Research on the Impact of Government Multiple Subsidies Policy on the Decision-Making of Green Supply Chain

Shengqiang Hu[1] and Wanyu Yuan[2(✉)]

[1] Research Institute of Innovation Competitiveness of Guangdong, Hongkong and Macao Bay Area, Guangdong University of Finance and Economics, Guangzhou 510320, China

[2] School of Business Administration, Guangdong University of Finance and Economics, Guangzhou 510320, China

Urywy1229@163.com

Abstract. Several governments pay attention to the environment due that getting worse. Gradually, the supply chain has also affiliated this concept. This paper explored the effect of the government's multiple subsidies policy on the GSC's decision-making, including subsidizing manufacturers' green R&D investment and price subsidies for consumers purchasing green products. The study constructed centralized decision-making model and Stackelberg decentralized decision-making game model. And figured out the manufacturer's green degree, wholesale price decision and retailer's price decision under different equilibrium situations, respectively. Further obtained the optimal profit and optimal social welfare of each organization. Research shows social welfare, the greenness of green products and the total supply chain profit will increase when the government makes multiple subsidies. Numerical analysis is used to perform sensitivity of the above outcomes and proposed that the two subsidies' factors are positively correlated with the result.

Keywords: Green Supply Chain · Multiple Subsidies · Stackelberg Game

1 Introduction

With the reduction of resources and the deterioration of environment, people pay great attention to the environmental protection issue. Chinese government made top-level design and overall deployment of an economic system with green and low-carbon circular development. The U.S. government has set its plans to cut emissions. Australia's laws clearly stipulate those violations of environmental laws and regulations are subject to severe penalties.

The supply chain has also introduced the concept of protecting the environment. In 2006, Huawei integrated the green concept into its procurement business and promised to prioritize the purchase of recyclable materials. Lenovo built the company's green supply chain system and "green information display platform". Hewlett-Packard (HP) has set an overall goal of reducing emissions by 10% in 2025 compared to 2015.

Green supply chain (GSC) is gradually formed in social development. Nowadays, it is generally believed that GSC is to minimize the adverse effect on the environment and improve the usage rate of resources [8].

Scholars also continue to research the related issues of GSC. From the perspective of sustainable environment and economy, Jamali et al. studied the green degree and pricing of products that compete with non-green products [7]. Swami et al. focused on the transportation problem in the GSC and studied the optimal decision-making [10]. Given the production process, enterprises face several issues, the government may intervene meantime. To further enhance and promote the GSC, many scholars have studied the strategy of the GSC with government. He et al. deduced the manufacturer's optimal structure, pricing strategy and government's optimal subsidies level by building a model [6]. Su et al. constructed a three-stage game model to consider the influence of fairness preference on the decision-making of dual-channel GSC with government subsidies to manufacturers [9].

Consumers should also be emphasized in GSC. Yang et al. considered consumers' green preference to construct three-game models of GSC under government intervention [13]. Xu et al. created an evolutionary game model in the behavioral selection process between green consumption and GSC [12]. Zhu et al. discussed the changes in the equilibrium results of various factors under three different subsidy strategies [14]. Cao et al. established the Stackelberg game model and researched the decision making of GSC under the non-government subsidy strategy and the single subsidy strategy [4].

Many scholars proposed the government's subsidy policy but did not consider the subsidy for the R&D cost of enterprises [9]. Others considered the subsidies to retailers' behavior or consumers' green purchasing, but do not take the government's cost subsidy policy for manufacturers into account [4, 12]. However, the above literature does not consider or only considers government subsidies unilaterally. Few scholars study the situation that the government subsidizes manufacturers and consumers simultaneously. In fact, government often implements multiple simultaneous subsidies to improve social welfare and enhance development. For example, the state not only subsidizes manufacturers subsidies but also give to consumers to stimulate consumption and revitalize the new energy vehicle industry during the COVID-19 period.

This paper considers the government's multiple subsidies policy and finds that the R&D subsidies to manufacturer should not be too high. We analyze the changes in relevant decision-making and social welfare of each organization with or without subsidies.

The rest of this paper: Sect. 2 describes the problem and hypotheses. Section 3 and Sect. 4 shows the model solution and analysis. Numerical analysis and discussion are displayed in Sect. 5. Section 6 provides our conclusion and outlook.

2 Problems Description and Notations Definition

We take the secondary GSC composed of a single manufacturer and a single retailer as research object. Manufacturer and retailer are risk-neutral and completely rational. Under centralized decision-making, manufacturer and retailer aim at maximizing the supply chain's interests. Retailer is follower while manufacturer is dominant, both parties seek

its own profit in Stackelberg game. Green products on the market are utterly replaceable with ordinary products, but clients are susceptive to the greenness and price of products. Manufacturer requires more investment to product green goods and the cost is $\frac{1}{2}hg^2$ [1]. Government subsidizes manufacturer according to the greenness degree of green products. To stimulate clients to buy green products, government provides price subsidies to clients who purchase green products [3]. Assumptions as follow:

(1) Clients are susceptive to the price of green products than to the greenness, i.e., $b > \beta > 0$. The market demand is $D = a - bp + \beta g$ when no government subsidies [11].
(2) Consumers are more willing to buy green products when the retail price of green products is low and the greenness is high. There is $p > \omega > c > 0$, $D > 0$.
(3) R&D costs are fully borne by the manufacturer. To ensure whole value is more realistic, take $h > \frac{-s\beta^2}{2(a-bc-bs)}$.
(4) The social welfare formula is $SW(s, t) = \frac{1}{2}D^2$ [5]. According to the above assumptions, we can know that $SW(s, t) = \frac{1}{2}(a - bp + \beta g)^2$.
(5) Notations

Notations	Definition
p	Retail price of green products ($p > 0$)
ω	Wholesale price of green products ($p > \omega > 0$)
c	Unit production cost of green products ($p > \omega > c > 0$)
a	Potential total market demand for green products
b	Consumer sensitivity to retail price
β	Consumer sensitivity to greenness ($b > \beta$)
h	Green Investment Coefficient (large enough to represent the investment coefficient)
g	Greenness of green products ($g > 0$)
s	The government subsidizes the unit price of consumers to buy green products ($p > s > 0$)
t	Proportion of government subsidies for manufacturers' R&D costs
D	The market demand
π_m	The profit of manufacturer
π_r	The profit of retailer
π_{sc}	The overall profit of the supply chain

3   Model Construction and Analysis Without Subsidies

On account of the above settings, profit function of each node without subsidies as follows:

$$\pi_m = (\omega - c)(a - bp + \beta g) - \frac{1}{2}hg^2 \qquad (1)$$

$$\pi_r = (p - \omega)(a - bp + \beta g) \qquad (2)$$

$$\pi_{sc} = (p - c)(a - bp + \beta g) - \frac{1}{2}hg^2 \qquad (3)$$

3.1   Centralized Decision Model Without Subsidies (CDUS)

Without subsidies, the node in the supply chain pursues the overall pursuit of profit maximization based on centralized decision-making. According to Eq. (3), the vertical game model is constructed:

$$\max_{p,g} \pi_{sc} = (p - c)(a - bp + \beta g) - \frac{1}{2}hg^2 \qquad (4)$$

Proposition 1: Under CDUS, manufacturer and retailer pursue overall profit maximization through cooperation, and the relevant decision-making result is (the upper right superscript * indicates the optimal solution):

$$p^* = \frac{ah - c\beta^2 + bch}{2bh - \beta^2} \qquad (5)$$

$$g^* = \frac{(a - bc)\beta}{2bh - \beta^2} \qquad (6)$$

$$\pi_{sc}^* = \frac{h(a - bc)^2}{2(2bh - \beta^2)} \qquad (7)$$

$$SW^* = \frac{b^2 h^2 (a - bc)^2}{2(2bh - \beta^2)^2} \qquad (8)$$

3.2   Decentralized Decision Model Without Subsidies (DDUS)

Under DDUS, each node in the supply chain pursues its own profit maximization to play the Stackelberg game. The game model under DDUS is as follows:

$$\begin{cases} \max\limits_{g,\omega} \pi_m = (\omega - c)(a - bp + \beta g) - \frac{1}{2}hg^2 \\ s.t. \max\limits_{p} \pi_r = (p - \omega)(a - bp + \beta g) \end{cases} \qquad (9)$$

Proposition 2: Under DDUS, the relevant decision-making results are as follows (the upper right mark ^{d} represents the optimal solution):

$$\omega^d = \frac{2ah - c\beta^2 + 2bch}{4bh - \beta^2} \tag{10}$$

$$g^d = \frac{(a - bc)\beta}{4bh - \beta^2} \tag{11}$$

$$p^d = \frac{3ah - c\beta^2 + bch}{4bh - \beta^2} \tag{12}$$

$$\pi_m^d = \frac{h(a - bc)^2}{2(4bh - \beta^2)} \tag{13}$$

$$\pi_r^d = \frac{bh^2(a - bc)^2}{(4bh - \beta^2)^2} \tag{14}$$

$$\pi_{sc}^d = \pi_m^d + \pi_r^d = \frac{h(6bh - \beta^2)(a - bc)^2}{2(4bh - \beta^2)^2} \tag{15}$$

$$SW^d = \frac{b^2h^2(a - bc + bs)^2}{2(4bh - \beta^2)^2} \tag{16}$$

Corollary 1: The retail price of products under DDUS is higher than that under CDUS while the product greenness and overall supply chain profit under DDUS are lower than those under CDUS.

4   Model Construction and Analysis with Subsidies

Model with multiple government subsidies is constructed (the right subscript s represents the government subsidies), as Eqs. (17)–(19):

$$\pi_{ms} = (\omega - c)\big[a - b(p - s) + \beta g\big] - \frac{1 - t}{2}hg^2 \tag{17}$$

$$\pi_{rs} = (p - \omega)\big[a - b(p - s) + \beta g\big] \tag{18}$$

$$\pi_{scs} = (p - c)\big[a - b(p - s) + \beta g\big] - \frac{1 - t}{2}hg^2 \tag{19}$$

4.1   Centralized Decision Model with Subsidies (CDS)

An optimization model under CDS is constructed according to Eq. (19):

$$\max_{p,g} \pi_{scs} = (p - c)\big[a - b(p - s) + \beta g\big] - \frac{1 - t}{2}hg^2 \tag{20}$$

Proposition 3: Under CDS, manufacturer and retailer pursue the maximization of overall profits through cooperation and the relevant decision-making results are (the right sign $^*_s$ represents the optimal solution):

$$p^*_s = \frac{(1-t)h(a - bc + bs) - c\beta^2}{2(1-t)bh - \beta^2} \tag{21}$$

$$g^*_s = \frac{(a - bc + bs)\beta}{2(1-t)bh - \beta^2} \tag{22}$$

$$\pi^*_{scs} = \frac{(1-t)h(a - bc + bs)^2}{2[2bh(1-t) - \beta^2]} \tag{23}$$

$$SW^*_s = \frac{b^2h^2(1-t)^2(a - bc + bs)^2}{2[2bh(1-t) - \beta^2]^2} \tag{24}$$

Corollary 2: When $0 \le t < 1 - \frac{\beta^2}{2bh}$, with the accretion of subsidies under CDS, the social welfare, greenness, price, overall profit of the supply chain will increase accordingly.

4.2 Decentralized Decision Model Without Subsidies (DDS)

The game model under DDS is constructed as:

$$\begin{cases} \max_{g,\omega} \pi_{ms} = (\omega - c)[a - b(p - s) + \beta g] - \frac{1-t}{2}hg^2 \\ s.t. \max_p \pi_{rs} = (p - \omega)[a - b(p - s) + \beta g] \end{cases} \tag{25}$$

Proposition 4: When $s > \frac{c\beta^2 - 2h(1-t)(a+bc)}{2bh(1-t)}$, $0 \le t < 1 - \frac{\beta^2}{4bh}$, the relevant results under DDS are shown in Eq. (26)–(32) (the right label ^d_s represents the optimal solution).

$$\omega^d_s = \frac{2(1-t)ah - c\beta^2 + 2(1-t)bch + 2(1-t)bsh}{4(1-t)bh - \beta^2} \tag{26}$$

$$g^d_s = \frac{(a - bc + bs)\beta}{4(1-t)bh - \beta^2} \tag{27}$$

$$p^d_s = \frac{3(1-t)ah - c\beta^2 + (1-t)bch + 3(1-t)bsh}{4(1-t)bh - \beta^2} \tag{28}$$

$$\pi^d_{ms} = \frac{(1-t)h(a - bc + bs)^2}{2[4(1-t)bh - \beta^2]} \tag{29}$$

$$\pi^d_{rs} = \frac{(1-t)^2bh^2(a - bc + bs)^2}{[4(1-t)bh - \beta^2]^2} \tag{30}$$

$$\pi^d_{scs} = \pi^{d*}_{ms} + \pi^{d*}_{rs} = \frac{(1-t)h(a - bc + bs)^2[6bh(1-t) - \beta^2]}{2[4(1-t)bh - \beta^2]^2} \tag{31}$$

Table 1. Optimal parameters under each model

Model	ω	p	g	π_m	π_r	π_{sc}	SW
CDUS	–	561.54	46.15	–	–	415384.62	426035.50
DDUS	555.70	783.54	22.78	205063.29	103829.51	308892.81	128184.59
CDS	–	618.52	74.07	–	–	518518.52	537722.91
DDS	609.09	863.64	36.36	254545.45	129586.78	384132.23	129586.78

$$\text{SW}_s^d = \frac{b^2 h^2 (1-t)^2 (a - bc + bs)^2}{2[4bh(1-t) - \beta^2]^2} \tag{32}$$

Corollary 3: Under the DDS, the retail price of the product is higher than that under CDS. However, the product greenness, the profit of the supply chain and the social welfare under DDS are lower than those under CDS.

Corollary 4: Compared with no subsidies, social welfare, the greenness of products, the retail and wholesale price increase with multiple subsidies under DDS. But in this case, consumers will still buy green products due to government subsidies. So, the profits of manufacturer, retailer and the entire supply chain have been improved.

5 Numerical Analysis and Discussion

Assumed the relevant parameters of this secondary GSC are set as $a = 2000$, $b = 2$, $\beta = 1$, $h = 10$, $c = 100$, $s = 100$, $t = 0.2$ in reference [11]. Obtained according to each proposition, get Table 1.

It can be seen from Table 1 that the retail price of green products under DCUS is higher than under CDUS. However, the greenness of products and the overall profit of the supply chain under DDUS are lower than those under CDUS. When the government conducts multiple subsidies, the conclusion is the same. Compared with no subsidies, and the retail price, greenness, overall profit of the supply chain and social welfare of green products all increase in the government's multiple subsidies.
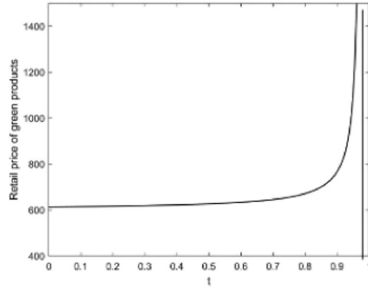
To further explore how each equilibrium decision is affected, we use MATLAB to make diagrams and the specific content is as follows. When $s = 100$ is controlled, the trend of parameters under CDS is shown in Fig. 1 (including Fig. 1-a-Fig. 1-c).

It can be seen from Fig. 1 that under CDS and DDS, when t is less than the critical value, the decision results will increase with the increase of t when the control s value is constant. Once t exceed a certain defined value, the greenness and the profit of the supply chain will be negative which indicates that the government's R&D subsidies to manufacturer should not be too high, otherwise the effect of subsidies will be counterproductive.
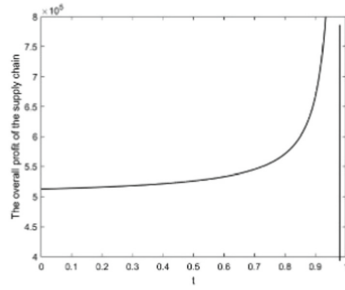
When considering the effects of s and t at the same time, MATLAB is used to draw a graph to explore the changing trend of parameters in DDS are shown in Fig. 2 (including Fig. 2-a-Fig. 2-e).
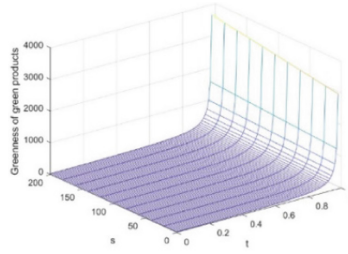
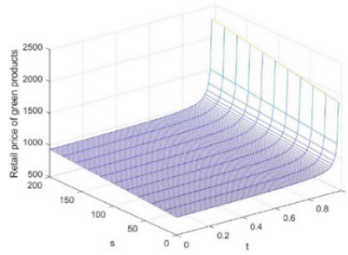(a) Trend of greenness

(b) Trend of retail price

(c) Trend of the overall profit of the supply chain

Fig. 1. Trend of parameters with t under CDS when controlling $s = 100$
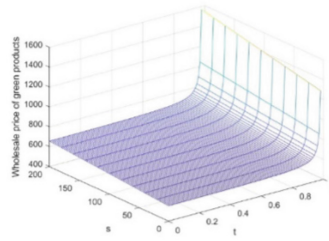
It's known that the equilibrium results increase with the increase of s and t whether under CDS or DDS from Fig. 2. The amount paid by consumers under the multiple government subsidies is $(p - s)$. Consumers' desire to purchase green products is stimulated with multiple subsidies. Under multiple subsidies, each node organization in the supply chain obtains greater profits. The subsidies to manufacturer under multiple subsidies have various effects on the overall benefit. When t is less than the critical value, each decision result will increase with the increase of t. Compared with a single price subsidy, the benefits are superimposed. But when t is greater than the critical value, even within the initial range $0 < t < 1$, it will still make the whole subsidies policy meaningless. It also can be concluded that the proportion of the government's green
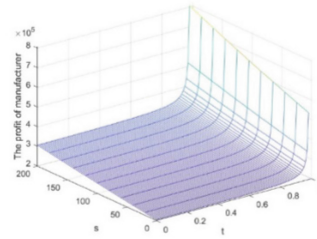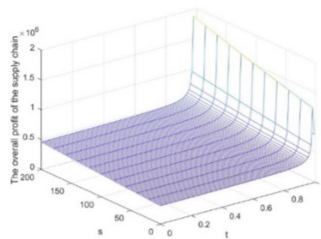
(a) Trend of greenness

(b) Trend of retail price

(c) Trend of wholesale price

(d) Trend of the profit of manufacturer

(e) Trend of the overall profit of the supply chain

Fig. 2. Trend diagram of parameters under DDS when *s* and *t* act together

R&D cost subsidies to manufacturer should not be too high, or else, the subsidies effect will be counterproductive.

6   Conclusion and Outlook

For the GSC, we considered the multiple subsidies that the government subsidizes the green R&D investment of manufacturer and subsidizes the price of consumers purchasing green products. Contrasted the differences in model construction and equilibrium decision-making under centralized decision-making and decentralized decision-making with or without multiple subsidies. Further analyzed the influence of multiple subsidies on the equilibrium decision-making of each organization. Under the multiple subsidies, consumers' willingness, the greenness, social welfare and the profit of the supply chain has been greatly improved under CDS. At the time of DDS, the profit of each node and the social welfare also improve.

We suggested that when the government implements multiple subsidies policy, the proportion of R&D subsidies to manufacturer should not be too high regardless of whether it is decentralized or centralized decision-making, otherwise the subsidies effect will be counterproductive. At the same time, the subsidies coefficient of the price subsidies for consumers should also meet a certain range. When s and t are the given regions, the equilibrium results will increase with the increase of s and t.

From the perspective of promoting the development of GSC, this paper aims to further promote GSC. On this basis, the following policy suggestions are put forward: (1) The government should not give manufacturer too much green R&D cost subsidies. (2) The government should consider subsidies in many aspects. For example, the multiple subsidies proposed in this paper is more beneficial than a single subsidy. (3) The government should further build GSC supervision system to prevent companies from abusing subsidies.

For the research questions of this paper it's extensible to consider the risk preference of the manufacturer or retailer what impact will it have on the decision-making result under the multiple government subsidies.

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