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Research on Government Subsidy Mechanism of Green Products Based on Heterogeneous Customers

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Abstract
This paper builds a model of government subsidies to green products in the face of heterogeneous customers with different green perferences. There are two kinds of subsidy mechanism in this paper: One is subsidies given to green manufactures, and other is subsidies given to customers. The result shows that the two subsidies both benefit development of green technology. And government subsidies given to manufacture can bring greater social welfare than those to customers. In addition, as green customers increase, the optimal subsidies for manufacturers decline, and the optimal subsidies for consumers increase.

Key words: Heterogeneous customers; Green product; Green technology; Government subsidies; Duopoly enterprises

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INTRODUCTION
In recent years, the problem of global warming is becoming more and more serious, which brings serious challenges to the survival and development of human beings. One way to solve this problem is the adoption and application of green technology. However, due to the high cost of developing green technology, most companies can not afford it. At the same time high costs lead to high prices, so the price of green products is far higher than consumers can accept. In order to promote green technology, government needs to introduce a lot of policies, such as green subsidies, sewage tax, to promote the production of green products.

Nowadays, Government subsidies have been a hot topic in academia. Atalay et al. (2009) analyzes that recovery subsidies are not necessarily optimal policies. Luo (2014) finds that government subsidies can improve the sales of electric vehicles; the higher the amount of subsidies, the better the performance of the supply chain. Zhu et al. (2014) considers two kinds of subsidy mechanism that to manufacturers or to consumers. The conclusion shows that government subsidies are more conducive to the development of manufacturing enterprises compared to direct subsidies to consumers. Zhou et al. (2015) shows that incentive subsidies can promote the development of reverse logistics. Cohen et al. (2015) studys the impact of government subsidies to consumers on green technology adoption, and shows that the subsidy mechanism is sufficient to coordinate the system.

As the market gradually changing from the seller's market to the buyer's market, more and more scholars concern about business decision-making on the impact of consumer's purchase behavior. Zhu and Dou (2011) shows that when the green products' cost is high and consumers' environmental awareness is low, the government should be appropriate to adjust the lowest limit of subsidies. Yu et al. (2016) find that the increase in consumer awareness will encourage companies to produce greener products. Sun and Peng (2013) study heterogeneous customers, assuming that one type of customer is more sensitive to the quality of the product. Zhang and Xiong (2016) find that for different consumers, enterprises should adopt a variety of production technology, so as to maximize corporate profits.

In the view of above analysis, this article intends to consider heterogeneous customers having different sensitivity coefficient on the production cost and using the cost of products, and purchase behavior is based consumer willingness. Establish different subsidy mechanisms such as subsidies to the green business, or subsidies to consumers. Furthermore, we compare different subsidy mechanisms from the perspective of social welfare and do numerical analysis.

1. DEMAND FUNCTION

Consider the decision-making system built by duopoly business, heterogeneous customers and government. Green enterprise only produces green products, and ordinary enterprise only produces ordinary products. The production cost of green products is higher, but the using cost is lower. And the production cost of ordinary products is lower, but the using cost is higher. There are two types of customers in the market, green customers who pay more attention to whether the product is environmentally friendly and ordinary customers who is more concerned about the price.

Green customers are more concerned about using cost of products, and ordinary customers are more sensitive to the price of the product. Take ordinary customers for example, the utility function as follows:

$$U_n^1 = v - \alpha_n p_1 - \beta_n e_1$$
$$U_n^2 = \theta v - \alpha_n p_2 - \beta_n e_2$$

The subscript n represents the ordinary customer. The superscript 1 represents the green product, and the superscript 2 represents the ordinary product. So $U^1{}_n$ is on behalf of utility function of ordinary customers to buy green products. p_1, p_2, e_1, e_2 respectively represent the price and using cost of green products and ordinary products v is retain utility of customer.v is obeying the uniform distribution $[0,A]$. A is the maximum value of the retained utility. α_n is sensitivity factor for the ordinary customer to the price of the product. β_n is sensitivity factor for the ordinary customer to the using cost of the product. Similarly, green consumers' utility function to buy green products and ordinary products as follows:

$$U_g^1 = v - \alpha_g p_1 - \beta_g e_1$$
$$U_g^2 = \theta v - \alpha_g p_2 - \beta_g e_2$$

α_g is sensitivity factor for the green customer to the price of the product. β_g is sensitivity factor for the green customer to the using cost of the product, satisfying $\alpha_n > \alpha_g, \beta_g > \beta_n$.

The retain utility of the customer determines whether to buy product and which product to purchase. Take the ordinary customer's purchase behavior as an example to analyze: Ordinary customers to buy green products should meet the conditions as:

$$U_n^1 \geq 0 \text{ and } U_n^1 \geq U_n^2$$

In summary, there are two cases available:

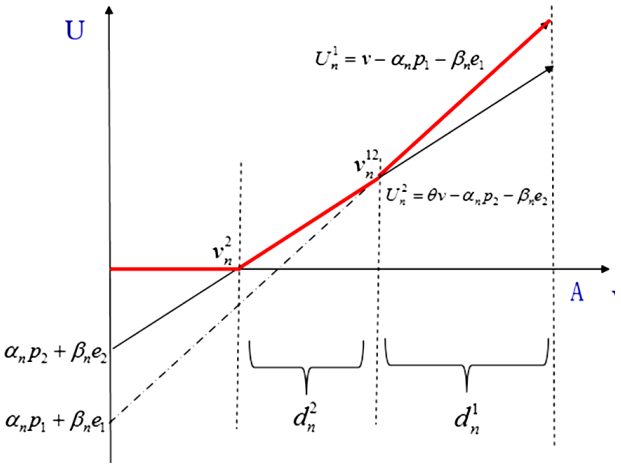

Figure 1

Situation One $\alpha_n p_1 + \beta_n e_1 > \dfrac{\alpha_n p_2 + \beta_n e_2}{\theta}$

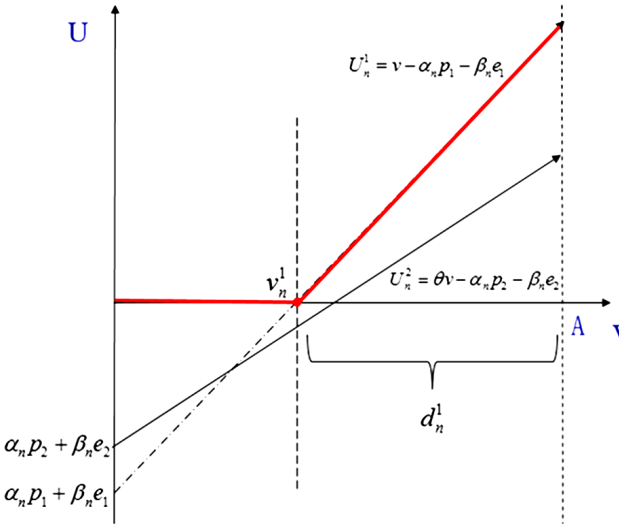

Figure 2

Situation Two $\alpha_n p_1 + \beta_n e_1 < \dfrac{\alpha_n p_2 + \beta_n e_2}{\theta}$

Figure 1, assuming v_n^2 is the utility value that ordinary customers whether to buy ordinary products. Assuming v_n^{12} is the utility value when ordinary customers buy ordinary products and buy green products without difference. Figure 2, assuming v_n^1 is the utility value that ordinary customers whether to buy green products. For the sake of generality, assuming that the total amount of consumers is 1, the proportion of ordinary consumers is δ, the ordinary customers demand function as follows:

$$d_n^1=\begin{cases}\delta\cdot\int_{v_n^{12}}^{A}\frac{1}{A}dv=\delta\left(1-\frac{\alpha_n(p_1-p_2)+\beta_n(e_1-e_2)}{A(1-\theta)}\right) if\ \alpha_n p_1+\beta_n e_1>\frac{\alpha_n p_2+\beta_n e_2}{\theta}\\ \delta\cdot\int_{v_n^{1}}^{A}\frac{1}{A}dv=\delta\left(1-\frac{\alpha_n p_1+\beta_n e_1}{A}\right)\end{cases}$$

$$d_n^2=\begin{cases}\delta\cdot\int_{v_n^{2}}^{v_n^{12}}\frac{1}{A}dv=\delta\left(\frac{\alpha_n(\theta p_1-p_2)+\beta_n(\theta e_1-e_2)}{A\theta(1-\theta)}\right) if\ \alpha_n p_1+\beta_n e_1>\frac{\alpha_n p_2+\beta_n e_2}{\theta}\\ 0\end{cases}$$

When the demand for ordinary products is zero, indicating that no customers are willing to buy ordinary products. At this time, ordinary enterprises are out of the market. Because this article is to consider the competition business, we ignore the situation that demand for ordinary products is zero.

Similarly, green consumers demand for green products and general products is as follows:

$$d_g{}^1=(1-\delta)\left(1-\frac{\alpha_g(p_1-p_2)+\beta_g(e_1-e_2)}{A(1-\theta)}\right)$$

$$d_g{}^2=(1-\delta)\left(\frac{\alpha_g(\theta p_1-p_2)+\beta_g(\theta e_1-e_2)}{A\theta(1-\theta)}\right)$$

Total demand for green products and general products is as follows:

$$d_1=d_n^1+d_g^1=1-\frac{\phi(p_1-p_2)+\varphi(e_1-e_2)}{A(1-\theta)}$$

$$d_2=d_n^2+d_g^2=\frac{\phi(\theta p_1-p_2)+\varphi(\theta e_1-e_2)}{A\theta(1-\theta)}$$

$\phi=\delta\alpha_n+(1-\delta)\alpha_g$, $\varphi=\delta\beta_n+(1-\delta)\beta_g$ respectively is average sensitivity factor for customer in the entire market to the price and using cost of the product. The higher sensitivity of using cost of the product, indicates that consumers are more concerned about green degree of products, indirectly reflecting consumer higher awareness of environmental protection.

2. MODEL

This section will analyze game decision-making between the government and enterprise. Government subsidy mechanism is divided into two types: First, government provide subsidies to green enterprises. Second, government subsidies to consumers' green behavior. The first stage is that the duopoly business determines optimal prices and quantities. The second stage is that government determine optimal subsidies.

2.1 Subsidies to Green Enterprises

Government subsidies to green manufacturers, indirectly reduce the production cost of enterprises, thereby promoting enterprise to produce more green products. When the government subsidizes the green business, the profit of green enterprise producing unit green product becomes p_1-c_1+s_1. So green and ordinary enterprises' profits are:

$$\pi_1{}^M=(p_1-c_1+s_1)d_1$$

$$\pi_2{}^M=(p_2-c_2)d_2$$

$c_1>c_2$, in reality, green enterprise for the production of green products often requires a lot of human resources and equipment, etc., which needs huge amounts of money. It will share to every product, so production cost will be greater than ordinary production cost.

By the first-order of formula, green and ordinary enterprises' optimal price, quantities and profits can be solved:

$$p_1{}^{M*}=\frac{2A(1-\theta)+\phi(2c_1+c_2-2s_1)+\varphi(\theta e_1-2e_1+e_2)}{(4-\theta)\phi}$$

$$d_1{}^{M*}=\frac{2A(1-\theta)+\phi(\theta c_1-2c_1+c_2+(2-\theta)s_1)+\varphi(\theta e_1-2e_1+e_2)}{A(1-\theta)(4-\theta)}$$

$$\pi_1{}^{M*}=\frac{(2A(1-\theta)+\phi(\theta c_1-2c_1+c_2+(2-\theta)s_1)+\varphi(\theta e_1-2e_1+e_2))^2}{A(1-\theta)(4-\theta)^2\phi}$$

$$p_2{}^{M*}=\frac{A\theta(1-\theta)+\phi(2c_2+\theta c_1-\theta s_1)+\varphi(\theta e_2-2e_2+\theta e_1)}{(4-\theta)\phi}$$

$$d_2{}^{M*}=\frac{A\theta(1-\theta)+\phi(\theta c_2-2c_2+\theta c_1-\theta s_1)+\varphi(\theta e_2-2e_2+\theta e_1)}{A\theta(1-\theta)(4-\theta)}$$

$$\pi_2{}^{M*}=\frac{(A\theta(1-\theta)+\phi(\theta c_2-2c_2+\theta c_1-\theta s_1)+\varphi(\theta e_2-2e_2+\theta e_1))^2}{A\theta(1-\theta)(4-\theta)^2\phi}$$

Conclusion 1:

a) $\frac{\partial p_1^{M*}}{\partial s_1}<0, \frac{\partial d_1^{M*}}{\partial s_1}>0, \frac{\partial \pi_1^{M*}}{\partial s_1}>0$

b) $\frac{\partial p_2^{M*}}{\partial s_1}<0, \frac{\partial d_2^{M*}}{\partial s_1}<0, \frac{\partial \pi_2^{M*}}{\partial s_1}<0$

From the conclusion 1, when government subsidizes green enterprises, the price of green product decreases, demand increases, the overall profits of green enterprise increase. At the same time, the price of ordinary products reduces, which is due to the ordinary products and green products to a certain extent can be substituted. When the price of green product reduces, the general business will adjust the price strategy that reducing the price of ordinary products. The demand for ordinary products decreases, and the overall profit of general business reduces. And when the larger the amount of subsidies, it will large benefit green enterprise.

Government will measure effectiveness of subsidy mechanism from the angle of social welfare and determine the optimal subsidies. The total social welfare consists of four parts: duopoly profits, consumer surplus, the externality and government expenditure. The consumer surplus under subsidizing the manufacturer is as follows:

$$U^M=\delta\left(\int_{v_n^{12}}^{A}\left(\frac{v-\alpha_n p_1^{M*}-\beta_n e_1}{A}\right)dv+\int_{v_n^{2}}^{v_n^{12}}\left(\frac{\theta v-\alpha_n p_2^{M*}-\beta_n e_2}{A}\right)dv\right)$$
$$++(1-\delta)\left(\int_{v_g^{12}}^{A}\left(\frac{v-\alpha_g p_1^{M*}-\beta_g e_1}{A}\right)dv+\int_{v_g^{2}}^{v_g^{12}}\left(\frac{\theta v-\alpha_g p_2^{M*}-\beta_g e_2}{A}\right)dv\right)$$

The consumer surplus includes the surplus of ordinary customers buying green products and ordinary products and the surplus of green customers buying green products and ordinary products.

Assuming that the marginal environmental benefits of green products are k, the marginal environmental damage of ordinary products is j, and the total social welfare function is:

$$SW=\Pi_1^M+\Pi_2^M+U^M+kd_1^M-jd_2^M-s_1d_1^M$$

After seeking the first derivative of the equation, can get the optimal subsidy value when government subsidizes the green manufacture:

$$s_1^*=\frac{\phi\left(\left(\phi\theta^2+\bar{\phi}\theta_5\right)c_1-\left(\phi\theta_5+\bar{\phi}\theta\right)c_2\right)+\left(\phi\varphi\theta^2+\phi\gamma\theta_1\theta_2-\bar{\phi}\varphi\theta_4\right)e_1+\left(-\phi\varphi\theta_5+\phi\gamma\theta_2-2\bar{\phi}\varphi\theta_1\right)e_2-E+A(1-\theta)\left(2\phi\left(\phi\theta_2+2\theta\right)+\bar{\phi}\theta_5\right)}{\phi h\theta_5}$$

Among them:

$$\theta_1=\theta-2,\theta_2=\theta-4,\theta_3=\theta^2-5\theta+8,\theta_4=\theta^2-3\theta+4,\theta_5=4-3\theta,\theta_6=\theta^2-\theta-4,\theta_7=\theta^2-7\theta+12$$

$$\bar{\phi}=\delta\alpha_n{}^2+\left(1-\delta\right)\alpha_g{}^2,\gamma=\delta\alpha_n\beta_n+\left(1-\delta\right)\alpha_g\beta_g,h=\delta\alpha_n{}^2+\left(1-\delta\right)\alpha_g{}^2-2(\delta\alpha_n+\left(1-\delta\right)\alpha_g),E=\phi^2\left(\theta_1\theta_2k-\theta_2j\right)$$

2.2 Subsidies to Customers

When consumers buy green products, government gives some subsidies to reduce the purchasing cost of green products to attract more consumers to buy green products. At this point, the demand function of green products and ordinary products changes:

$$d_1^C=1-\frac{\phi(p_1-p_2)+\varphi(e_1-e_2)-s_2}{A\left(1-\theta\right)}$$
$$d_2^C=\frac{\phi\left(\theta p_1-p_2\right)+\varphi\left(\theta e_1-e_2\right)-\theta s_2}{A\theta\left(1-\theta\right)}$$

The profit function of green enterprises and ordinary enterprises is as follows:

$$\pi_1^C=\left(p_1-c_1\right)d_1^C$$
$$\pi_2^C=\left(p_2-c_2\right)d_2^C$$

By the first-order of formula, green and ordinary enterprises' optimal price, quantities and profits can be solved:

$$p_1^{C*}=\frac{2A(1-\theta)+\phi(2c_1+c_2)+\varphi(\theta e_1-2e_1+e_2)+(2-\theta)s_2}{(4-\theta)\phi}$$
$$d_1^{C*}=\frac{2A(1-\theta)+\phi(\theta c_1-2c_1+c_2)+\varphi(\theta e_1-2e_1+e_2)+\left(2-\theta\right)s_2}{A(1-\theta)\left(4-\theta\right)}$$
$$\pi_1^{C*}=\frac{\left(\left(2-\theta\right)s_2+2A(1-\theta)+\phi(\theta c_1-2c_1+c_2)+\varphi(\theta e_1-2e_1+e_2)\right.}{A\left(1-\theta\right)\left(4-\theta\right)^2\phi}$$

$$p_2^{C*} = \frac{A\theta(1-\theta)+\phi(2c_2+\theta c_1)+\varphi(\theta e_2-2e_2+\theta e_1)-\theta s_2}{(4-\theta)\phi}$$

$$d_2^{C*} = \frac{A\theta(1-\theta)+\phi(\theta c_2-2c_2+\theta c_1)+\varphi(\theta e_2-2e_2+\theta e_1)-\theta s_2}{A\theta(1-\theta)(4-\theta)}$$

$$\pi_2^{C*} = \frac{\left((A\theta(1-\theta)+\phi\left(\theta c_2-2c_2+\theta c_1\right)+\varphi(\theta e_2-2e_2+\theta e_1))-\theta s_2\right)^2}{A\theta\left(1-\theta\right)(4-\theta)^2\phi}$$

Conclusion 2:

a) $\frac{\partial p_1^{M*}}{\partial s_1}>0, \frac{\partial d_1^{M*}}{\partial s_1}>0, \frac{\partial \pi_1^{M*}}{\partial s_1}>0$

b) $\frac{\partial p_2^{M*}}{\partial s_1}<0, \frac{\partial d_2^{M*}}{\partial s_1}<0, \frac{\partial \pi_2^{M*}}{\partial s_1}<0$

From the conclusion 2, when the government subsidizes consumers, the price of green products increases and demand increases, and the overall profits of green enterprises increase. At the same time, the price of ordinary products reduces and the demand reduces, and the profit of ordinary enterprises reduces. And when the amount of government subsidies increases, it's more conducive to the development of green enterprise. After comparing conclusion 2 and 1, we find that when government subsidies to consumers, the green product prices increase. Indirectly reflecting the phenomenon of subsidy transfer, that is, green enterprises will increase the price of the product to share some of the government subsidies.

At this point the consumer surplus has changed:

$$U^C = \delta\left(\int_{v_n^{12}}^{A}\left(\frac{v-\alpha_n p_1^{C*}-\beta_n e_1+s_2}{A}\right)dv+\int_{v_n^2}^{v_n^{12}}\left(\frac{\theta v-\alpha_n p_2^{C*}-\beta_n e_2}{A}\right)dv\right)$$
$$+\left(1-\delta\right)\left(\int_{v_g^{12}}^{A}\left(\frac{v-\alpha_g p_1^{C*}-\beta_g e_1+s_2}{A}\right)dv+\int_{v_g^2}^{v_g^{12}}\left(\frac{\theta v-\alpha_g p_2^{C*}-\beta_g e_2}{A}\right)dv\right)$$

The social welfare function is:

$$SW^C = \Pi_1^C+\Pi_2^C+U^C+Kd_1^C-Jd_2^C-s_2d_1^C$$

After seeking the first derivative of the equation, can get the optimal subsidy value when government subsidizes the green behavior of customers:

$$s_2^* = \frac{\phi\theta_4 hc_1+2\phi\theta_1 hc_2+\left(-2\phi\varphi\theta_4-2\phi\gamma\theta_2+\bar{\phi}\varphi\theta_6\right)e_1+\left(-4\phi\varphi\theta_1-\phi\gamma\theta_7+\bar{\phi}\varphi\theta_3\right)e_2+E+A\left(\theta-1\right)\left(\phi\left(\phi\theta_1\theta_2-2\theta_5\right)-\bar{\phi}\theta_4\right)}{\phi\left(\phi{\theta_2}^2-2\theta_4\right)+\bar{\phi}\theta_6}$$

Conclusion 3: when $\alpha_n=\alpha_g=1$, $s_1^*=s_2^*$.When not considering the heterogeneity of the customer's sensitivity to price of product, the government optimal subsidy giving manufacturer or consumer is the same. At this point, $\phi=1$,combined with conclusions of 1,2, under subsidies to consumers and to the manufacturer, two policies on the role of inciting green business are equal.

3. NUMERICAL ANALYSIS

In this section, real data is used to simulate the model. Take two different types of cars produced by BYD as an example. One is F3, another is Qin EV. We assume that the profit of producing a car is 10%. According to the manufacturer guide price of car, we can calculate the cost of car.

Through the Sohu car network, we can query detail information of the car. Through the data available, BYD F3 manufacturer guide price is ￥55,900; 100 km fuel consumption is 6.9L / 100 km; a car in its life cycle can travel 152,137 miles, 93 gasoline latest offer for 6.51 yuan / L, therefore, BYD F3 using cost is: 6.9*15.2137*1.61*6.51/100=￥110,000. Qin EV manufacturers guide price is ￥259,800. BYD Qin EV battery capacity is of 47.5KWh, the maximum mileage of 300 km, mileage in life cycle of 152,137 miles , energy price of 0.61 yuan / KWh, therefore, BYD Qin EV using cost is:(47.5/300)*15.2137*1.61*0.61= ￥23,7000.

The positive externalities of pure electric vehicles are reduced CO_2 emissions during their life cycle. According to Arar (2010) data analysis, each consumption of 1000 kWh produces 755 kg of carbon dioxide. So BYD Qin EV produces emissions of carbon dioxide: (47.5/300)* 0.152137*1.61*755=29.28 ton CO_2. Ordinary fuel cars produce 2.8 kg of CO_2 per liter of oil. So we can calculate

ordinary vehicle emissions of CO_2: 2.8*6.9*152,137*1.61/100,000=47.32 ton CO_2. As a result, pure electric vehicles save: 47.32-29.28=18.04 ton CO_2. According to Maxime (2015) , a tonnage of CO_2 has a conversion factor of 52 $ / ton. Therefore, the positive externalities of pure electric vehicles can be obtained as: 52*7*18.04/10,000=￥6,600. The negative externalities of ordinary cars is : 52*7*47.32/10,000=￥17,2000. Therefore, the parameters are summarized as:

c_1=23.62,c_2=5.08,e_1=2.37,e_2=11,k=0.66, j=1.72.The other parameters are set as :

θ=0.8, A=110, α_n=1.5, α_g=1, β_n=1, β_g=1.5.

(a) The effect of parameters δ on optimal subsidies and social welfare

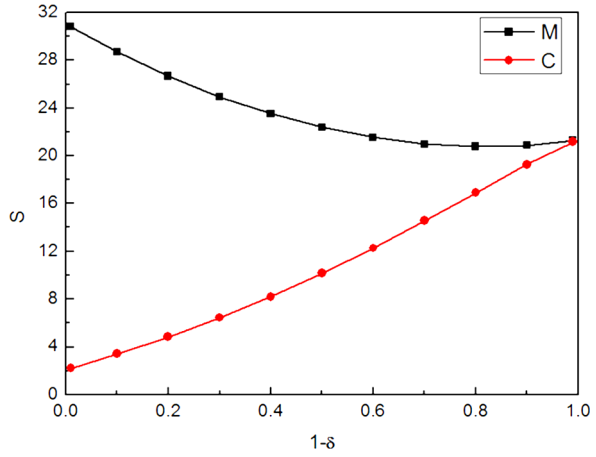

Figure 3
The Proportion of Green Consumers (1-δ) on the Impact of the Optimal Subsidies

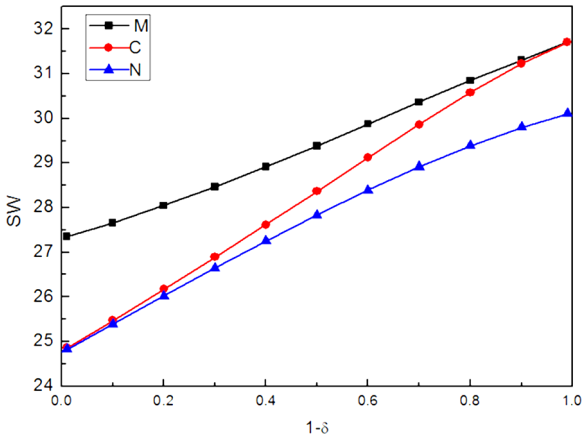

Figure 4
The Proportion of Green Consumers (1-δ) on the Impact of the Social Welfare

From Figure 3, when the proportion of green customers in the market increases, the optimal subsidies to the manufacturer decrease. This is because when the government subsidies to green enterprises, the price of green products declines. So the utility of consumers increases, optimal subsidies show a downward trend. On the contrary, the optimal subsidies to the consumers increase. This is because when the government subsidizes to consumers, the green product prices increase and consumer utility declines. At this time, government should increase the amount of subsidies.

Figure 4 shows that when there are more and more green customers in the market, the social welfare under the two subsidy mechanisms is improving. And the social welfare is greater when subsidies to the manufacturers than the subsidies given to consumer. Without any financial constraints, government should give priority to subsidies to manufacturers in order to bring better social welfare.

(b) The effect parameters θ on optimal subsidies and social welfare

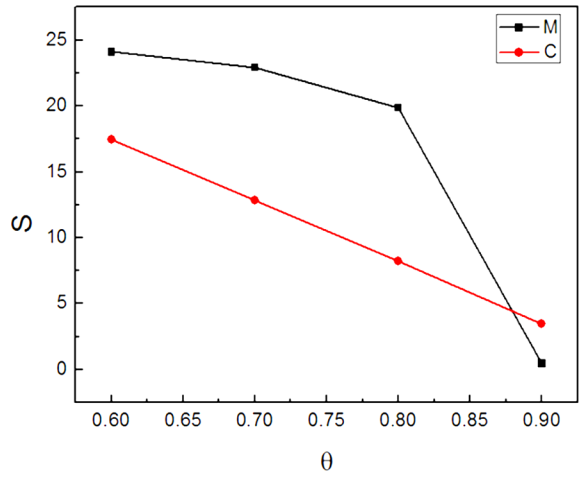

Figure 5
The Effect of θ on the Optimal Subsidy

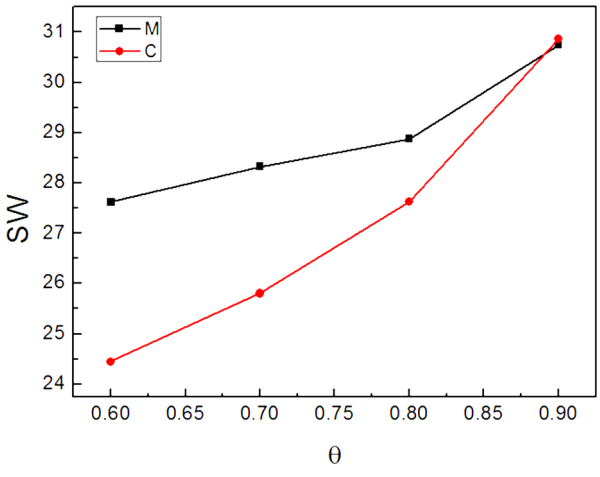

Figure 6
The Effect of θ on the Social Welfare

From the above figure, when θ increases, the optimal subsidies drop. When θ is greater, indicate that higher replacement of two types of products, competition between products is servious. Enterprises in order to obtain more customers often take the price war. The price of two kinds of products decreases significantly. So the utility of the consumer increases, optimal social subsidies drop. Figure 6 shows that θ increases and social welfare also increases.

CONCLUSION

For the above analysis, we get the following conclusion:

(a) Government subsidies to green enterprises, the green product prices decline, green business profits increase. When government subsidizes consumers who buy green products, the price of green products is rising. Because green companies tend to shift some of the consumer subsidies by raising prices. Both mechanism can promote the development of green enterprises.

(b) When replacement of two types of products is small, green enterprises should increase the green technology investment in order to improve green degree of product. When two types of products are easy to replace, the green business should be more concerned about controlling producing cost, corresponding reducing product prices in order to attract more customers. Such as BYD will reduce the cost of new energy vehicles by 30% in five years.

(c) When the proportion of green customers in the market increases, subsidies to the manufacturer's optimal subsidies drop and subsidies to the consumer's rise. And without considering the premise of financial constraints, subsidies to manufacturers are better than subsidies to consumers. When not considering the heterogeneity of the customer's sensitivity to price of product, the government optimal subsidy giving manufacturers or consumers is the same.

This paper only considers deterministic demand, the uncertainty of demand can be studied in future. In addition, this paper assumes that consumer utility is uniform distribution, and other types of distribution are research directions in future.

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