Supply Chain Cooperative Emission Reduction Strategy Considering Government Subsidies and Sales Efforts

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Abstract : In recent years, consumers' awareness of low-carbon consumption has gradually increased, and consumers have a growing preference for low-carbon products. Low-carbon economy has become a new global trend, and enterprises need to choose the best level of carbon reduction. This paper constructs a supply chain composed of suppliers and a sales platform and explores the impact of government subsidies and sales efforts on enterprise behavior decision-making under three contracts: centralized decision-making (sc), revenue-sharing (rs), and cost-sharing (cs). The results show that under the three modes, with the improvement of consumers' green awareness, the green degree of manufacturers, the marketing intensity of the platform, and the sales price of products are also increasing. When the marketing effort input coefficient is low, the manufacturer chooses the cost-sharing cooperation mode, and when the green input technology is high, both the manufacturer and the sales platform choose the cost-sharing mode.

Keywords: consumer green awareness; government subsidies; sales efforts; cooperative emission reduction

1 INTRODUCTION

With rapid economic growth and urbanization, carbon emissions will increase naturally (Sarwar, 2019). On the one hand, the improvement of consumers' low-carbon awareness is that they can accept and buy low-carbon products at high prices, on the other hand, government subsidies make enterprises reduce the cost of emission reduction. In addition, sales platforms working with manufacturers to reduce emissions can promote low carbon demand, contributing to carbon control and profitability throughout the supply chain. However, manufacturers and sales platforms also face many challenges in emission reduction cooperation. The manufacturer indeed bears the technical cost of carbon emission reduction, but in the cooperative emission reduction, whether the sales platform considers sharing this part of the cost? how to coordinate between the manufacturer and the sales platform between costs and benefits to ensure the stable implementation of a cooperative emission reduction strategy.

Therefore, this paper considers the cooperative supply chain under government subsidies and sales efforts, which is composed of a manufacturer and a sales platform. We try to answer the

EMIS 2023, February 24-26, Chengdu, People's Republic of China

DOI 10.4108/eai.24-2-2023.2330673

following questions:

(1) How does consumer green preference affect the profits of supply chains, manufacturers and sales platforms?

(2) Do manufacturers and sales platforms have stable energy-saving and emission-reduction strategies?

(3) How does it affect the emission reduction strategy when revenue sharing or cost sharing is formed between the manufacturer and the sales platform?

The other parts of this paper are organized as follows, the second part reviews the relevant literature, the third part explains the symbols and assumptions of the model, the fourth part is the establishment and solution of the model, and the fifth part discusses the impact of different factors on the supply chain. Part 6 summarizes the conclusions of this paper, provides management insights on supply chain cooperation and emission reduction and discusses limitations and future research directions.

2 REVIEWED

This paper is closely related to the research of green low-carbon supply chain management, emission reduction of the low-carbon green supply chain, and the problem flow of operation cooperation of low-carbon supply chain.

Li et al. (2016) analyzed the optimal emission reduction level and profit of the main body under the two contracts of sharing the benefits of emission reduction and sharing the investment cost of emission reduction. Lang et al. (2021) found that consumers' preference for low-carbon products can increase the profits of both manufacturers and retailers, but there will be a phenomenon of retailers "hitchhiking", which can be eliminated after retailers invest in emission reduction. Wu et al. (2020) studied the emission reduction decision-making of two-tier iron and steel supply chain enterprises in four ways: independent decision-making, emission reduction cost sharing, profit sharing, and full cooperation. to explore the impact of different carbon trading prices and emission reduction investment cost coefficients on enterprise pricing and emission reduction decision-making. Liao et al. (2021) use the Stackelberg game model to discuss the cooperative emission reduction strategy of the supply chain with the participation of energy-saving service companies. The pricing and emission reduction strategies of retailers and dual-channel members are discussed (Du, 2021). Meng (2018) constructed a three-stage government-enterprise game model to compare and analyze the three situations of non-government subsidies, input subsidies, and emission reduction subsidies. Zhao (2018) studies the optimal emission reduction and pricing decisions of upstream and downstream enterprises in three cases: complete non-cooperation, semi-cooperation, and complete cooperation. Wang et al. (2018) have shown that cooperative carbon reduction strategies have more advantages than independent carbon reduction methods. Li et al (2019) studied 2018 different game structures of CLSC and found that retailers agreed to share the collection costs of manufacturers under the condition of reducing consumers' low-carbon preferences. Ji et al (2022) consider two different power structures and study a single emission reduction model and a cooperative emission reduction model in which manufacturers invest in low-carbon technology and retailers invest in low-carbon promotion.

To sum up, the research on the sustainable strategy of emission reduction in supply chain cooperation has received widespread attention from scholars. We follow the existing literature, but we also consider the impact of government subsidies and sales efforts on emission reduction cooperation. At the same time, we explore the impact of balanced decision-making on profits under different modes by studying the different cooperation modes between manufacturers and sales platforms.

3 SYMBOLIC DESCRIPTIONS OF THE MODEL

This paper establishes a two-level supply chain based on a manufacturer and sales platform to explore the impact of government subsidies and sales efforts on enterprise behavior decision-making under three contracts centralized decision-making, revenue-sharing, and cost-sharing. The main symbols are described in Table 1.

Table 1 meaning of the main parameters of the model

α	Consumers' green consciousness
v	Consumer utility
τ	Green input coefficient
η	Sales effort input coefficient
s_i^j	The proportion of input cost of government subsidy
λ	Income sharing ratio coefficient
χ	Cost-sharing ratio coefficient
w_i^j	Wholesale price
p_i^j	selling price
e_i^j	Sales effort
g_i^j	Proportional coefficient of per unit emission reduction

Two hypotheses are given in this paper:

Suppose 1. The valuation v of consumers is evenly distributed over the interval [0,1].

Suppose 2. Without losing generality, we normalize production costs, cost of sales, salvage value of products, and other fixed costs to zero.

4 MODEL

In this paper, a two-level supply chain composed of green product manufacturers and a sales platform, considering that the sales platform plays a leading role in the supply chain, the government provides green emission reduction subsidies to the sales platform. the sales platform then uses the government's green subsidies to subsidize green production to manufacturers. We consider the benchmark model under centralized decision-making without government subsidies, and we consider the revenue-sharing contract model and cost-sharing model respectively under government subsidies.

The net utility of the consumer is given by formula (1) below:

$$\begin{aligned} u &= g(v-p+\alpha+e)+(1-g)(v-p+e) \\ &= v-p+\alpha g+e \end{aligned} \tag{1}$$

Describe the demand function, the market demand can be obtained from the consumer utility model, the market potential is normalized to 1, the demand formula.

$$D(p,g,e)=P\{v\geq p-\alpha g-e\}=1-p+\alpha g+e \tag{2}$$

The sum of the consumer surplus, the retailer's profit, and the manufacturer's profit is regarded as the total revenue of the government, and the difference minus the amount of subsidy is its "profit", that is, the total social welfare in economics, specifically expressed as follows.

$$SW=\frac{1}{2}(1-p+\alpha g+e)^2+p(1-p+\alpha g+e)-\frac{1}{2}\tau g^2-\frac{1}{2}\eta e^2 \tag{3}$$

4.1 Centralized Decision Marking (SC)

Under the centralized decision model, the manufacturer and the sales platform fully cooperate and make decisions together, and the ultimate goal of the decision is to maximize the total expected profit of the supply chain system, so the objective function of the system decision is

$$\max \pi^{sc}(p^{sc},e^{sc},g^{sc})=p^{sc}(1-p^{sc}+\alpha g^{sc}+e^{sc})-\frac{1}{2}\eta(e^{sc})^2-\frac{1}{2}\tau(g^{sc})^2 \tag{4}$$

The above formula, p^{sc},e^{sc},g^{sc} takes the partial derivative and makes it equal to zero respectively, and solves the optimal solution pair together, so it is easy to get the optimal sales price, green degree of emission reduction, and sales effort level.

$$\begin{aligned} p^{sc} &= -\frac{\eta\tau}{\alpha^2\eta+\tau-2\eta\tau} \\ g^{sc} &= -\frac{\alpha\eta}{\alpha^2\eta+\tau-2\eta\tau} \\ e^{sc} &= -\frac{\tau}{\alpha^2\eta+\tau-2\eta\tau} \end{aligned} \tag{5}$$

4.2 Decentralized Decision

4.2.1 Revenue Sharing Contract (RS)

To further encourage manufacturers to reduce emissions and the enthusiasm of the sales platform for green products, the government gives manufacturers emission reduction subsidies, and manufacturers give a part of the government subsidies to the sales platform for low-carbon green promotion subsidies. Manufacturers subsidize the sales platform and provide

green and low-carbon products for the sales platform at a lower wholesale price, encouraging the sales platform to carry out low-carbon publicity, and improve consumers' recognition of green and low-carbon products, thus increasing the demand for products. At the same time, the sales platform returns a certain proportion of its income （λ） to the manufacturer, which indirectly increases the manufacturer's enthusiasm for emission reduction, which will be more conducive to the realization of cooperative emission reduction targets. Under the decision-making of a revenue-sharing contract, the manufacturer's decision-making goal is.

$$\pi_m^{rs}(g^{rs}) = (1-\lambda)w^{rs}(1-p^{rs}+\alpha g^{rs}+e^{rs}) - \frac{1}{2}s^{rs}\tau(g^{rs})^2 \tag{6}$$

$$\pi_p^{rs}(e^{rs},p^{rs}) = \lambda(p^{rs}-w^{rs})(1-p^{rs}+\alpha g^{rs}+e^{rs}) - \frac{1}{2}\eta(e^{rs})^2 \tag{7}$$

According to the reverse order solution rule, the platform first determines the optimal retail price p and marketing effort e, and obtains the partial derivative of p and e. and through the hessian matrix. the second-order matrix is expressed as.

$$H = \begin{bmatrix} \dfrac{\partial^2 \pi_p^{rs}}{\partial (p^{rs})^2} & \dfrac{\partial^2 \pi_p^{rs}}{\partial p^{rs} \partial e^{rs}} \\ \dfrac{\partial^2 \pi_p^{rs}}{\partial e^{rs} \partial p^{rs}} & \dfrac{\partial^2 \pi_p^{rs}}{\partial (e^{rs})^2} \end{bmatrix} = \begin{bmatrix} -2\lambda & \lambda \\ \lambda & -\eta \end{bmatrix} \tag{8}$$

As the first order principal determinant $-2\lambda < 0$, Second order primary and secondary determinant $2\lambda\eta - \lambda^2$, when $\lambda < 2\eta$, the Hessian matrix is negative definite, We verify the profit function of the sales platform $\pi_p^{rs}(p^{rs},e^{rs})$ is joint concave in. (p^{rs},e^{rs}) . There is only retail price and sales effort to maximize the profit of the sales platform. By making the $\partial \pi_p^{rs} / \partial p^{rs} = 0$ and $\partial \pi_p^{rs} / \partial e^{rs} = 0$. The optimal solution pair is solved simultaneously, so the optimal retail price and sales effort level are as follows.

$$\begin{aligned} p^{rs} &= \frac{\eta + \alpha\eta g^{rs} + \eta w^{rs} - \lambda w^{rs}}{2\eta - \lambda} \\ e^{rs} &= \frac{\lambda\left(1 + \alpha g^{rs} - w^{rs}\right)}{2\eta - \lambda} \end{aligned} \tag{9}$$

The manufacturer determines the green emission reduction level and wholesale price and substitutes p^{rs} and e^{rs} into the manufacturer's profit function. According to the profit function of the manufacturer, the first derivative of w^{rs} and g^{rs} is obtained. If the first derivative is zero, you can get it.

$$
\begin{aligned}
w^{rs} &= \frac{1}{2}(1+\alpha g^{rs}) \\
g^{rs} &= \frac{\alpha\eta w^{rs} - \alpha\eta\lambda w^{rs}}{2\eta s^{rs}\tau - \lambda s^{rs}\tau}
\end{aligned}
\tag{10}
$$

Through the hessian matrix, we can get., the second-order matrix expressed as:

$$
H == \begin{bmatrix}
-\dfrac{2\eta(-1+\lambda)}{-2\eta+\lambda} & \dfrac{\alpha\eta(-1+\lambda)}{-2\eta+\lambda} \\
-\dfrac{\alpha\eta(-1+\lambda)}{2\eta-\lambda} & -s^{rs}\tau
\end{bmatrix}
\tag{11}
$$

The optimal solution can be obtained.

$$
\begin{aligned}
w^{rs} &= \frac{(2\eta-\lambda)s^{rs}\tau}{\alpha^2\eta(-1+\lambda)+2(2\eta-\lambda)s^{rs}\tau} \\
g^{rs} &= -\frac{\alpha\eta(-1+\lambda)}{\alpha^2\eta(-1+\lambda)+2(2\eta-\lambda)s^{rs}\tau}
\end{aligned}
\tag{12}
$$

According to the decision of the manufacturer and the sales platform, the government determines the optimal subsidy ratios, that is, we substitute p^{rs}, e^{rs}, g^{rs} into the total social welfare $SW(s^{rs})$.

And because $SW(s^{rs})$ is a concave function in s^{rs}, we also make rs $\partial sw^{rs}/\partial s^{rs}$ equation zero to solve the problem.

Therefore, the optimal subsidy ratio that the government can give to the manufacturer.

$$
s^{rs} = -\frac{2(2\eta-\lambda)(-1+\lambda)}{7\eta-\lambda(2+\lambda)}
\tag{13}
$$

4.2.2 Cost Sharing (CS)

Under this decision, the manufacturer cooperates partially with the sales platform, the manufacturer dominates the supply chain, the government subsidizes the manufacturer for emission reduction, and the sales platform chooses to share a certain proportion （χ） of the manufacturer's carbon reduction cost, In this decentralized decision, the sales platform and the manufacturer still make pricing decisions with the maximum expected value of their respective profit functions as the ultimate goal, and the profit functions of the manufacturer and the sales platform are:

$$
\pi_m^{cs}(w^{cs}, g^{cs}) = w^{cs}(1 - p^{cs} + \alpha g^{cs} + e^{cs}) - \frac{1}{2}(1-\chi)s^{cs}\tau(g^{cs})^2
\tag{14}
$$

$$\pi_p^{cs}(p^{cs},e^{cs})=(p^{cs}-w^{cs})(1-p^{cs}+\alpha g^{cs}+e^{cs})-\frac{1}{2}\chi\eta(e^{cs})^2 \tag{15}$$

First of all, the sales platform first determines the sales price, the level of the sales effort, and derives the partial derivation of p^{cs} and e^{cs}, and makes the first derivative equal to zero. The negative definite is proved by hessian, and the optimal solution is obtained.

$$\begin{aligned} p^{cs} &= \frac{-w^{cs}+\chi\eta\left(1+\alpha g^{cs}+w^{cs}\right)}{-1+2\chi\eta} \\ e^{cs} &= \frac{1+\alpha g^{cs}-w^{cs}}{-1+2\chi\eta} \end{aligned} \tag{16}$$

The manufacturer decides the wholesale price w^{cs} and green emission reduction degree g^{cs} of the product through the sales price p^{cs} and sales effort e^{cs} of the sales platform decision. Substitute the above p^{cs} and e^{cs} into the manufacturer's profit function, and derive the partial derivation of w^{cs} and g^{cs}. So that the first-order partial derivative is equal to zero. And through the verification of the hessian matrix, the optimal solution pair can be obtained.

According to the decision of the manufacturer and the sales platform, the government determines the optimal subsidy ratios, that is, we substitute p^{cs},e^{cs},g^{cs} into the total social welfare $SW(s^{cs})$. The final equilibrium solution.

$$\begin{aligned} p^{cs} &= \frac{(-1+\chi)(-1+3\chi\eta)s^{cs}\tau}{\alpha^2\chi\eta+2(-1+\chi)(-1+2\chi\eta)s^{cs}\tau} \\ e^{cs} &= \frac{(-1+\chi)s^{cs}\tau}{\alpha^2\chi\eta+2(-1+\chi)(-1+2\chi\eta)s^{cs}\tau} \\ g^{cs} &= -\frac{\alpha\chi\eta}{\alpha^2\chi\eta+2(-1+\chi)(-1+2\chi\eta)s^{cs}\tau} \\ w^{cs} &= \frac{(-1+\chi)(-1+2\chi\eta)s^{cs}\tau}{\alpha^2\chi\eta+2(-1+\chi)(-1+2\chi\eta)s^{cs}\tau} \\ s^{cs} &= \frac{2\chi(1-2\chi\eta)}{(-1+\chi)(-1+\chi(-2+7\chi\eta))} \end{aligned} \tag{17}$$

5 ANALYSIS

5.1 The Influence of Consumers' Green Preference on Equilibrium Decision-making

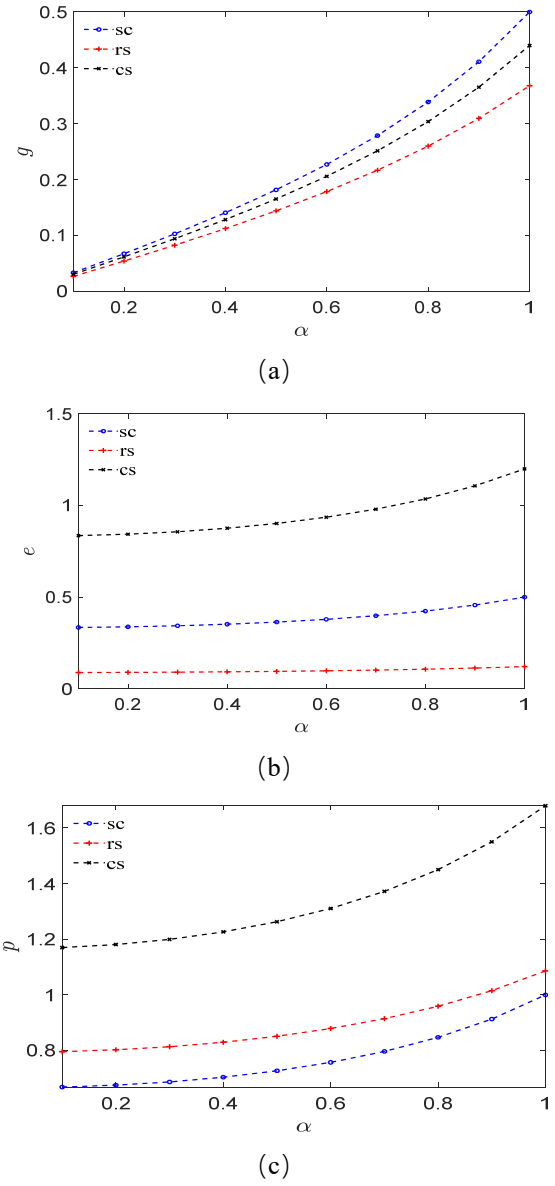

Fig. 1 the influence of consumers' green preference on equilibrium decision

From figure 1, we can know that the sales efforts of the sales platform to the product, the manufacturer's level of the greenness of the product, and the sales price of the product have all

increased with the improvement of consumers' green awareness. $e_{cs} > e_{sc} > e_{rs}$, $g_{sc} > g_{cs} > g_{rs}$, $p_{cs} > p_{rs} > g_{sc}$, In the CS mode, the sales platform has a higher level of effort, which is counterintuitive to our intuition. The possible reason is that in this model, the manufacturer leads and shares the cost of emission reduction with the sales platform, which leads to an increase in the manufacturer's production so that the sales platform chooses a higher level of sales effort to increase product sales to gain higher profits. In the SC mode, the manufacturer's green level of the product is higher than that of the other two modes. The possible explanation is that, in the centralized mode, the manufacturer and the sales platform cooperate fully, and for the sake of the profit of the whole supply chain, the green degree of the product is relatively high, because consumers have a green preference, and the green degree of the product directly affects whether consumers buy or not. Therefore, under the three modes, the stronger consumers' perception of green preference, the higher the greenness level of the product. In addition, the stronger the green awareness of the product, the more willing to pay a higher price to buy the product, so in the three modes, the price of the product increases with the increase of consumers' green preference.

5.2 The Influence of Consumers' Green Preference on Profits

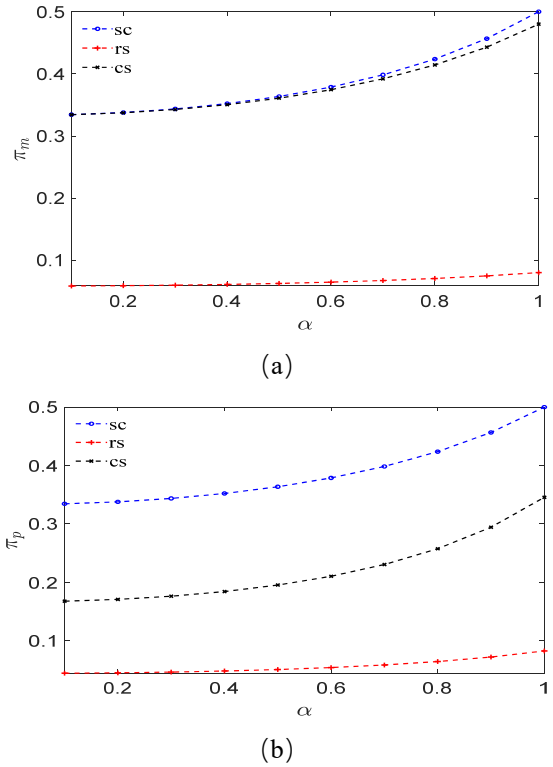

Fig. 2 the influence of consumers' green preference on profits

From figure 2, we know that the profits of manufacturers and sales platforms increase with the increase in consumers' green awareness, and $\pi_m^{sc} > \pi_m^{cs} > \pi_m^{rs}$, $\pi_p^{sc} > \pi_p^{cs} > \pi_p^{rs}$. Our explanation for this is that the increase in consumers' green awareness will lead to an increase in their demand for green products, and consumers are more willing to buy green products than ordinary products. and greener products are more willing to spend more prices to buy, to drive product sales and increase the profits of manufacturers and sales platforms.

5.3 The Influence of Input Cost Coefficient on Profit

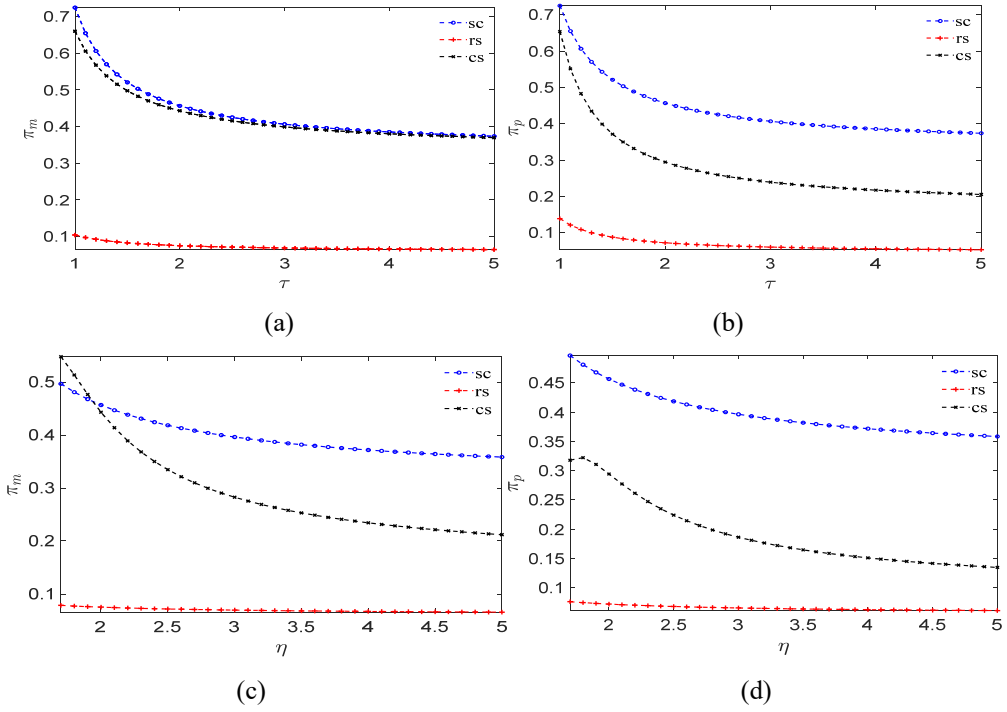

Fig. 3 influence of input cost coefficient on profit

From figure 3, we can see that the profits of manufacturers and sales platforms decrease with the higher green input coefficient $\pi_m^{sc} > \pi_m^{cs} > \pi_m^{rs}$, $\pi_p^{sc} > \pi_p^{cs} > \pi_p^{rs}$. The possible explanation is that the higher the green cost input coefficient, the higher the manufacturer's production cost, the higher the manufacturer's cost, and the lower the manufacturer's overall profit. In addition, we can find from figures (a) and (b) that $\pi_m^{cs} > \pi_p^{cs}$ emissions reduction may be since the government subsidizes manufacturers to reduce emissions and the sales platform shares a certain cost of emission reduction, so that when the emission reduction coefficient decreases, the profit of the manufacturer as a whole is higher than that of the sales platform, which is close to that of the centralized mode.

In addition, the profit of the sales platform decreases with the increase of the input coefficient

of sales efforts, that is $\pi_p^{sc} > \pi_p^{cs} > \pi_p^{rs}$, although the profit of the manufacturer also shows a downward trend with the increase of the input coefficient of sales efforts, it is at a certain threshold η_0 , when $\eta < \eta_0$, $\pi_m^{cs} > \pi_m^{sc} > \pi_m^{rs}$, When the threshold is exceeded, then $\pi_m^{sc} > \pi_m^{cs} > \pi_m^{rs}$. This is because the sales platform bears the manufacturer's emission reduction cost, so when the sales effort input coefficient of the sales platform is higher, the input cost of the sales platform is higher, and when it exceeds a certain threshold, the profit of the sales platform will be lower than that of the SC mode, and with the increase of the input coefficient of sales efforts, the overall profit gap will be more obvious.

6 CONCLUSION

With the increasingly severe form of environment, the cooperation between supply chains plays a more and more important role in the existence and development of enterprises. This paper establishes a two-level supply chain based on a manufacturer and sales platform to explore the impact of government subsidies and sales efforts on enterprise behavior decision-making under three contracts centralized decision-making, revenue-sharing, and cost-sharing. Through the comparative analysis of the model, we try to explain the impact of consumers' green awareness on each equilibrium solution. Through the research, we show that: under the three modes, with the improvement of consumers' green awareness, the green degree of manufacturers, the marketing intensity of the platform, and the sales price of products are also increasing, when the green input technology is high, both manufacturers and sales platforms choose the cost-sharing mode. When the input coefficient of marketing effort is low, the manufacturer chooses the cooperation mode of cost sharing.

This paper has some limitations, which provide a potential direction for future research. We only study a single manufacturer and sales platform. Considering reality, it can be extended to multiple manufacturers and multiple sales platforms in the future.

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