Social Security and Administration Management (2023)
Clausius Scientific Press, Canada

DOI: 10.23977/socsam.2023.040808
ISSN 2523-5796 Vol. 4 Num. 8

Supply Chain Optimization Decisions Considering Equity Concerns and Government Subsidies under CSR

Yang Zhipeng

Shandong University of Technology, Zibo City, Shandong Province, China
1322831196@qq.com.

Keywords: Dual-channel green supply chain, Corporate social responsibility, Greenness, Equity concerns, Government subsidies

Abstract: This paper takes the green supply chain consisting of a single retailer and manufacturer as the research object, constructs five game models based on the CSR commitment of different supply chain members, and explores the impact of fairness concerns and government subsidies on the CSR commitment of the party on the greenness decision of the dual-channel supply chain and the profit of the supply chain members. The results show that the CSR commitment of supply chain members is beneficial to the whole system and other members, but it will damage their own economic profits and cause unfair income distribution. Taking into account the fairness concerns of members who feel unfair will increase their income and eliminate the injustice, but it will lead to a reduction in the greenness of products and social welfare. The introduction of government subsidies can improve the greenness of products, at the same time realize the coordination between the profits of supply chain member enterprises and social welfare, and improve the motivation of member enterprises to actively undertake CSR. Finally, the feasibility and rationality of the relevant research results are verified by Mathematica numerical simulation.

1. Introduction

With the continuous development of economy, there have been a series of problems such as the widening gap between the rich and the poor and the increasingly serious environmental pollution. How can sustainable development be achieved if the pursuit of economic growth ignores environmental protection? By the same token, how far can a company go if it pursues its own profits, regardless of the interests of society as a whole? Therefore, enterprises should actively undertake social responsibilities and CSR (Panda 2016) to help themselves and the society develop together. In this study, it is found that although CSR can improve the overall income of the supply chain system, it also produces a phenomenon of "free riding". That is, one party who undertakes CSR suffers a loss of economic income, while the other party benefits from the behavior of supply chain members who undertake CSR.

Due to the emergence of "free rider" phenomenon, this paper considers the implementation of equity concerns for firms with loss of revenue to see whether they can coordinate the economic benefits of both sides of the supply chain. Equity concerns refer to the decision maker's comparison of its own benefits with those of one party and aversion to unfairness in the distribution of benefits(Cao 2020).Through the study of this paper, it is found that considering the implementation of fairness concerns to the party who undertakes CSR can solve the "free rider" phenomenon, but it

also leads to adverse conditions such as the reduction of product greenness, green product sales and social welfare. Therefore, in order to better improve the greenness of products and attract consumers, this paper introduces the strategy of government subsidies to coordinate the benefits of all parties and further enhance social welfare[1].

2. Literature Review

As for the relevant research in the field of corporate social responsibility, Ni and Li (2012) point out that products with CSR commitment are more attractive to consumers, reduce the competitive dimension and improve the profitability of products. Zhang and Wang (2014) explored the relationship between competitive supply chain and government under different policies with incomplete information, and found that enterprises with higher CSR level received more subsidies. Instead, businesses with environmentally unfriendly products are subject to higher tax rates, which ultimately affect their own earnings. Therefore, it is very important for enterprises to undertake CSR.Servaes (2013)also pointed out that enterprises that actively undertake CSR are more likely to win consumer recognition. Panda and Modak (2017) point out that when members of the supply chain have CSR behaviors respectively, the retailer's strategy of maximizing revenue can effectively alleviate the conflict between the two parties[2].

In reality, whether the income distribution is fair is often highly valued by people, which is the so-called "fairness concern". Many scholars have conducted in-depth research in this field. Based on dual-channel supply chain, Du Shaofu et al.(2010) studied the influence of equity concern tendency on supply chain contract and coordination. Zhang Keyong et al. (2013) discussed the impact of fairness concern behavior on the supply chain system, and made a comparative analysis based on the consideration of fairness concerns of retailers and the consideration of fairness by both sides of the supply chain. Cao Jian(2020) introduced fairness concerns into a dual-channel supply chain where retailers consider recycling, and used the optimal control theory to study the optimal feedback equilibrium strategy of member enterprises[3].

Regarding the relevant research in the field of government subsidies, Jiang Shiying et al. (2019) established a three-stage game model composed of the government, manufacturers and retailers, and analyzed the impact of price sensitivity coefficient and government subsidies on supply chain decision-making. Cao Yu et al. (2019) studied the effects of manufacturers' green quality efforts, retailers' green investment efforts and different government subsidies on the optimal decision-making of the supply chain. Zhu Qinghua et al. (2011) analyzed the optimal pricing decisions of the government and supply chain members by comprehensively considering government subsidies, competitive strategies of enterprises and green preferences of consumers.Han Tongyin et al. (2022) analyzed whether government subsidies could coordinate the impact of retailers' fairness concerns on the supply chain by considering government subsidies and fairness concerns.

3. Problem description and research hypothesis

3.1 Description of the problem

This paper constructs a green supply chain that includes a retailer and a manufacturer (with the manufacturer as the leader), aiming at the phenomenon that CSR commitment by supply chain members will damage their own economic returns and increase the partners' returns.Based on the above background, this paper includes five game models, systematically studies the equilibrium strategy of product greenness level, and analyzes the impact of government subsidies, fairness concern degree and other parameters on each member of the supply chain system and the overall profit[4].

3.2 Research hypothesis

Referring to the treatment method in literature (Liu 2020), assuming that the market size is 1, the market demand for green products is jointly determined by the product greenness level and retail price: Q=1-p+kg.

Hypothesis 1: With reference to the research of Panda (2017) et al., this paper believes that CSR behavior awareness is reflected through its concern for consumer surplus.Consumer surplus is the difference between the maximum price consumers are willing to pay for a product and the actual price, which can be expressed as: $\mathrm{CS} = \frac{t}{2} Q^2$.

Hypothesis 2: The manufacturer's green R&D innovation input cost is a quadratic function relationship with product greenness (Chen 2019), expressed as: $C = \frac{1}{2} u g^2$.u is the input cost factor of green R&D innovation.

Hypothesis 3: Based on the theoretical viewpoint of Freeman et al. (1984), the benefits brought by undertaking CSR can be expressed as : $\pi_E = t\,\mathrm{CS} = t\,Q^2/2 = t\,(1-p+kg)^2/2$;;Where, t is the level of social responsibility undertaken, that is, the cancellation of supply chain members.

Hypothesis 4: Following the practice in (Du 2010), the utility function of the manufacturer's equity concern is: $U_M = (1+\lambda)\pi_m - \lambda\pi_r$.The utility function of retailers' equity concerns is: $U_r = (1+\lambda)\pi_r - \lambda\pi_m$.Where λ is the equity concern coefficient[5].

Hypothesis 5: In order to encourage supply chain members to produce or sell green products, the government gives certain financial subsidies.It is assumed that there are two forms of government subsidies (Wen 2018) : (1) Financial subsidies based on the greenness level of a unit product.Reference (Gao 2022), the total amount of government subsidy expenditure is E(s)=s g, where S is the subsidy coefficient of product greenness.(2) Give certain subsidies according to the manufacturer's green R&D innovation cost input.Reference (He 2019), the amount of government subsidy is E(η)=ηug2/2, η is the cost subsidy coefficient of green R&D innovation. As shown inTable 1:

Table 1: Symbols and definitions

Notation	Definition
p	Unit retail price of products, w<p
k	Consumer green preference coefficient, 0<k<1
w	The wholesale price per unit of product given to retailers by manufacturers, 0<w<1
c	The manufacturer's unit production cost to produce the product, 0<c<w<1
t	Level of social responsibility, 0<t<1
u	Green R&D innovation input cost coefficient
Q	Market demand
g	Greenness of the product
π_r	Economic benefits for retailers
π_m	Economic benefits for manufacturers
Γ	Overall revenue for manufacturers/retailers
CS	Consumer surplus
π_E	Income from CSR commitments
E	Total government subsidy amount
SW	Social welfare
λ	Equity concern coefficient

4. Model construction and solution

4.1 Scenario 1: Where neither manufacturer nor retailer undertakes CSR (AH)

In the AH model, no member of the supply chain undertakes CSR.The returns of both manufacturers and retailers are pure economic returns, and they play a Stackelberg game.The profit function of the manufacturer and the retailer can be expressed as:

$$\pi_r = (p - w)Q \tag{1}$$

$$\pi_m = (w - c)Q - (1/2)ug^2 \tag{2}$$

In case 1, the game sequence is as follows: In the first stage, the manufacturer decides the wholesale price w and the greenness g of the product with the goal of maximizing its own profit; In the second stage, the retailer decides the retail price p with the goal of maximizing its own profit.

Theorem 1: In the case that neither manufacturer nor retailer undertakes CSR, if the parameter conditions are $4U>k^2$, then the optimal product greenness, wholesale price, retail price, demand and economic benefits of supply chain members in the equilibrium state are as follows: $g_{AH} = \frac{(c-1)k}{k^2-4u}$; $w_{AH} = \frac{ck^2-2(1+c)u}{k^2-4u}$; $p_{AH} = \frac{ck^2-(3+c)u}{k^2-4u}$; $Q_{AH} = \frac{(c-1)u}{k^2-4u}$; $\pi_{rAH} = \frac{(c-1)^2u^2}{(k^2-4u)^2}$; $\pi_{mAH} = -\frac{(c-1)^2u}{2(k^2-4u)}$; $SW_{AH} = \frac{(c-1)^2(k^2-6u)u}{-2(k^2-4u)^2}$;

4.2 Scenario 2: A retailer or manufacturer undertakes CSR (BJ/BI)

In the BJ model, the manufacturer undertakes CSR alone, and its decision goal is to maximize social welfare. In this case, the revenue function of the manufacturer and the retailer can be expressed as:

$$\Gamma = \pi_m + \pi_E = (w - c)Q - \frac{1}{2}ug^2 + \frac{t}{2}Q^2 \tag{3}$$

$$\pi_r = (p - w)Q; \tag{4}$$

Similarly, in the BI model, retailers bear CSR alone and take maximizing social welfare as the decision-making goal. Therefore, the revenue function for manufacturers and retailers can be expressed as:

$$\Gamma = \pi_r + \pi_E = (p - w)Q + \frac{t}{2}Q^2 \tag{5}$$

$$\pi_m = (w - c)Q - \frac{1}{2}ug^2; \tag{6}$$

Similar to the solution process of scenario 1, the equilibrium result of green supply chain when supply chain members respectively undertake CSR can be obtained, as shown below:

Theorem 2: When the retailer undertakes CSR, if the parameter conditions meet $k^2 + (t-4)u < 0$, then the optimal product greenness, wholesale price, retail price, order quantity, optimal expected profit, consumer surplus and social welfare of the supply chain members under the equilibrium state are: $g_{BJ} = \frac{(c-1)k}{k^2+2(t-2)u}$; $w_{BJ} = \frac{ck^2+(1+c)(t-2)u}{k^2+2(t-2)u}$; $p_{BJ} = \frac{ck^2-(3+c-2t)u}{k^2+2(t-2)u}$; $Q_{BJ} = \frac{(c-1)u}{k^2+2(t-2)u}$; $\pi_{rBJ} = -\frac{(c-1)^2(t-1)u^2}{(k^2+2(t-2)u)^2}$; $\pi_{mBJ} = -\frac{(c-1)^2u}{2(k^2+2(t-2)u)}$; $\Gamma_{BJ} = -\frac{(c-1)^2(t-2)u^2}{2(k^2+2(t-2)u)^2}$; $CS_{BJ} = \frac{(c-1)^2u^2}{2(k^2+2(t-2)u)^2}$; $SW_{BJ} = \frac{(c-1)^2u(k^2+(3t-7)u)}{-2(k^2+2(t-2)u)^2}$;

Theorem 3: When the manufacturer undertakes CSR, if the parameter conditions meet $k^2 +$

$2(t-2)u<0$, then the optimal product greenness, wholesale price, retail price, order quantity, optimal expected profit, consumer surplus and social welfare of supply chain members under the equilibrium state are: $g_{BI}=\frac{(c-1)k}{k^2+(t-4)u}$; $\mathrm{w}_{BI}=\frac{c(k^2-2u)+(t-2)u}{k^2+(t-4)u}$; $\mathrm{p}_{BI}=\frac{ck^2+(t-3-c)u}{k^2+(t-4)u}$; $\mathrm{Q}_{BI}=\frac{(c-1)u}{k^2+(t-4)u}$; $\pi_{\mathrm{r}BI}=\frac{(c-1)^2u^2}{(k^2+(t-4)u)^2}$; $\pi_{\mathrm{m}BI}=-\frac{(c-1)^2u(k^2+2(t-2)u)}{2(k^2+(t-4)u)^2}$; $\Gamma_{BI}=-\frac{(c-1)^2u}{2(k^2+(t-4)u)}$; $CS_{BI}=\frac{(c-1)^2u^2}{2(k^2+(t-4)u)^2}$; $\mathrm{SW}_{BI}=\frac{(c-1)^2u(k^2+(t-7)u)}{-2(k^2+(t-4)u)^2}$;

4.3 Scenario 3: Equitable concern for manufacturers/retailers undertaking CSR (CK/CL)

According to the study of the above situation, it is found that the party who undertakes CSR needs to pay a lot of money, which will lead to the loss of its own economic profits, while the party who does not undertake CSR benefits from the other party's CSR behavior, that is, the phenomenon of "free riding". Therefore, consider imposing equity concerns on the party that undertakes CSR to incentivize green production or the sale of new products [6].

In the CK model, the fairness concern behavior is considered for the manufacturer who undertakes CSR. In this case, the decision objective functions of the retailer and the manufacturer are as follows:

$$\pi_r=(p-w)Q; \tag{7}$$

$$\Gamma=U_M+\pi_E=(1+\lambda)\pi_m-\lambda\pi_r+(t/2)Q^2; \tag{8}$$

In the CL model, the fairness concern behavior is considered for the retailer who undertakes CSR. In this case, the decision objective functions of the manufacturer and retailer are as follows:

$$\pi_m=(w-c)Q-(1/2)ug^2; \tag{9}$$

$$\Gamma=U_r+\pi_E=(1+\lambda)\pi_r-\lambda\pi_m+(t/2)Q^2; \tag{10}$$

In case 3, the order of the game is as follows: in the first stage, the manufacturer decides the product wholesale price w and product greenness g with the goal of maximizing its own profit;In the second stage, the retailer decides the sales price p with the goal of maximizing its own utility.

Theorem 4: When the manufacturer undertakes CSR, if the parameter conditions meet $u(t-6\lambda-4)+k^2(1+\lambda)<0$, then the optimal product greenness, wholesale price, retail price, order quantity, optimal expected profit, consumer surplus and social welfare of the supply chain members under the equilibrium state are: $p_{CK}=\frac{u(-3+t-5\lambda)+c(k^2-u)(1+\lambda)}{u(-4+t-6\lambda)+k^2(1+\lambda)}$; $g_{CK}=\frac{(c-1)k(1+\lambda)}{u(-4+t-6\lambda)+k^2(1+\lambda)}$; $w_{CK}=\frac{u(t-2-4\lambda)+c(k^2-2u)(1+\lambda)}{u(t-4-6\lambda)+k^2(1+\lambda)}$; $Q_{CK}=\frac{(c-1)u(1+\lambda)}{u(t-4-6\lambda)+k^2(1+\lambda)}$; $\pi_{\mathrm{r}CK}=\frac{(c-1)^2u^2(1+\lambda)^2}{(u(t-4-6\lambda)+k^2(1+\lambda))^2}$; $U_{\mathrm{M}CK}=-\frac{(c-1)^2u(1+\lambda)^2(2u(-2+t-3\lambda)+k^2(1+\lambda))}{2(u(t-4-6\lambda)+k^2(1+\lambda))^2}$; $\Gamma_{CK}=-\frac{(c-1)^2u(1+\lambda)^2}{2(u(t-4-6\lambda)+k^2(1+\lambda))}$; $\mathrm{CS}_{CK}=\frac{(c-1)^2u^2(1+\lambda)^2}{2(u(t-4-6\lambda)+k^2(1+\lambda))^2}$; $\mathrm{SW}_{CK}=\frac{(c-1)^2u(1+\lambda)^2(u(t-6\lambda-7)+k^2(1+\lambda))}{-2(u(t-6\lambda-4)+k^2(1+\lambda))^2}$;

Theorem 5: When a retailer undertakes CSR, if the parameter conditions meet $k^2(1+\lambda)^2+2u(1+2\lambda)\big(t-2(1+\lambda)\big)<0$, then the optimal product greenness, wholesale price, retail price, order quantity, optimal expected profit, consumer surplus and social welfare of supply chain members under the equilibrium state are: $p_{CL}=\frac{u(1+2\lambda)(2t-3(1+\lambda))+c(1+\lambda)(k^2(1+\lambda)-u(1+2\lambda))}{k^2(1+\lambda)^2+2u(1+2\lambda)(t-2(1+\lambda))}$; $g_{CL}=\frac{(c-1)k(1+\lambda)^2}{k^2(1+\lambda)^2+2u(1+2\lambda)(t-2(1+\lambda))}$; $w_{CL}=\frac{u(1+\lambda)(t-2(1+\lambda))+c(k^2(1+\lambda)^2+u(-2+t-2\lambda)(1+3\lambda))}{k^2(1+\lambda)^2+2u(1+2\lambda)(t-2(1+\lambda))}$; $Q_{CL}=\frac{(c-1)u(1+\lambda)(1+2\lambda)}{k^2(1+\lambda)^2+2u(1+2\lambda)(t-2(1+\lambda))}$; $U_{\mathrm{r}CL}=\frac{(c-1)^2u(1+\lambda)^2(k^2\lambda(1+\lambda)^2-2u(-1+t-\lambda)(1+2\lambda)^2)}{2(k^2(1+\lambda)^2+2u(1+2\lambda)(t-2(1+\lambda)))^2}$; $\pi_{\mathrm{m}CL}=$

$-\frac{(c-1)^2u(1+\lambda)^2}{2k^2(1+\lambda)^2+4u(1+2\lambda)(t-2(1+\lambda))}$; $\Gamma_{CL}=\frac{(c-1)^2u(1+\lambda)^2(k^2\lambda(1+\lambda)^2+u(1+2\lambda)^2(2-t+2\lambda))}{2(k^2(1+\lambda)^2+2u(1+2\lambda)(t-2(1+\lambda)))^2}$; $\mathrm{CS}_{CL}=\frac{(c-1)^2u^2(1+\lambda)^2(1+2\lambda)^2}{2(k^2(1+\lambda)^2+2u(1+2\lambda)(t-2(1+\lambda)))^2}$; $\mathrm{SW}_{CL}=\frac{(\Delta_{12}u(k^2(\lambda-1)\Delta_6^2+\Delta_{14}))}{(2(k^2\Delta_6^2+2u(1+2\lambda)(t-2\Delta_6))^2)}$. $\triangle_6=(1+\lambda);\triangle_{12}=(c-1)^2(1+\lambda)^2;\Delta_{14}=u(1+2\lambda)(7+4\lambda(3+\lambda)-t(3+2\lambda))$.

4.4 Scenario 4: Government subsidies for fair manufacturers (M1/M2)

Through the above research, it is found that the party who undertakes CSR will benefit consumers by sacrificing its own interests.Although the implementation of fair concern behavior to the party bearing CSR can solve the "free rider" phenomenon, it also leads to adverse results such as the reduction of product greenness and social welfare.Therefore, consider government subsidies to coordinate the benefits of supply chain members and increase social welfare[7].

Under the greenness subsidy mechanism, the income function of the unsubsidized side remains unchanged.At this time, the decision objective function of the retailer and the manufacturer is:

$$\pi_r=(p-w)Q; \tag{11}$$

$$\Gamma=U_M+\pi_E=(1+\lambda)\pi_m-\lambda\pi_r+s\,g+(t/2)Q^2; \tag{12}$$

Similarly, under the green R&D innovation cost subsidy mechanism, the income function of the unsubsidized party also remains unchanged. At this time, the decision objective function of the retailer and the manufacturer is:

$$\pi_r=(p-w)Q; \tag{13}$$

$$\Gamma=U_M+\pi_E=(1+\lambda)\pi_m-\lambda\pi_r+s\,g+(t/2)Q^2; \tag{14}$$

Theorem 6: When the manufacturer undertakes CSR and considers the greenness subsidy, if the parameter conditions meet $(1+\lambda)\big(u(t-6\lambda-4)+k^2(1+\lambda)\big)<0$, then the optimal product greenness, wholesale price, retail price, order quantity, optimal expected profit and consumer surplus of the supply chain members under the equilibrium state are: $g_{\mathrm{M1}}=\frac{s(t-6\lambda-4)+(c-1)k(1+\lambda)^2}{(1+\lambda)(u(t-6\lambda-4)+k^2(1+\lambda))}$; $w_{\mathrm{M1}}=\frac{\triangle_1+(t-4\lambda-2)(ks+u+u\lambda)}{((1+\lambda)(u(t-6\lambda-4)+k^2(1+\lambda)))}$; $p_{\mathrm{M1}}=\frac{\triangle_1+(t-5\lambda-3)(ks+u+u)}{((1+\lambda)(u(t-6\lambda-4)+k^2(1+\lambda)))}$; $Q_{\mathrm{M1}}=\frac{(c-1)u(1+\lambda)-ks}{u(t-6\lambda-4)+k^2(1+\lambda)}$; $\pi_{\mathrm{rM1}}=\frac{(ks-(c-1)u(1+\lambda))^2}{(u(t-6\lambda-4)+k^2(1+\lambda))^2}$; $U_{\mathrm{MM1}}=\frac{\triangle_2}{(2(1+\lambda)(u(t-6\lambda-4)+k^2(1+\lambda))^2)}$; $\Gamma_{\mathrm{M1}}=\frac{\triangle_3}{(2(1+\lambda)(u(-4+t-6\lambda)+k^2(1+\lambda)))}$; $\mathrm{CS}_{\mathrm{M1}}=\frac{(ks-(c-1)u(1+\lambda))^2}{2(u(t-6\lambda-4)+k^2(1+\lambda))^2}$. $\triangle_1=c(k^2-2u)(1+\lambda)^2$,$\triangle_2=\Big(4(c-1)ksu(t-3\lambda-2)(1+\lambda)^2+2(c-1)k^3s(1+\lambda)^3+u(s^2(t-6\lambda-4)^2-2(c-1)^2u(t-3\lambda-2)(1+\lambda)^3)-k^2(1+\lambda)\big((c-1)^2u(1+\lambda)^3+s^2(4+6\lambda)\big)\Big)$,$\triangle_3=(s^2(t-6\lambda-4)+2(c-1)ks(1+\lambda)^2-(c-1)^2u(1+\lambda)^3)$.

Theorem 7: When the manufacturer undertakes CSR and considers innovation cost subsidies, if the parameter conditions meet $k^2(1+\lambda)^2+u(t-6\lambda-4)(1-\eta+\lambda)<0$, then the optimal product greenness, wholesale price, retail price, order quantity, optimal expected profit and consumer surplus of the supply chain members under the equilibrium state are: $g_{\mathrm{M2}}=\frac{(c-1)k(1+\lambda)^2}{k^2(1+\lambda)^2+(t-6\lambda-4)\triangle_4}$; $w_{\mathrm{M2}}=\frac{u(t-4\lambda-2)\triangle_4+c\triangle_6(2\triangle_5+k^2\triangle_6)}{k^2(1+\lambda)^2+(t-6\lambda-4)\triangle_4}$; $p_{\mathrm{M2}}=\frac{u(t-5\lambda-3)\triangle_4+c\triangle_6(\triangle_5+k^2\triangle_6)}{k^2(1+\lambda)^2+(t-6\lambda-4)\triangle_4}$; $Q_{\mathrm{M2}}=-\frac{(c-1)u(\eta-\lambda-1)(1+\lambda)}{k^2(1+\lambda)^2+(t-6\lambda-4)\triangle_4}$; $\pi_{\mathrm{rM2}}=\frac{(c-1)^2u^2(1+\lambda)^2(1-\eta+\lambda)^2}{(k^2(1+\lambda)^2+(t-6\lambda-4)\triangle_4)^2}$; $U_{\mathrm{MM2}}=\frac{((c-1)^2\triangle_5\triangle_6^2(k^2\triangle_6^2+2(t-3\lambda-2)\triangle_4))}{(2(k^2\triangle_6^2+(t-6\lambda-4)\triangle_4)^2)}$; $\Gamma_{\mathrm{M2}}=\frac{(c-1)^2u(\eta-\lambda-1)\triangle_6^2}{2(k^2\triangle_6^2+(t-6\lambda-4)\triangle_4)}$; $\mathrm{CS}_{\mathrm{M2}}=\frac{(c-1)^2(1+\lambda)^2\triangle_4^2}{2(k^2(1+\lambda)^2+(t-6\lambda-4)\triangle_4)^2}$. $\triangle_4=$

$u(1-\eta+\lambda)$, $\triangle_5 = u(\eta-\lambda-1)$, $\triangle_6 = (1+\lambda)$.

4.5 Scenario 5: The scenario of government subsidies for fair retailers (N1/N2)

When retailers undertake CSR, the government subsidizes those who consider fairness concerns. At this time, under the greenness subsidy mechanism, the income functions of both sides of the supply chain are as follows:

$$\pi_m = (w-c)Q - (1/2)ug^2; \tag{15}$$

$$\Gamma = U_r + \pi_E = (1+\lambda)\pi_r - \lambda\pi_m + sg + (t/2)Q^2 \tag{16}$$

Under the green R&D innovation cost subsidy mechanism, when subsidies are considered for retailers who undertake CSR, the benefit letters of both sides of the supply chain are as follows:

$$\pi_m = (w-c)Q - (1/2)ug^2; \tag{17}$$

$$\Gamma = U_r + \pi_E = (1+\lambda)\pi_r - \lambda\pi_m + sg + (t/2)Q^2 \tag{18}$$

Theorem 8: When the retailer undertakes CSR and considers the government subsidy of green degree, if the parameter conditions meet $k^2(1+\lambda)^2 + 2u(1+2\lambda)\big(t-2(1+\lambda)\big) < 0$, then the optimal product greenness, wholesale price, retail price, order quantity, optimal expected profit and consumer surplus of supply chain members under the equilibrium state are: $g_{N1} = \frac{(c-1)k\triangle_6^2}{k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6)}$; $w_{N1} = \frac{u(1+\lambda)(t-2(1+\lambda))+\triangle_7}{k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6)}$; $p_{N1} = \frac{u(1+2\lambda)(2t-3(1+\lambda))+\triangle_8}{k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6)}$; $Q_{N1} = \frac{(c-1)u\triangle_6(1+2\lambda)}{k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6)}$; $U_{rN1} = \frac{(\triangle_9(\triangle_{10}-2(c-1)(t-\lambda-1)(u+2u\lambda)^2+\triangle_{11}))}{(2(k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6))^2)}$; $\pi_{mN1} = -\frac{(-1+c)^2u\triangle_6^2}{2k^2\triangle_6^2+4u(1+2\lambda)(t-2\triangle_6)}$; $\Gamma_{N1} = \frac{(\triangle_9(\triangle_{10}+(c-1)(2-t+2\lambda)(u+2u\lambda)^2+\triangle_{11}))}{(2(k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6))^2)}$; $\mathrm{CS}_{N1} = \frac{(c-1)^2u^2(1+3\lambda+2\lambda^2)^2}{2(k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6))^2}$. $\triangle_7 = c\big(k^2(1+\lambda)^2 + u(t-2\lambda-2)(1+3\lambda)\big)$,$\triangle_8 = c(1+\lambda)\big(k^2(1+\lambda) - u(1+2\lambda)\big)$,$\triangle_9 = (c-1)(1+\lambda)^2$,$\triangle_{10} = 2k^3s(1+\lambda)^2 + (c-1)k^2u\lambda(1+\lambda)^2$, $\triangle_{11} = 4ksu(1+2\lambda)\big(t-2(1+\lambda)\big)$.

Theorem 9: When the retailer undertakes CSR and considers the innovation cost subsidy, if the parameter conditions meet $k^2(1+\lambda)^2 + 2u(1+2\lambda)\big(t-2(1+\lambda)\big) < 0$, then the optimal product greenness, wholesale price, retail price, order quantity, optimal expected profit and consumer surplus of the supply chain members under the equilibrium state are: $g_{N2} = \frac{(c-1)k\triangle_6^2}{k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6)}$; $w_{N2} = \frac{u(1+\lambda)(t-2\triangle_6)+\triangle_7}{k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6)}$; $p_{N2} = \frac{u(1+2\lambda)(2t-3\triangle_6)+\triangle_8}{k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6)}$; $Q_{N2} = \frac{(c-1)u\triangle_6(1+2\lambda)}{k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6)}$; $U_{rN2} = \frac{\triangle_{12}u(\triangle_{13}-2u(t-\lambda-1)(1+2\lambda)^2)}{2(k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6))^2}$; $\pi_{mN2} = -\frac{(c-1)^2u\triangle_6^2}{2k^2\triangle_6^2+4u(1+2\lambda)(t-2\triangle_6)}$; $\Gamma_{N2} = \frac{\triangle_{12}u(\triangle_{13}+u(1+2\lambda)^2(2-t+2\lambda))}{2(k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6))^2}$; $\mathrm{CS}_{N2} = \frac{(c-1)^2u^2\triangle_6^2(1+2\lambda)^2}{2(k^2\triangle_6^2+2u(1+2\lambda)(t-2\triangle_6))^2}$;$\triangle_{12} = (c-1)^2(1+\lambda)^2$, $\triangle_{13} = k^2(1+\lambda)^2(\eta+\lambda)$.

5. Analysis of equilibrium results

5.1 Manufacturers or retailers bear the impact of CSR on supply chain pricing decisions

Proposition 1: Compare the situations where supply chain members do not consider CSR with those where retailers and manufacturers bear CSR alone, and find that: $g_{BJ} > g_{AH}, w_{BJ} > w_{AH}, p_{BJ} < p_{AH}, Q_{BJ} > Q_{AH}, \pi_{mBJ} < \pi_{mAH}, \pi_{rBJ} > \pi_{rAH}, CS_{BJ} > CS_{AH}$; and $g_{BI} > g_{AH}, w_{BI} < w_{AH}, p_{BI} < p_{AH}, Q_{BI} > Q_{AH}, \pi_{mBI} > \pi_{mAH}, \pi_{rBI} < \pi_{rAH}, CS_{BI} > CS_{AH}$.

Proposition 1 shows that when the retailer undertakes CSR, the retail price of the new product decreases, while the wholesale price, the greenness of the product, the market demand and the consumer surplus are all greater than when the retailer does not undertake CSR.When the manufacturer undertakes CSR, the wholesale price and retail price of the new product decrease, while the greenness, market demand and consumer surplus of the product are greater than that of the two without CSR.Under the model in which retailers bear CSR alone, manufacturers' profits increase while retailers' profits decrease.When the manufacturer undertakes CSR, the situation is similar, the other party's profit increases while its own profit decreases, but whether the manufacturer or the retailer undertakes CSR, the overall profit of the green supply chain will increase.

Proposition 2: When the wholesale price is an endogenous variable, it is found that SWBJ > SWBI > SWAH, that is, the social welfare when the retailer undertakes CSR is higher than that when the manufacturer undertakes CSR.

Proposition 2 shows that when the manufacturer undertakes CSR alone, because the manufacturer is also responsible for the research and development of green products, it will sacrifice more economic profits than when the retailer undertakes CSR, which will lead to lower social welfare than when the retailer undertakes CSR[8].

5.2 The impact of equity concerns on equilibrium outcomes

Proposition 3: When considering the fairness concerns of manufacturers, wholesale prices, retail prices and manufacturers' earnings all increase with the increase of fairness concerns, while the greenness of products, market demand and retailers' earnings all decrease with the increase of government subsidies($\frac{\partial g_{ck}}{\partial \lambda} < 0; \frac{\partial w_{ck}}{\partial \lambda} > 0; \frac{\partial p_{ck}}{\partial \lambda} > 0; \frac{\partial Q_{ck}}{\partial \lambda} < 0; \frac{\partial \pi_r}{\partial \lambda} < 0; \frac{\partial U_M}{\partial \lambda} > 0$).

Proposition 3 shows that when the level of fairness concern of the manufacturer is increased, the manufacturer will continuously increase the wholesale price and reduce the greenness of the product in order to obtain more economic benefits.With the increase of wholesale price, retailers will increase the retail price of green products in order to obtain more profits. As a result, consumers will buy fewer new products, which will lead to lower profits for retailers. But because manufacturers' equity concerns about reduced costs are greater than the reduction in green demand, manufacturers have achieved revenue growth[9].

Proposition 4: When the fairness concern is taken into account by the retailer, the wholesale price, retail price and the retailer's income increase with the increase of the fairness concern, while the greenness of the product, market demand and the manufacturer's income decrease with the increase of government subsidies($\frac{\partial g_{cl}}{\partial \lambda} < 0; \frac{\partial w_{cl}}{\partial \lambda} < 0; \frac{\partial p_{cl}}{\partial \lambda} > 0; \frac{\partial Q_{cl}}{\partial \lambda} < 0; \frac{\partial U_r}{\partial \lambda} > 0; \frac{\partial \pi_m}{\partial \lambda} < 0$).

Proposition 4 shows that with the enhancement of fairness concern, retailers will increase the retail price of products in order to obtain more profits, and the higher retail price exceeds the purchasing ability of consumers, thus leading to the reduction of the sales volume of green products, thus damaging the interests of manufacturers.In order to increase the sales volume, the manufacturer will moderately reduce the wholesale price, which makes the economic benefits of both sides show a state of decline and decline, that is, the fair concern behavior causes the change of product prices, resulting in the redistribution of profits of the supply chain member enterprises[10].

5.3 Influence of government subsidies to manufacturers on equilibrium results

Proposition 5: When the government implements greenness subsidies for manufacturers who undertake CSR, the greenness, wholesale price, retail price and market demand of products will continue to increase with the strengthening of government subsidies ($\frac{\partial g_{M1}}{\partial s} > 0; \frac{\partial w_{M1}}{\partial s} > 0; \frac{\partial p_{M1}}{\partial s} >$

$0;\ \frac{\partial Q_{M1}}{\partial s} > 0$).The economic returns of retailers and the overall returns of manufacturers also improved with the increase of government subsidies ($\frac{\partial \pi_r}{\partial s} > 0; \frac{\partial U_M}{\partial s} > 0$).

Proposition 5 shows that because manufacturers have to pay a lot of costs to produce green products, such as machinery, equipment, labor and higher cost of raw materials, the government will provide certain subsidies to manufacturers according to the degree of green products to improve their enthusiasm to produce green products. At the same time, because the production of green products increases the cost of enterprises, it brings higher sales prices. However, because consumers with green consumption consciousness are willing to pay a certain amount of money to buy more green products, the benefits of both sides of the supply chain will be improved[11].

Proposition 6: When the government implements green R&D innovation cost subsidies for manufacturers who undertake CSR, the greenness, wholesale price, retail price and market demand of products will continue to increase with the strengthening of government subsidies ($\frac{\partial g_{M2}}{\partial \eta} > 0, \frac{\partial w_{M2}}{\partial \eta} > 0; \frac{\partial p_{M2}}{\partial \eta} > 0; \frac{\partial Q_{M2}}{\partial \eta} > 0$).The economic benefits of retailers and the overall benefits of manufacturers are also increasing with the increase of government subsidies ($\frac{\partial \pi_r}{\partial \eta} > 0; \frac{\partial U_M}{\partial \eta} > 0$).

Proposition 6 shows that the government subsidize the cost of green R&D and innovation for manufacturing enterprises, which can effectively reduce the double marginal effect in the supply chain and improve the economic benefits of both manufacturers and retailers. Therefore, the government should provide timely and appropriate financial subsidies to enterprises, encourage the member enterprises of the supply chain to actively fulfill their social responsibilities, and take consumers as the core to pay attention to their product satisfaction[12].

5.4 Influence of government subsidies to retailers on equilibrium results

Proposition 7: When a retailer undertakes CSR, the greenness, wholesale price, retail price and market demand of the product are not affected by the amount of government subsidy, no matter the greenness subsidy or the cost subsidy for green R&D and innovation. Government subsidies improved retailers' overall earnings, while manufacturers' earnings were unaffected by government subsidies[13].

6. Numerical Analysis

In order to demonstrate the validity of the model and conclusion, Mathematica was used to conduct numerical simulation to further explore the influence of fairness concern behavior and different government subsidy mechanisms on dual-channel green supply chain. Since when the government subsidizes the retailer who undertakes CSR, the greenness, wholesale price, retail price and market demand of the product are not affected by the amount of government subsidy, therefore, this chapter only studies the subsequent situation when the manufacturer undertakes CSR [13].

In this section, numerical simulation is used to explore: (1) How manufacturers' CSR performance affects the economic returns of supply chain members;(2) When considering manufacturers' equity concerns, whether product greenness reduction and "free riding" in the supply chain still exist;(3) according to the assumptions and satisfy the scope of this paper calculates the parameters of conditions($u(t-6\lambda-4)+k^2(1+\lambda)<0$)set: t =1;k=0.4;u=0.2;η=0.015;s=0.2;w=0.1;c=0.087; λ=1=1.The results are shown in Table 2 to Table 3.

As can be seen from Table 2, the increased level of fairness concern of manufacturers will lead to the increase of wholesale and retail prices, the decrease of product greenness and the decrease of retailers' profits, which will lead to serious damage to retailers' economic earnings. At the same time,

manufacturers will be concerned about fairness due to the "free riding" behavior of retailers, and use their dominant position in the supply chain to raise wholesale prices to meet their own fairness psychology. At this time, retailers will also raise the retail prices of green products to prevent profit loss, which leads to non-win-win competition among members of the green supply chain. The profits of retailers and social welfare have declined to a certain extent [14].

Table 2: Equity concerns

λ	**0**	**0.2**	**0.4**	**0.6**	**0.8**
g_{CK}	0.83	0.676	0.597	0.549	0.517
W_{CK}	0.502	0.594	0.641	0.670	0.689
P_{CK}	0.917	0.932	0.940	0.945	0.948
π_{rCK}	0.172	0.114	0.089	0.075	0.067
U_{MCK}	0.103	0.128	0.146	0.162	0.179
SW_{CK}	0.448	0.357	0.325	0.314	0.312

Table 3: Government subsidies

s	**0**	**0.015**	**0.039**	**0.085**	**0.178**
g_{M1}	0.493	0.539	0.612	0.752	0.934
π_{rM1}	0.061	0.063	0.066	0.072	0.086
U_{MM1}	0.195	0.202	0.213	0.242	0.318
η	0	0.2	0.4	0.6	0.8
g_{M2}	0.493	0.562	0.652	0.777	0.961
π_{rM2}	0.061	0.064	0.068	0.074	0.088
U_{MM2}	0.195	0.199	0.204	0.211	0.961

It can be seen from Table 3 that the subsidy coefficient s=0.085 (η =0.6) of unit product greenness is the critical value. Specifically, when s<0.085 (η <0.6), the profit of the manufacturer under the greenness subsidy is better than the corresponding value under the green R&D cost subsidy mechanism. In other words, in the same government subsidy expenditure and the total expenditure is small, manufacturers tend to accept green degree subsidies and improve manufacturers' profits. On the contrary, when the amount of subsidy expenditure is large, manufacturers tend to accept green R&D cost subsidies. In addition, under the same government subsidy expenditure, the greenness of products under the green R&D cost subsidy mechanism has always been higher than the corresponding value under the greenness subsidy, and it keeps increasing with the growth of the subsidy coefficient of unit product greenness. Therefore, from the perspective of the government's pursuit of environmental benefits, it will choose the green R&D cost subsidy mechanism to subsidize .

7. Conclusions

This paper comprehensively considers factors such as green supply chain, corporate social responsibility, equity concerns and government subsidies, analyzes the impact of different government subsidy strategies on green supply chain under equity concerns, and draws the following conclusions:(1) Although the enhancement of CSR will stimulate sales to a certain extent and increase the overall revenue of the supply chain, it will cause losses in the economic revenue of the party who undertakes CSR, resulting in the other party gaining more revenue without making efforts, and the party who undertakes CSR will feel unfair;(2) In order to eliminate the social injustice of the party who undertakes CSR, consider implementing the fairness concern behavior, which can solve the phenomenon of unfair income distribution, but also reduce the greenness of products and social welfare;(3) Government subsidies can solve the problem of product greenness reduction under the

equity concern model, and maximize the economic benefits and social welfare of both sides of the supply chain. To sum up, subsidy strategies affect the development of green supply chain, and moderate subsidies can improve the overall efficiency of supply chain. At the same time, members of the green supply chain should not pay too much attention to their own fairness, but should strengthen cooperation and reduce vicious competition, so as to maximize the benefits of subsidy strategy for the green supply chain.

References

[1] Pan Xiaofei, Zhang Tao. Fresh product supply chain preservation effort and pricing optimization considering loss avoidance [J]. Journal of Highway and Transportation Science and Technology, 2023, 40(05):15-17

[2] Xu Na, Zhao Lindu, Chen Jing et al. Research on Optimization decision of community e-commerce supply chain cooperation considering net recommendation Value (NPS) [J]. Journal of Management Engineering, 2019,37(04):443-447

[3] Wang Dong. Research on Optimization of Blockchain using Decision path -- Based on supply chain perspective [J]. Friends of Accounting, 2022,(22):67-69

[4] Mi Liyang, Shang Chunyan. Research on closed-loop supply chain decision optimization under Equity Concern and innovation input [J]. Journal of Nanjing Audit University, 2022, 19(04):17-18

[5] Chen Y X. Research on decision-making optimization of agricultural supply chain participants based on quality traceability system [D]. South China University of Technology, 2022. 33-41

[6] Konstantaras Ioannis, Skouri Konstantina, Benkherouf Lakdere. Optimizing inventory decisions for a closed-loop supply chain model under a carbon tax regulatory mechanism[J]. International journal of production economics, 2021, 239(Sepa):108185.1-108185.13

[7] Tang Wenguang, Li Haitao, Cai Kaihao. Optimising the credit term decisions in a dual-channel supply chain[J]. International Journal of Production Research, 2021, 59(13a14):4324-4341

[8] Saeid Rezaei, Reza Maihami. Optimizing the sustainable decisions in a multi-echelon closed-loop supply chain of the manufacturing/ remanufacturing products with a competitive environment[J]. Environment, development and sustainability, 2020,22(7):6445-6471

[9] Li Haitao, Mai Liuqing, Zhang Wenlong, Tian Xiangyu. Optimizing the credit term decisions in supply chain finance[J]. Journal of Purchasing & Supply Management, 2019, 25(2):146-156

[10] Xiong Yixuan, Du Gang,Jiao Roger J. Modular product platforming with supply chain postponement decisions by leader-follower interactive optimization[J]. International journal of production economics, 2018, 205(NOVa):272-286

[11] J. Wheeler, M.A. Páez, G. Guillén-Gosálbez, F.D. Mele. Combining multi-attribute decision-making methods with multi-objective optimization in the design of biomass supply chains[J]. Computers & Chemical Engineering,2018,113(maya8):11-31

[12]Arashpour Mehrdad, Bai Yu, Aranda-mena Guillermo, Bab-Hadiashar Alireza, Hosseini Reza, Kalutara Pushpitha. Optimizing decisions in advanced manufacturing of prefabricated products: Theorizing supply chain configurations in off-site construction[J]. Automation in construction, 2017,84(deca):146-153

[13] Lin Tao, Wang Shaowen, Rodriguez Luis F., Hu Hao, Liu Yan. CyberGIS-enabled decision support platform for biomass supply chain optimization[J]. Environmental Modelling & Software,2015,70(auga):138-148

[14] Mohammad Hossein Gorji, Mostafa Setak, Hossein Karimi. Optimizing inventory decisions in a two-level supply chain with order quantity constraints[J]. Applied Mathematical Modelling,2014,38(3):814-827