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Research on Game Strategy of Green Supply Chain under Different Subsidy Policies

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Abstract: *This paper discusses the retailer-manufacturer Stackelberg model under the background of green supply chain. The manufacturer needs to decide product green degree and the retailer needs to determine green promotion levels. This study considers the optimal decision-making, profit and social welfare of each member of the supply chain under the three decision scenarios: government does not subsidize, government subsidizes manufacturers, and government subsidizes retailers, in order to provide reference for the government to promote the implementation of green supply chain strategies. The results show that government subsidies have a positive effect on the implementation of green supply chains. Moreover, the government's strategy of subsidizing manufacturers will improve the product green degree, social welfare, and the profits of manufacturers and retailers. And the strategy of subsidizing manufacturers is shown to be better through comprehensive analysis. When consumers' preference for green products is low, the green promotion level is highest when retailers are subsidized, but the unit subsidy gain of social welfare is greater when manufacturers are subsidized.*

Keywords: *Green supply chain, Stackelberg game model, Government subsidies.*

1. Introduction

The issue of global warming is one of the most severe challenges facing human society in the 21st century. With the rapid growth of economy, a large amount of petrochemical energy has been consumed, causing serious environmental pollution. Under the circumstances, green supply chain was proposed by the Michigan State University Manufacturing Research Association as early as 1996, which emphasizes the minimization of environmental impact and the maximization of resource efficiency in the entire product life cycle. Scholars have begun to carry out related research in the field of green supply chain management over the years. Studies found that companies have encountered many obstacles in the process of developing and implementing green supply chains, such as increased corporate burden, insufficient technical support, information asymmetry, and cultural differences, etc. Therefore, the government often offers subsidies to the enterprises or consumers to encourage the optimization of green supply chain strategies from the perspectives of process improvement, carbon emission reduction, and pollution emissions. For example, Jiayi et al. [1] studied the form of government subsidies for basic commodities. They explored the consumer welfare and manufacturer's profit under three scenarios: government subsidizes consumers only, manufacturers only, or both, and showed the optimal subsidy plans in different environments. Jonathan et al. [2] studied how the timing of government subsidies for consumers to purchase green products affects the promotion of green technologies. Maxime C. et al. [3] studied how government subsidies for green technologies affect the production and pricing decisions of suppliers when demand is uncertain. Other related researches include Dmitry [4], Kelly [5], Sangeeta [6], etc. In addition to government subsidies, manufacturers and retailers will adopt cooperative emission reduction strategies in response to consumers' preference for green products. Hui Li et al. [7] studied the impact of manufacturers' carbon emission reduction levels and retailers' low-carbon promotion efforts on the closed-loop supply chain in one case of non-cooperative game and three cases of cooperative game. Tao Li et al. [8] studied the impact of revenue sharing and cost sharing contracts provided by retailers on emission reduction efforts and corporate profitability.

More relevant studies have shown that the improvement of consumer environmental awareness is helpful to the implementation of green supply chain management strategies. For example, Liu [9] pointed out that the improvement of consumer environmental awareness can benefit highly environmentally friendly companies; Ghosh and Shah [10-11] studied the optimal strategy when product pricing and greenness are affected by consumers' environmental awareness. In fact, the improvement of consumers'

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environmental awareness is a gradual process. In addition to the guidance of the government, retailers need to make more promotion efforts in the promotion of green products. Most of the existing studies considered the case of providing subsidies to manufacturers and consumers, and few considered offering subsidies to retailers for green promotion. In addition, the existing research on green supply chain mostly considers the dominant position of manufacturers, but actually it is not uncommon for retailers to dominate in practice. For example, Wal-Mart formulated a "sustainable development" strategy as early as 2005, and begin to formulate a sustainable production evaluation plan for its global food procurement network suppliers in 2011, in order to establish a green corporate image from all aspects, and to make continuous efforts to actively implement green marketing. In summary, under the retailer-dominated market condition, this paper discusses the optimal supply chain strategy and social welfare of the three subsidy policies: no subsidy, subsidizing manufacturers, and subsidizing retailers, expecting to provide a reference for the government, retailers and manufacturers to implement green supply chain strategies.

2. Problem Description

In a two-stage supply chain composed of a single manufacturer and a single retailer, the retailer occupies a dominant position. Considering that consumers have a preference for green products, manufacturers and retailers are willing to increase consumer preference for products through research and development of the green products and green promotion. In order to encourage the production and sales of green products, the government will launch a green product subsidy policy. This paper mainly considers the impact of different subsidy strategies on the profits of all parties in the supply chain under three different cases: no subsidy, subsidizing manufacturers, and subsidizing retailers. The manufacturer produces a green product, mainly by developing new technologies and introducing new equipment to reduce the impact on the environment during the production process. Assume that w is the wholesale price of the product produced by the manufacturer, and e is the green degree ($w, e > 0$). As consumers have a certain preference for green products, retailers will invest in the advertisement or other measures for green promotion, thereby increasing the sales of green products. Suppose the retailer's selling price is p, and the green promotion effort level is z. It should be noted that the cost coefficient of both green quality input and green investment effort are assumed to be 1 in this study. The reason is that according to many literatures, although the cost coefficient is considered, it has been found that the cost coefficient and green degree and profit is always negatively correlated, that is, the larger the cost coefficient, the lower the manufacturer's green production motivation, and the profit will be reduced then. For simplicity, only the case where the cost coefficient is 1 is taken into discussion. Similarly, we standardize the manufacturer's unit cost c to 0, which will not affect the overall conclusion of this study.

As market demand is affected by the price, green degree and green promotion level of the product, the demand function is assumed as $D = a - p + k(e + z)$, where a represents the potential market demand, $(e + z)$ represents the green level of the product perceived by consumers, and k represents consumers' preference for green products. The higher the green degree of the product produced by the manufacturer, the higher the R&D cost it needs to invest in. Set the manufacturer's cost function as e^2, which means that the green degree of the product will be increased to e with the input cost e^2. The higher the green promotion level of the product, the higher the cost the retailer has to pay. Let z^2 denotes the retailer's green promotion cost, and w denotes the wholesale price per unit paid by the retailer to the manufacturer. The retailer's cost function is $wD + z^2$. Referring to the description of social welfare by Zhou Yanju [12], this paper assumes that the total government revenue is $SW = CS + \pi - GS + seD$, which is composed of consumer surplus CS, total supply chain profit π, government subsidy amount GS, and the government's preference for product greenness eD, that is, the total social welfare. When the demand is 0, $\check{p} = a + k(e + z)$, then the consumer surplus is expressed as $CS = (\check{p} - p)D/2$. The total profit of the supply chain is the sum of the retailer's profit π_M and the manufacturer's profit π_R. The amount of government subsidies is related to the subsidy coefficient t. eD represents the degree of improvement of the environmental quality level. The higher the green degree e of the product, the higher the degree of environmental improvement. Let A_j^i denote the variable expressions under each subsidy case, where $i \in \{M, R\}$ represents the manufacturer and retailer respectively, and $j \in \{N, M, R\}$ respectively represent three cases: no subsidy, subsidizing manufacturers, and subsidizing retailers. In order to simplify and clearly describe the problem, the following assumptions are made. (1) The information between the manufacturer and the retailer is completely symmetrical. (2) Considering the profit-seeking between manufacturers and retailers, set $p > w$. (3) Consumers have a preference for green products, and this preference should be within a reasonable range based on the actual situation.

Related symbols and their meanings are shown in Table 1.

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Table 1 : Symbols and description.

Symbol	Description
w	Wholesale price
p	Retailer selling price
m	Retailer margin
e	Product green degree
z	Green promotion effort level
a	Potential market demand
k	Consumers' preference for green products
t	Government subsidy coefficient

3. Model

3.1. No subsidy (model N)

When the government does not provide subsidies, the decision-making process is divided into two stages. In the first stage, the retailer determines its marginal profit m and green promotion effort level z. In the second stage, the manufacturer determines its wholesale price w and product green degree e by following the retailer's decision. According to the assumption that consumer preference is within a reasonable range, let $0 < k < \sqrt{\frac{8}{3}}$. When the government does not subsidize, the profit function and social welfare of manufacturers and retailers are shown in equations (1)(2)(3).

$$\begin{cases} \pi_N^M(w_N, e_N) = w_M(a - m_N - w_N + ke_N + kz_N) - {e_N}^2 \\ s.t.\ {e_N}^* > 0, {w_N}^* > 0 \end{cases} \tag{1}$$

$$\begin{cases} \pi_N^R(m_N, z_N) = m_N(a - m_N - w_N + ke_N + kz_N) - {z_N}^2 \\ s.t.\ {m_N}^* > 0, {z_N}^* > 0 \end{cases} \tag{2}$$

$$SW_N = CS_N + \pi_N - GS_N + e_N D_N \tag{3}$$

Lemma 1. The manufacturer's best wholesale price is ${w_N}^* = \frac{2a}{8-3k^2}$ and product green degree is ${e_N}^* = \frac{ak}{8-3k^2}$. The retailer's optimal profit margin is ${m_N}^* = \frac{a(4-k^2)}{8-3k^2}$ and the green promotion effort level is ${z_N}^* = \frac{ak}{8-3k^2}$.

Proposition 1. Substituting Lemma 1 into the price and profit function of the manufacturer and retailer as well as the social welfare function, ${p_N}^* = \frac{a(6-k^2)}{8-3k^2}$, $\pi_N^M = \frac{a^2(4-k^2)}{(8-3k^2)^2}$, $\pi_N^R = \frac{a^2}{8-3k^2}$, ${SW_N}^* = \frac{2a^2(7-2k^2+k)}{(8-3k^2)^2}$ is obtained.

Proposition 2. The optimal solution ${w_N}^*, {p_N}^*, {z_N}^*, {e_N}^*$ and profit function $\pi_N^{M^*}, \pi_N^{R^*}$, social welfare ${SW_N}^*$ all increase with consumers' green preference k. And the positive effects of k on the optimal product green degree ${e_N}^*$ and the optimal promotion level ${z_N}^*$ are the same.

Proposition 2 shows that the higher the consumer's green preference, the higher the profits of manufacturers and retailers, and the higher the social welfare. The main reason is that consumers' green preference improves the green degree of products and the green promotion level, so that the wholesale and sales prices are at a high value, leading to increased profits.

Proposition 3. If $0 < k < \sqrt{\frac{4}{3}}$, then the retailer's optimal profit growth rate will be higher than that of the manufacturer; if $\sqrt{\frac{4}{3}} < k < \sqrt{\frac{8}{3}}$, then the manufacturer's optimal profit growth rate will be higher than that of retailers.

Proposition 3 shows that when consumers have a low green preference, the retailer's profit growth rate is higher than that of the manufacturer, and vice versa. Consumers may be divided into low preference type and high preference type. According to the analysis of the actual situation, low preference consumers are less concerned about the greenness of the product, and they generally make purchase decisions directly based on the green promotion of the retailer, instead of taking actively investigating

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the real situation of the green degree of the product. Hence, the increase in green preference has a greater positive impact on retailers, and vice versa.

3.2. Subsidizing the Manufacturer (model M)

In this model, the government subsidizes the manufacturer to improve the product green degree, and the product subsidy per unit is set as te, and the decision-making process is divided into two stages. In the first stage, the retailer determines its marginal profit m and green promotion effort level z. In the second stage, the manufacturer decides its wholesale price w and product green degree e by following the retailer's decision. According to the assumption that consumer preference is within a reasonable range, let $0 < k < \frac{\sqrt{2(12-t^2)}-2t}{3}$. Each decision variable is related to the government subsidy coefficient t. When the government subsidizes the manufacturer, the profit function and social welfare of the manufacturer and retailer are shown in equations (4) (5) (6).

$$\begin{cases} \pi_M^M(w_M, e_M) = (w_M + te_M)(a - m_M - w_M + ke_M + kz_M) - {e_M}^2 \\ s.t.\ {e_M}^* > 0, {w_M}^* > 0 \end{cases} \tag{4}$$

$$\begin{cases} \pi_M^R(m_M, z_M) = m_M(a - m_M - w_M + ke_M + kz_M) - {z_M}^2 \\ s.t.\ {m_M}^* > 0, {z_M}^* > 0 \end{cases} \tag{5}$$

$$SW_M = CS_M + \pi_M - GS_M + e_M D_M \tag{6}$$

Lemma 2. The retailer's optimal selling price is $\boldsymbol{{p_M}^* = \frac{a(2+k(1-t)+t-t^2)}{8-3k^2-4kt-2t^2}}$ and green promotion effort level is $\boldsymbol{{z_M}^* = \frac{ak}{8-3k^2-4kt-2t^2}}$. The manufacturer's optimal wholesale price is $\boldsymbol{{w_M}^* = \frac{a(2-kt-t^2)}{8-3k^2-4kt-2t^2}}$ and product green degree is $\boldsymbol{{e_M}^* = \frac{a(k+t)}{8-3k^2-4kt-2t^2}}$. Thus, the manufacturer's profit is $\boldsymbol{\pi_M^{M^*} = \frac{a^2(4-k^2-2kt-t^2)}{(8-3k^2-4kt-2t^2)^2}}$, the retailer's profit is $\boldsymbol{\pi_M^{R^*} = \frac{a^2}{8-3k^2-4kt-2t^2}}$, and the social welfare is $\boldsymbol{{SW_M}^* = \frac{a^2(14-4k^2+2k(1-4t)+2t-5t^2)}{(8-3k^2-4kt-2t^2)^2}}$.

Proposition 4. $\boldsymbol{{e_M}^*, {z_M}^*, {p_M}^*, {w_M}^*, \pi_M^{M^*}, \pi_M^{R^*}, {SW_M}^*}$ all increase with the government subsidy coefficient t.

Proposition 4 shows that with the increase of the government subsidy coefficient, the profits of the manufacturer and retailer increase. The main reason is that government subsidies have reduced the costs of manufacturers and retailers to some extent, thus making them more willing to improve product green degree and green promotion level. Consumers' preference for greenness makes the wholesale and sales prices at a high level, leading to increased profits. In addition, the increase in the government subsidy coefficient will lead to an increase in social welfare.

Proposition 5. $\boldsymbol{{e_M}^*, {z_M}^*, {p_M}^*, \pi_M^{M^*}, \pi_M^{R^*}, {SW_M}^*}$ are all increasing functions of consumers' green preferences k. With the increase of consumers' green preference k, $\boldsymbol{{w_R}^*}$ decreases when $\boldsymbol{0 < k < \frac{6-3t^2-\sqrt{3}\sqrt{12-12t^2+t^4}}{3t}}$, and increases when $\boldsymbol{\frac{6-3t^2-\sqrt{3}\sqrt{12-12t^2+t^4}}{3t} < k < \frac{\sqrt{24-2t^2}-2t}{3}}$.

Proposition 5 shows that the higher the consumer's green preference, the higher the profit, product green degree and green promotion level of manufacturers and retailers. It is worth noting that with the increase in consumers' green preference, the product price will continue to be improved, but the product wholesale prices will decrease first and then increase. In addition, the increase of consumers' green preference will lead to the increase of social welfare.

3.3. Subsidizing the Retailer (model R)

In this model, the government subsidizes the retailer to improve its green promotion, and the product subsidy per unit is set as tz. The decision-making process is divided into two stages. In the first stage, the retailer decides its marginal profit m and the green promotion effort level z. In the second stage, the manufacturer decides its wholesale price w and product green degree e by following the retailer's decision. According to the assumption that consumer preference is within a reasonable range, let $0 < k < \frac{\sqrt{2(12-t^2)}-t}{3}$. Each decision variable is related to the government subsidy coefficient t. When the

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government subsidizes the manufacturer, the profit function and social welfare of the manufacturer and retailer are shown in equations (7) (8) (9).

$$\begin{cases}\pi_R^M(w_R, e_R) = w_R(a - m_R - w_R + ke_R + kz_R) - {e_R}^2 \\ s.t.\, {e_R}^* > 0, {w_R}^* > 0\end{cases} \tag{7}$$

$$\begin{cases}\pi_R^R(m_R, z_R) = (m_R + tz_R)(a - m_R - w_R + ke_R + kz_R) - {z_R}^2 \\ s.t.\, {m_R}^* > 0, {z_R}^* > 0\end{cases} \tag{8}$$

$$SW_R = CS_R + \pi_R - GS_R + se_R D_R \tag{9}$$

Lemma 3. The retailer's optimal selling price is ${p_R}^* = \frac{a(6-k^2-kt-t^2)}{8-3k^2-2kt-t^2}$ and green promotion effort level is ${z_R}^* = \frac{a(k+t)}{8-3k^2-2kt-t^2}$. The manufacturer's optimal wholesale price is ${w_R}^* = \frac{2a}{8-3k^2-2kt-t^2}$ and product green degree is ${e_R}^* = \frac{ak}{8-3k^2-2kt-t^2}$. Thus, the manufacturer's profit is $\pi_R^{M^*} = \frac{a^2(4-k^2)}{(8-3k^2-2kt-t^2)^2}$, the retailer's profit is $\pi_R^{R^*} = \frac{a^2}{8-3k^2-2kt-t^2}$, and the social welfare is ${SW_R}^* = \frac{a^2(14-4k^2+2k(1-2t)-3t^2)}{(8-3k^2-2kt-t^2)^2}$.

Proposition 6. ${e_R}^*, {z_R}^*, {p_R}^*, {w_R}^*, \pi_R^{M^*}, \pi_R^{R^*}, {SW_R}^*$ all increase with the government subsidy coefficient t.

Proposition 6 is similar to Proposition 4, indicating that no matter which subsidy strategy the government adopts, the increase in the subsidy coefficient will lead to the improvement of social welfare and the profits of the two members in the supply chain.

Proposition 7. ${e_R}^*, {z_R}^*, {p_R}^*, {w_R}^*, \pi_R^{M^*}, \pi_R^{R^*}, {SW_R}^*$ increase with consumers' green preference k.

Proposition 7 is similar to the conclusion of Proposition 5. It should be noted that when the government adopts the strategy of subsidizing retailers, the increase in consumers' green preference k will lead to the steady growth of wholesale price ${w_R}^*$, which is different from the conclusion obtained in Proposition 5 that the wholesale price first decreases and then increases with k.

4. Analyze

According to the analysis in the previous section, the range of k is obtained to be $0 < k < \frac{\sqrt{2(12-t^2)}-2t}{3}$ by finding the intersection of all the assumptions. The optimal strategies and profit functions of the manufacturer and retailer under the three scenarios are obtained, as shown in Table 2.

Table 2: Equilibrium solutions and profits of three models.

Symbol	Model N	Model M	Model R
w	$\frac{2a}{8-3k^2}$	$\frac{a(2-kt-t^2)}{8-3k^2-4kt-2t^2}$	$\frac{2a}{8-3k^2-2kt-t^2}$
e	$\frac{ak}{8-3k^2}$	$\frac{a(k+t)}{8-3k^2-4kt-2t^2}$	$\frac{ak}{8-3k^2-2kt-t^2}$
p	$\frac{a(6-k^2)}{8-3k^2}$	$\frac{a(2+k(1-t)-t+t^2)}{8-3k^2-4kt-2t^2}$	$\frac{a(6-t^2-k^2-kt)}{8-3k^2-2kt-t^2}$
z	$\frac{ak}{8-3k^2}$	$\frac{ak}{8-3k^2-4kt-2t^2}$	$\frac{a(k+t)}{8-3k^2-2kt-t^2}$
π_M	$\frac{a^2(4-k^2)}{(8-3k^2)^2}$	$\frac{a^2(4-k^2-2kt-t^2)}{(8-3k^2-4kt-2t^2)^2}$	$\frac{a^2(4-k^2)}{(8-3k^2-2kt-t^2)^2}$
π_R	$\frac{a^2}{8-3k^2}$	$\frac{a^2}{8-3k^2-4kt-2t^2}$	$\frac{a^2}{8-3k^2-2kt-t^2}$
SW	$\frac{2a^2(7-2k^2+k)}{(8-3k^2)^2}$	$\frac{a^2(14-4k^2+2k(1-4t)+2t-5t^2)}{(8-3k^2-4kt-2t^2)^2}$	$\frac{a^2(14-4k^2+2k(1-2t)-3t^2)}{(8-3k^2-2kt-t^2)^2}$

Proposition 8. ${e_M}^* > {e_R}^* > {e_N}^*$. When $0 < k < \frac{\sqrt{160-15t^2}-5t}{10}$, then ${z_R}^* > {z_M}^* > {z_N}^*$; when $\frac{\sqrt{160-15t^2}-5t}{10} < k < \frac{\sqrt{2(12-t^2)}-2t}{3}$, then we have ${z_M}^* > {z_R}^* > {z_N}^*$.

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Proposition 8 shows that compared with the scenario where the government does not provide subsidies (model N), the optimal product green degree and green promotion level of the two scenarios with government subsidies (model M and model R) are improved, indicating that government subsidies have a positive effect on the improvement of product green degree and green promotion level. The green degree of products is the highest when the government directly subsidizes manufacturers, which shows that it is more effective for the government to subsidize manufacturers than to subsidize retailers in improving product green degree. When consumers' preference for green products is low, the level of green promotion is the highest when subsidizing retailers, and vice versa.

Proposition 9. $\pi_M^{M^*} > \pi_R^{M^*} > \pi_N^{M^*}$; $\pi_M^{R^*} > \pi_R^{R^*} > \pi_N^{R^*}$; $SW_M{}^* > SW_R{}^* > SW_N{}^*$; When $0 < k < \frac{1-t}{2}$, $\overline{SW}_M^* > \overline{SW}_R^*$; When $\frac{1-t}{2} < k < \frac{\sqrt{2(12-t^2)}-2t}{3}$, $\overline{SW}_M^* < \overline{SW}_R^*$.

Proposition 9 indicates that when the government provides subsidies, social welfare and the profits of manufacturers and retailers have a certain increase. And the government's strategy of subsidizing manufacturers will make social welfare as well as the profits of manufacturers and retailers higher. Therefore, it is obvious that the strategy of subsidizing manufacturers is better. When the consumers' preference is low, the unit subsidy gain of social welfare is greater when subsidizing the manufacturer than subsidizing the retailer.

Proposition 10. The relationship between w^*, p^* and k under the three subsidy strategies is shown in Figure 1-2.

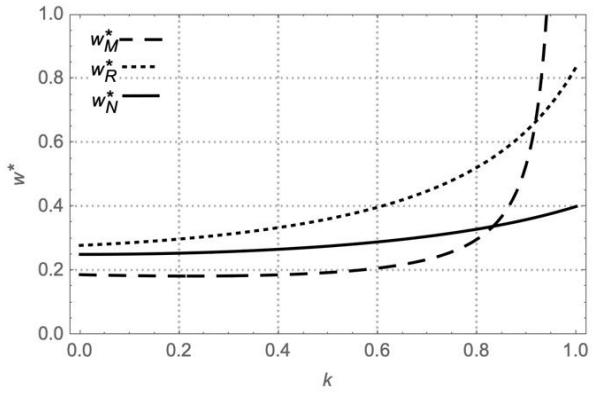

Figure 1: Optimal Strategy $w^*(a = 1, t = 0.9)$

Figure 1-2 show that $w_R{}^* > w_N{}^*$, that is, the wholesale price of products when subsidizing retailers is always greater than that with no subsidy. As k increases, $w_M{}^*$ surpasses $w_N{}^*$ and $w_R{}^*$ in turn. This indicates that when consumers' preference for green products is beyond a certain level, the wholesale price in model M will be higher than that of model R and model N, and the wholesale price decided by subsidized manufacturers has the highest growth rate at this point.

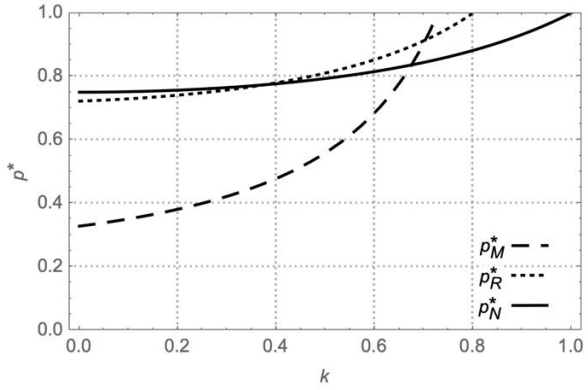

Figure 2: Optimal Strategy $p^*(a = 1, t = 0.9)$

When k is low, $p_N{}^* > p_R{}^* > p_M{}^*$; when k is at the middle level, $p_R{}^* > p_N{}^* > p_M{}^*$; when k is high, $p_M{}^* > p_R{}^* > p_N{}^*$. It shows that if consumers have a low preference for green products, the price of products is the highest when government does not provide subsidy; when the preference is at an intermediate level, the product price is the highest when the retailer is subsidized; and if the preference

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is strong, the product price is the highest when the manufacturer is subsidized.

5. Conclusion

This paper discusses the optimal strategy and social welfare benefits of the supply chain in a retail-dominated market environment under three subsidy policies: no government subsidy, subsidizing manufacturers, and subsidizing retailers. Results show that when the government provides subsidies, the social welfare and the profits of manufacturers and retailers, as well as their optimal product green degree and green promotion level, will all increase to a certain extent. And the government's strategy of subsidizing manufacturers will lead to greener products, higher social welfare and profits of manufacturers and retailers. Thus, the strategy of subsidizing manufacturers is shown to be better through comprehensive analysis. When consumers' preference for green products is low, the green promotion level is higher when subsidizing retailers, but the unit subsidy gain of social welfare is greater when subsidizing manufacturers. The situation of joint subsidies for manufacturers and retailers can be further explored in the future.

References

[1] Jiayi Joey Yu, Christopher S. Tang, Zuo-Jun Max Shen. (2018) Improving Consumer Welfare and Manufacturer Profit via Government Subsidy Programs: Subsidizing Consumers or Manufacturers?. Manufacturing & Service Operations Management. 20, 752-766.
[2] Jonathan Chemama, Maxime C. Cohen, Ruben Lobel, Georgia Perakis. (2019) Consumer Subsidies with a Strategic Supplier: Commitment vs. Flexibility. Management Science. 65, 681-713.
[3] Maxime C. Cohen, Ruben Lobel, Georgia Perakis. (2016) The Impact of Demand Uncertainty on Consumer Subsidies for Green Technology Adoption. Management Science. 62, 1235-1258.
[4] Dmitry Krass, Timur Nedorezov, Anton Ovchinniko. (2013) Environmental Taxes and the Choice of Green Technology. Production and Operations Management Society. 22, 1035-1055.
[5] Kelly Sims Gallagher, Erich Muehlegger. (2011) Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology. Journal of Environmental Economics and Management. 61,1-15.
[6] Sangeeta Bansala, and Shubhashis Gangopadhyay. (2003) Tax/subsidy policies in the presence of environmentally aware consumers. Journal of Environmental Economics and Management. 45, 333–355.
[7] Hui Li, Chuanxu Wang, Meng Shang, Wei Ou, Xiaohui Qin. (2018) Cooperative Decision in a Closed-Loop Supply Chain Considering Carbon Emission Reduction and Low-Carbon Promotion.
[8] Tao Li, Rong Zhang, Senlin Zhao, Bin Liu. (2019) Low carbon strategy analysis under revenue-sharing and cost-sharing contracts. Journal of Cleaner Production. 212, 1462-1477.
[9] Liu Z.L., Anderson T.D., Cruz J.M. (2012) Consumer Environmental Awareness and Competition in Two-stage Supply chains Research. 218, 602-613.
[10] Ghosh D, Shah J.A. (2012) Comparative analysis of greenlining policies across supply chain structures. International Journal of Production Economics. 135, 568-583
[11] Ghosh D, Shah J. (2015) Supply chain analysis under green sensitive consumer demand and cost sharing contract. 164, 319-329.
[12] Zhou Yanju, Hu Fengying, Zhou Zhenglong. (2019) Research on Supply Chain Pricing Strategy and Social Welfare of Manufacturer Competition under Carbon Tax Policy. Chinese Management Science. 27, 94-105.

Appendix Proofs of Propositions, Lemmas

Since the proof methods of the Proposition and Lemma of the three models are similar, the appendix only shows the proof of model N & model M, and the proof of Proposition 6, 7 in model R is omitted.

Proof of Lemma 1&Proposition 1. The Hessian matrix of $\pi_N^M(w_N, e_N)$ is obtained to be $\begin{bmatrix} -2 & k \\ k & -2 \end{bmatrix}$. According to the hypothesis $0 < k < \sqrt{\frac{8}{3}}$, the Hessian matrix is proven to be negative definite, indicating that the manufacturer's profit $\pi_N^M(w_N, e_N)$ is a concave function of the wholesale price w_N and the product green degree e_N, so there is a unique maximum point. Let the first-order conditions equal to 0, according to the backward induction method, we can obtain ${e_N}^* = \frac{ak}{8-3k^2}, {w_N}^* = \frac{2a}{8-3k^2}$, According to the hypothesis $0 < k < \sqrt{\frac{8}{3}}$, we can know that ${e_N}^*, {w_N}^* > 0$, which conforms to the assumptions above.

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Substituting $e_N{}^*, w_N{}^*$ into the retailer's profit function $\pi_N^R(m_N, z_N)$, we obtain the Hessian matrix: $\begin{bmatrix} \frac{4}{-4+k^2} & -\frac{2k}{-4+k^2} \\ -\frac{2k}{-4+k^2} & -2 \end{bmatrix}$. According to the hypothesis $0 < k < \sqrt{\frac{8}{3}}$, the Hessian matrix is proven to be negative definite, indicating that the retailer's profit is a concave function of m_N, z_N, and there is a unique maximum point. Let the first-order conditions equal to 0, according to the backward induction method, we can obtain $m_N{}^* = \frac{a(4-k^2)}{8-3k^2}, z_N{}^* = \frac{ak}{8-3k^2}$. According to the hypothesis $0 < k < \sqrt{\frac{8}{3}}$, we can know $m_N{}^*, z_N{}^* > 0$, which conforms to the assumptions above. Thus, lemma 1 is proved. Substituting the $e_N{}^*, w_N{}^*, m_N{}^* z_N{}^*$ obtained by Lemma 1 into the social welfare and the profit function of the manufacturer and retailer, Proposition 1 can be obtained.

Proof of Proposition 2. According to the hypothesis $0 < k < \sqrt{\frac{8}{3}}$, it can be obtained: $\frac{\partial w_N{}^*}{\partial k} = \frac{12ak}{(8-3k^2)^2} > 0, \frac{\partial e_N{}^*}{\partial k} = \frac{\partial z_N{}^*}{\partial k} = \frac{a(8+3k^2)}{(8-3k^2)^2} > 0, \frac{\partial p_N{}^*}{\partial k} = \frac{20ak}{(8-3k^2)^2} > 0, \frac{\partial \pi_N^{R^*}}{\partial k} = \frac{6a^2k}{(8-3k^2)^2} > 0, \frac{\partial \pi_N^{M^*}}{\partial k} = \frac{2a^2k(3k^2-16)}{(3k^2-8)^3} > 0, \frac{\partial SW_N{}^*}{\partial k} = \frac{2a^2(12k^3-52k-8s-9k^2s)}{(-8+3k^2)^3} > 0.$

Proof of Proposition 3. According to Proposition 2, when $\frac{\partial \pi_N^{M^*}}{\partial k} > \frac{\partial \pi_N^{R^*}}{\partial k}$, we can obtain the range of k: $\sqrt{\frac{4}{3}} < k < \sqrt{\frac{8}{3}}$, and vice versa.

Proof of Proposition 4. According to Lemma 2, it can be obtained that $\frac{\partial p_M{}^*}{\partial t} = \frac{a(3k^3+2(-2+t)^2+2kt(2+t)+k^2(1+6t))}{(8-3k^2-4kt-2t^2)^2}, \frac{\partial z_M{}^*}{\partial t} = \frac{4ak(k+t)}{(8-3k^2-4kt-2t^2)^2}, \frac{\partial w_R{}^*}{\partial t} = \frac{a(3k^3-8t+6k^2t+2kt^2)}{(8-3k^2-4kt-2t^2)^2}, \frac{\partial e_M{}^*}{\partial t} = \frac{a(8+k^2+4kt+2t^2)}{(8-3k^2-4kt-2t^2)^2}, \frac{\partial \pi_M^{M^*}}{\partial t} = \frac{2a^2(k+t)(-8+k^2+4kt+2t^2)}{(8-3k^2-4kt-2t^2)^3}, \frac{\partial \pi_M^{R^*}}{\partial t} = \frac{4a^2(k+t)}{(8-3k^2-4kt-2t^2)^2}, \frac{\partial SW_M{}^*}{\partial t} = \frac{2a^2(-8+4k^3+2t(1+t)(-8+5t)+k^2(-5+17t)+12k(-2+t(-1+2t)))}{(8-3k^2-4kt-2t^2)^3}$. According to the condition $0 < k < \frac{\sqrt{2(12-t^2)}-2t}{3}$, it is derived that $\frac{\partial p_M{}^*}{\partial t} > 0, \frac{\partial e_M{}^*}{\partial t} > 0, \frac{\partial z_M{}^*}{\partial t} > 0, \frac{\partial w_M{}^*}{\partial t} > 0, \frac{\partial \pi_M^{M^*}}{\partial t} > 0, \frac{\partial \pi_M^{R^*}}{\partial t} > 0, \frac{\partial SW_M{}^*}{\partial t} > 0.$

Proof of Proposition 5. According to Lemma 2, we can obtain $\frac{\partial p_M{}^*}{\partial k} = \frac{a(3k^3+2(-2+t)^2+2kt(2+t)+k^2(1+6t))}{(-8+3k^2+4kt+2t^2)^2}, \frac{\partial e_M{}^*}{\partial k} = \frac{a(8+3k^2+6kt+2t^2)}{(-8+3k^2+4kt+2t^2)^2}, \frac{\partial w_M{}^*}{\partial k} = \frac{a(6k(2-t^2)-3k^2t-2t^3)}{(-8+3k^2+4kt+2t^2)^2}, \frac{\partial z_M{}^*}{\partial k} = \frac{a(8+3k^2-2t^2)}{(-8+3k^2+4kt+2t^2)^2}, \frac{\partial \pi_M^{M^*}}{\partial k} = \frac{2a^2(3k^3+9k^2t+2t(-4+t^2)+8k(-2+t^2))}{(-8+3k^2+4kt+2t^2)^3}, \frac{\partial \pi_M^{R^*}}{\partial k} = \frac{2a^2(3k+2t)}{(-8+3k^2+4kt+2t^2)^2}, \frac{\partial SW_M{}^*}{\partial k} = \frac{2a^2(-8+12k^3+9k^2(-1+4t)+6t(-4+t(-1+2t))+2k(-26+t(-8+19t)))}{(-8+3k^2+4kt+2t^2)^3}$. According to the condition $0 < k < \frac{\sqrt{2(12-t^2)}-2t}{3}$, it is derived that $\frac{\partial p_M{}^*}{\partial k} > 0, \frac{\partial e_M{}^*}{\partial k} > 0, \frac{\partial z_M{}^*}{\partial k} > 0, \frac{\partial \pi_M^{M^*}}{\partial k} > 0, \frac{\partial \pi_M^{R^*}}{\partial k} > 0, \frac{\partial SW_M{}^*}{\partial k} > 0$. Finding the range of k according to the condition $\frac{\partial w_R{}^*}{\partial k} > 0$, we obtain the monotonicity of $w_R{}^*$ with respect to k.

Proof of Proposition 8. Let $\nabla e_1^* = \frac{e_M{}^*}{e_R{}^*}, \nabla z_1^* = \frac{z_M{}^*}{z_R{}^*}$, then we have $\nabla e_1^* = \frac{(k+t)(-8+3k^2+2kt+t^2)}{k(-8+3k^2+4kt+2t^2)}, \nabla z_1^* = \frac{k(-8+3k^2+2kt+t^2)}{(k+t)(-8+3k^2+4kt+2t^2)}$. According to known conditions $0 < k < \frac{\sqrt{2(12-t^2)}-2t}{3}$ and $0 < t < 1$, we can obtain $\nabla e_1^* > 1$. When $0 < k < \frac{\sqrt{160-15t^2}-5t}{10}$, $\nabla z_1^* < 1$ and $z_R{}^* > z_M{}^*$; when $\frac{\sqrt{160-15t^2}-5t}{10} < k < \frac{\sqrt{2(12-t^2)}-2t}{3}$, $\nabla z_1^* > 1$ and $z_M{}^* > z_R{}^*$.

Proof of Proposition 9. Suppose $\overline{SW}_M^* = \frac{SW_M{}^*}{GS_M{}^*}, \overline{SW}_R^* = \frac{SW_R{}^*}{GS_R{}^*}$, we can obtain that when $0 < k < \frac{1-t}{2}$, $\overline{SW}_M^* > \overline{SW}_R^*$, and when $\frac{1-t}{2} < k < \frac{\sqrt{2(12-t^2)}-2t}{3}$, $\overline{SW}_M^* < \overline{SW}_R^*$.