\left(a-bc-t\beta b\right)}{2b\left(2\mu b-\theta^2\right)\left(4\mu b-\theta^2\right)}$$

Since $0<\varepsilon=\frac{\theta^2}{\mu b}<1$, $\theta^2<\mu b$ is achieved. Accordingly:

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

$$p^{*}-p^{**}=\frac{\theta^{2}\left(\mu b-\theta^{2}\right)\cdot(a-bc-t\beta b)}{2b\left(2\mu b-\theta^{2}\right)\left(4\mu b-\theta^{2}\right)}>0$$

$$\begin{aligned}p^{**}-p^{***}&=\frac{\left(3\mu b-\theta^{2}\right)a+\left(\mu b-\theta^{2}\right)(bc+t\beta b)}{2b\left(2\mu b-\theta^{2}\right)}-\frac{3\left(\mu b-\theta^{2}\right)a+\left(\mu b-2\theta^{2}\right)(bc+t\beta b)}{b\left(4\mu b-5\theta^{2}\right)}\\&=\frac{-\theta^{2}\left(\mu b+\theta^{2}\right)\cdot(a-bc-t\beta b)}{2b\left(2\mu b-\theta^{2}\right)\left(4\mu b-5\theta^{2}\right)}<0\end{aligned}$$

$$\begin{aligned}p^{*}-p^{***}&=\frac{3\mu(a-bc-t\beta b)}{4\mu b-\theta^{2}}+c+t\beta-\frac{3\left(\mu b-\theta^{2}\right)a+\left(\mu b-2\theta^{2}\right)(bc+t\beta b)}{b\left(4\mu b-5\theta^{2}\right)}\\&=\frac{-6\theta^{2}\left(2\mu b-\theta^{2}\right)}{\left(4\mu b-\theta^{2}\right)\left(4\mu b-5\theta^{2}\right)}\cdot\frac{\theta^{2}(a-bc-t\beta b)}{2\left(2\mu b-\theta^{2}\right)}<0\end{aligned}$$

We can prove that $p^{***} > p^{*} > p^{**}$.

It is illustrated that the maximal retail price appears in the model with the revenue-sharing contract, followed by the decentralized decision model, and the retail price is minimal under the cost-sharing contract. Therefore the retailer's sharing green innovation cost for the manufacturer leads to the increase in the retail price for consumers.

Proposition 4. The optimal retailer's profit satisfies the condition: $\pi_R^{**} > \pi_R^{*} > \pi_R^{***}$.

Proof: The values of the optimal retailer's profit are $\pi_R^{*}=\frac{\mu^{2}b(a-bc-t\beta b)^{2}}{\left(4\mu b-\theta^{2}\right)^{2}}$, $\pi_R^{**}=\frac{\mu(a-bc-t\beta b)^{2}}{4\left(2\mu b-\theta^{2}\right)}$ and $\pi_R^{***}=\frac{(a-bc-t\beta b)^{2}\cdot\left(2\mu^{2}b^{2}-4\mu b\theta^{2}+\theta^{4}\right)}{2b\left(4\mu b-5\theta^{2}\right)^{2}}$. Therefore:

$$\begin{aligned}\pi_R^{*}-\pi_R^{**}&=\frac{\mu^{2}b(a-bc-t\beta b)^{2}}{\left(4\mu b-\theta^{2}\right)^{2}}-\frac{\mu(a-bc-t\beta b)^{2}}{4\left(2\mu b-\theta^{2}\right)}\\&=\frac{\mu(a-bc-t\beta b)^{2}}{4\left(2\mu b-\theta^{2}\right)\left(4\mu b-\theta^{2}\right)^{2}}\cdot\left(-8\mu^{2}b^{2}+4\mu b\theta^{2}+\theta^{4}\right)<0\end{aligned}$$

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

$$\pi_R^{***} - \pi_R^{**} = \frac{(a-bc-t\beta b)^2 \cdot (2\mu^2 b^2 - 4\mu b\theta^2 + \theta^4)}{2b(4\mu b - 5\theta^2)^2} - \frac{\mu(a-bc-t\beta b)^2}{4(2\mu b - \theta^2)}$$
$$= \frac{(a-bc-t\beta b)^2}{4b(2\mu b-\theta^2)(4\mu b - 5\theta^2)^2} \cdot (-8\mu^3 b^3 + 20\mu^2 b^2 - 13\mu b\theta^4 - 2\theta^6) < 0$$

$$\pi_R^{***} - \pi_R^{*} = \frac{(a-bc-t\beta b)^2 \cdot (2\mu^2 b^2 - 4\mu b\theta^2 + \theta^4)}{2b(4\mu b - 5\theta^2)^2} - \frac{\mu^2 b(a-bc-t\beta b)^2}{(4\mu b - \theta^2)^2}$$
$$= \frac{(a-bc-t\beta b)^2 \theta^6}{2b(4\mu b-\theta^2)^2 (4\mu b - 5\theta^2)^2} \cdot (\theta^2 - 12\mu b) < 0$$

It is proved that $\pi_R^{**} > \pi_R^{*} > \pi_R^{***}$.

The retailer’s profit reaches the highest under the revenue-sharing contract, and the lowest under the cost-sharing contract.

In terms of the cost-sharing model, the comprehensive effect of excessively high product prices and additional expenditures for sharing the green innovation cost have greatly reduced the retailer’s profits.

Proposition 5. The profit of optimal manufacturer satisfies the condition: $\pi_M^{**} > \pi_M^{***} > \pi_M^{*}$.

Proof: The optimal manufacturer’s profit obtained above are $\pi_M^{*} = \frac{\mu(a-bc-t\beta b)^2}{2(4\mu b - \theta^2)}$, $\pi_M^{**} = \frac{\mu(a-bc-t\beta b)^2}{4(2\mu b - \theta^2)}$ and $\pi_M^{***} = \frac{(a-bc-t\beta b)^2 \cdot (\mu b - \theta^2)}{2b(4\mu b - 5\theta^2)^2}$ respectively.

$$\pi_M^{**} - \pi_M^{*} = \frac{\mu(a-bc-t\beta b)^2}{4(2\mu b - \theta^2)} - \frac{\mu(a-bc-t\beta b)^2}{2(4\mu b - \theta^2)}$$
$$= \frac{\mu\theta^2 (a-bc-t\beta b)^2}{4(2\mu b - \theta^2)(4\mu b - \theta^2)} > 0$$

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

$$\pi_M^{***} - \pi_M^{*} = \frac{(a-bc-t\beta b)^2 \cdot (\mu b - \theta^2)}{2b(4\mu b - 5\theta^2)^2} - \frac{\mu(a-bc-t\beta b)^2}{2(4\mu b - \theta^2)}$$
$$= \frac{(4\mu b - 5\theta^2)(a-bc-t\beta b)^2}{2b(4\mu b - \theta^2)(4\mu b - 5\theta^2)^2} > 0$$

$$\pi_M^{***} - \pi_M^{**} = \frac{(a-bc-t\beta b)^2 \cdot (\mu b - \theta^2)}{2b(4\mu b - 5\theta^2)^2} - \frac{\mu(a-bc-t\beta b)^2}{4(2\mu b - \theta^2)}$$
$$= \frac{\theta^2(a-bc-t\beta b)^2}{4b(2\mu b - \theta^2)(4\mu b - 5\theta^2)} \cdot (2\theta^2 - \mu b)$$

On the basis of calculation above, it is obvious that $\mu b > \frac{3}{2}\theta^2$. In this condition, we should discuss whether $(2\theta^2 - \mu b)$ greater than zero. When $\frac{3}{2}\theta^2 < \mu b < 2\theta^2$, that is $\pi_M^{***} - \pi_M^{**} \geq 0$, it is inferred that $\pi_M^{***} \geq \pi_M^{**} > \pi_M^{*}$; when $\mu b > 2\theta^2$, that is $\pi_M^{***} - \pi_M^{**} < 0$, it is inferred that $\pi_M^{**} > \pi_M^{***} > \pi_M^{*}$. The sharing ratio of the green technology innovation cost affects the manufacturer's revenue. The retailer's sharing the green innovation cost of manufacturer motivates the manufacturer to carry out green innovation and ultimately improves the overall performance of the green supply chain, rather than maximizing the manufacturer's profit. Therefore, the retailer will not share the green innovation cost for the manufacturer in an excessively high proportion. In this condition, $\pi_M^{**} > \pi_M^{***} > \pi_M^{*}$ is proved.

Proposition 6. As a whole, the optimal value for the green supply chain's profit satisfies the condition: $\pi_{SC}^{**} > \pi_{SC}^{***} > \pi_{SC}^{*}$.

Proof: As it is known that $\pi_{SC}^{*} = \frac{\mu(a-bc-t\beta b)^2(6\mu b - \theta^2)}{2(4\mu b - \theta^2)^2}$, $\pi_{SC}^{**} = \frac{\mu(a-bc-t\beta b)^2}{2(2\mu b - \theta^2)}$ and $\pi_{SC}^{***} = \frac{(a-bc-t\beta b)^2 \cdot (6\mu^2 b^2 - 13\mu b\theta^2 + 6\theta^4)}{2b(4\mu b - 5\theta^2)^2}$, therefore:

$$\pi_{SC}^{*} - \pi_{SC}^{**} = \frac{\mu(a-bc-t\beta b)^2(6\mu b - \theta^2)}{2(4\mu b - \theta^2)^2} - \frac{\mu(a-bc-t\beta b)^2}{2(2\mu b - \theta^2)}$$
$$= \frac{\mu(a-bc-t\beta b)^2}{2(2\mu b - \theta^2)(4\mu b - \theta^2)^2} \cdot (-4\mu^2 b^2) < 0$$

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

$$\pi_{SC}^{***} - \pi_{SC}^{**} = \frac{\left(a-bc-t\beta b\right)^2 \cdot \left(6\mu^2 b^2 - 13\mu b\theta^2 + 6\theta^4\right)}{2b\left(4\mu b - 5\theta^2\right)^2} - \frac{\mu\left(a-bc-t\beta b\right)^2}{2\left(2\mu b - \theta^2\right)}$$

$$= \frac{\left(a-bc-t\beta b\right)^2}{2b\left(2\mu b-\theta^2\right)\left(4\mu b - 5\theta^2\right)^2} \cdot \left(-4\mu^3 b^3 + 8\mu^2 b^2\theta^2 - 6\theta^6\right) < 0$$

$$\pi_{SC}^{***} - \pi_{SC}^{*} = \frac{\left(a-bc-t\beta b\right)^2 \cdot \left(6\mu^2 b^2 - 13\mu b\theta^2 + 6\theta^4\right)}{2b\left(4\mu b - 5\theta^2\right)^2} - \frac{\mu\left(a-bc-t\beta b\right)^2\left(6\mu b - \theta^2\right)}{2\left(4\mu b - \theta^2\right)^2}$$

$$= \frac{\theta^4\left(a-bc-t\beta b\right)^2}{b\left(4\mu b-\theta^2\right)^2\left(4\mu b - 5\theta^2\right)^2} \cdot \left(8\mu^2 b^2 - 18\mu b\theta^2 + 3\theta^4\right) > 0$$

In summary, $\pi_{SC}^{**} > \pi_{SC}^{***} > \pi_{SC}^{*}$ is proved.

The profit of the overall green supply chain with the revenue-sharing contract reaches the highest, followed by that with the cost-sharing contract, and the lowest in the decentralized decision-making model. Therefore, both the cost-sharing contract and revenue-sharing contract are beneficial to improving the overall performance of the GSC, especially the revenue-sharing contract.

V. CONCLUSIONS AND IMPLICATIONS

Taking the influence of carbon tax and products' greening level on the GSC into consideration, this paper constructs a GSC game model consisting of a single manufacturer and a single retailer with different contracts. We have examined how the revenue-sharing contract and cost-sharing contract affected the products' price, greening level and profitability of green supply chain separately.

By comparing and discussing three models, the cost-sharing contract and revenue-sharing contract are found to be important means to promote cooperation among members of the green supply chain. Specifically, the green supply chain provides products with the highest greening level under the cost-sharing contract, resulting in the highest retail price of green products in three models. In the cost-sharing contract model, when the retailer shares partial cost of green innovation, the retailer's revenue will be reduced. Additionally, the revenue of the green supply chain reaches the highest under the revenue-sharing contract among three models. In particular, the revenue of the manufacturer, retailer, and supply chain with the revenue-sharing contract exceed those under the decentralized control. Therefore, the sales revenue subsidies provided by the retailer enables the manufacturer to offset part of the cost of green technology innovation, motivating the manufacturer to conduct the green innovation activities. It is demonstrated that applying the revenue-sharing contract to the green supply chain management is an optimization mechanism to raise the overall revenue of the green supply chain and members involved. An effective contract coordination mechanism plays an active role in the implementation of a green supply chain and the establishment of cooperation among members in the green supply chain.

However, there still exist some limitations needed to be further discussed in this work. This paper merely studies the influence of a cost-sharing contract and revenue-sharing contract on the product's greenness and the green supply chain's revenue. In the future, different supply chain contracts can be introduced to examine whether it can coordinate the revenue distribution and increase the overall revenue of the green supply chain. In addition, differing from the green supply chain composed of a single manufacturer and a single retailer, there exist more participants involved in the practical chain. Thus, more complicated research on the GSC game models under different contracts should be conducted. Meanwhile, this paper incorporates carbon tax into the model, representing the impact of government environmental regulations on the green technology innovation of the supply chain enterprises. In further studies, the government subsidies to green supply chain members can also be considered.

REFERENCES

[1] Srivastava, S.F. (2007) Green Supply-Chain Management: A State-of-the-Art Literature Review. International Journal of Management Reviews, 9(1), 53-80.

[2] Wu, Z. and Pagell, M. (2011) Balancing Priorities: Decision-Making in Sustainable Supply Chain Management. Journal of Operations Management, 29(6), 577-590.

[3] Hong, Z.F. and Guo, Y.H. (2019) Green Product Supply Chain Contracts Considering Environmental Responsibilities. Omega, 83, 155-166.

[4] Vachon, S. and Klassen, R.D. (2008) Environmental Management and Manufacturing Performance: The Role of Collaboration in the Supply Chain. International Journal of Production Economics, 111(2), 299-315.

[5] Liu, Z.L., Anderso, T.D. and Cruz, G.M. (2012) Consumer Environmental Awareness and Competition in Two-Stage Supply Chain. European Journal of Operational Research, 218(3): 602-613.

[6] Zhang, L., Wang, J. and You, J. (2015) Consumer Environmental Awareness and Channel Coordination with Two Substitutable Products. European Journal of Operational Research, 241(1): 63-73.

[7] Linton, J.D., Klassen, R. and Jayaraman, V. (2007) Sustainable Supply Chains: An Introduction. Journal of Operations Management, 25(6): 1075-1082.

[8] Subramanian, R., Gupta, S. and Talbot, B. (2009) Product Design and Supply Chain CoordinationUnder Extended Producer Responsivity. Production and Operations Management, 18(3): 259-277.

[9] Zhang, J., Gou, Q.D., Liang, L. and Huang, Z.M. (2013) Supply Chain Coordination Through Cooperative Advertising with Reference Price Effect. Omega, 41(2): 345-353.

[10] Xu, J.T., Chen, Y.Y. and Bai, Q.G. (2003) Game and Optimization of a Two-Level Low-Carbon Supply Chain Under the Carbon Quota Policy. Control Decision, 5: 924-928.

[11] Cao, J., Zhang, X.M. and Zhou, G.G. (2016) Supply Chain Coordination with Revenue-Sharing Contracts Considering Carbon Emissions and Governmental Policy Making. Sustainability, 35(2): 479-488.

[12] Cao, E. and Yu, M. (2018) Trade Credit Financing and Coordination for an Emission-dependent Supply Chain. Computers & Industrial Engineering, 119: 50-62.

[13] Hsueh, C.F. (2014) Improving Corporate Social Responsibility in a Supply Chain Through a New Revenue Sharing Contract. International Journal of Production Economics, 151: 214-222.

[14] Li, X.M., Liao, X.W. and Liu, Y. (2013) Research om Service Supply Chain Coordination Based on Saas Model. Chinese Journal of Management Science, 21(2): 98-106.

[15] Ghosh, D. and Shah, J. (2015) Supply Chain Analysis Under Green Sensitive Consumer Demand and Cost Sharing Contract. International Journal of Production Economics, 164: 319-329.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1606 – 1623
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

[16] Liu, X.J., Du, W.Y. and Sun, Y.J. (2020) Green Supply Chain Decisions Under Different Power Structures: Wholesale Price vs. Revenue Sharing Contract. International Journal of Environmental Research and Public Health, 17(21): 7737.
[17] Jiang, J.Y. and Li, S.C. (2015) Green Supply Chain Game Models And Revenue Sharing Contract with Product Green Degree. Chinese Journal of Management Science; 23(6): 169-176 .