A Study on the Impact of Different Government Subsidies on the Environmental Protection Capability and Social Welfare of Motor Manufacturers in the Supply Chain of New Energy Vehicles

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Abstract. In order to reveal the influence of different subsidy strategies adopted by the government on the decision-making behaviors of each subject in the new energy vehicle supply chain, this paper takes the Stankelberg game model with the motor manufacturer as the leader and the new energy vehicle manufacturer as the follower to study the optimal decision-making of the supply chain subjects under the three strategies of no government subsidy (n), motor manufacturer subsidy (b), and new energy vehicle manufacturer subsidy (m). n strategy Under the n strategy, the environmental protection capability of motors is negatively correlated with the wholesale price of motors. Government subsidies can improve the environmental performance of motors and the recycling rate of used motors. Regardless of the strategy, the environmental protection capability of new energy vehicle motors is affected by both the wholesale price and the environmental protection degree of motors, and is positively correlated with the environmental protection degree of motors and negatively correlated with the wholesale price of motors. Numerical analysis shows that the social welfare of the two subsidized strategies is greater than that of the unsubsidized strategy.

Keywords: new energy vehicles; environmental capacity; motor recycling; government subsidies; social welfare.

1 Introduction

Sustainable development has become one of the great challenges facing the whole world, and green, circular and low-carbon development is a global consensus [1]. As a representative of energy saving and emission reduction in the transportation field, new energy vehicles have become the main way to alleviate China's energy and environmental problems and promote the good development of the automobile industry. China has promulgated the Energy Saving and New Energy Vehicle Industry Development Plan (2012-2020) and other measures to promote the development of new energy vehicle industry [2].

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1.1 Presentation of the Research Problem

With the international community's concern about global climate change, green development has gradually become a new development consensus. To this end, the government has proposed a variety of preferential policies, such as subsidies, tax reductions, government priority procurement, etc., of which the subsidy strategy is the most common and effective incentive style [3]. For example, in order to incentivize consumers to purchase new energy vehicles, the Ministry of Finance subsidized the purchase of new energy vehicles in 2015; the financial subsidy policy for new energy vehicles was further adjusted in 2018. These policies have greatly promoted the development of green industry, but their policy effects vary due to different subsidy targets and subsidy quantities, so for the government, how to choose subsidy targets and determine the number of subsidies to maximize incentives for enterprises and consumers to produce and consume green products is an issue worthy of study [4]. At the same time, the development of green industry is not only related to production enterprises, but also affected by the decision-making of upstream and downstream enterprises associated with them [5]. Based on this, this study intends to explore, from the supply chain perspective, the impact of different governmental subsidy strategies on the environmental protection capability of supply chain motors based on the joint green efforts of motor manufacturers and retailers.

2 Decision Model and Optimal Strategy Analysis of New Energy Vehicle Supply Chain

Consider a secondary supply chain consisting of a motor manufacturer (A) and a new energy vehicle manufacturer (B). The decision-making sequence is that the motor manufacturer first decides on the environmental protection capability and wholesale price of the motor, and then the new energy vehicle manufacturer decides on the environmental protection capability of the new energy vehicle and the selling price of the vehicle based on the environmental protection degree of the motor and the wholesale price. The government chooses to subsidize either the new energy vehicle manufacturer or the motor manufacturer. For the convenience of exposition, n,b and m are used to denote the no-government-subsidy strategy, the motor producer-subsidy strategy and the new energy vehicle manufacturer-subsidy strategy, respectively. Since the cost of the power motor system of new energy vehicles occupies a large proportion of the development cost of the whole vehicle and the motor is as important to new energy vehicles as the engine is to the car, the importance of the motor to new energy vehicles is obvious. According to the above background and drawing on the literature [6] model for the determination of the order of decision-making, this section establishes the Stackelberg game model with the motor manufacturer as the leader and the new energy vehicle manufacturer as the follower, and the decision-making behaviors of each participant are described as follows.

2.1 Demand for New Energy Vehicles

The market demand of new energy vehicles is simultaneously affected by product price, environmental protection ability and recycling of used motors. Based on the demand function of Hong et al [7], the demand function is set according to the specific situation of the system studied in this paper. The utility of consumers for the functional attributes of new energy vehicles is denoted by U. U is a random variable whose cumulative distribution function is F (-). The total number of consumers is assumed to be 1, and one new energy vehicle corresponds to one motor. The notation is shown in Table 1.

Table 1. Description of variables and parameters

Symbol	Definition	Symbol	Definition
g	Motor environmental protection capacity	τ	Recycling rate of used motors
ω	Motor wholesale price	p	New Energy Vehicle Sales Price
c	Unit motor production cost	A	Unit revenue of used motor recycling
1/μ	Proportion of motor cost in new energy vehicles	λ2	Coefficient of sustainable investment cost for motor recycling
K1	Consumer environmental sensitivity coefficient	K2	Consumer green awareness
λ1	R&D cost coefficient of motor environmental protection capability	s	Government subsidy level

2.2 No Government Subsidy Policy

In this paper, it is assumed that U is uniformly distributed obeying [0,1] [8]. When the government does not subsidize the supply chain, the profit functions of the car manufacturer and motor producer are respectively:

$$\pi_n^B(\omega_n, g_n) = (\omega_n - c)(1 - p_n + k_1 g_n + k_2 \tau_n) - \lambda_1 g_n^2, \tag{1}$$

$$\pi_n^M(p_n, \tau_n) = (p_n - \mu\omega_n + A\tau_n)(1 - p_n + k_1 g_n + k_2 \tau_n) - \lambda_2 \tau_n^2 \tag{2}$$

$$p_n^* = \frac{[2\lambda_2 - (A + k_2)k_2]\mu\omega_n + [2\lambda_2 - (A + k_2)A]g_n + 2\lambda_2 - (A + k_2)A}{4\lambda_2 - (A + k_2)^2} \tag{3}$$

$$\tau_n^* = \frac{k_1 k_2 - (A + k_2)\mu\omega + A + k_2}{4\lambda_2 - (A + k_2)^2} \tag{4}$$

According to equations (3) and (4) we can get the following conclusions.

Proposition 1 Under the strategy of no government subsidy, the sales price of new energy vehicles increases with the increase of the wholesale price of motors, while the recycling rate of used motors increases with the increase of the environmental protection capability of motors. Meanwhile, the scrap motor recycling rate is affected by both the wholesale motor price and the environmental protection capability. This suggests that in addition to reducing the recycling cost through government subsidies, allowing motor manufacturers to improve the environmental protection capability of motors will also increase the recycling rate of used motors.

Proposition 2 Under the government subsidy strategy, the wholesale price of motors, the environmental protection capability and the sales price of new energy vehicles increase with the increase of consumers' environmental protection sensitivity coefficient; the recycling rate of used motors and the sales price of new energy vehicles increase with the increase of consumers' awareness of environmental protection; the profit of motor manufacturers decreases with the increase of the coefficient of the research and development cost of the environmental protection capability of motors, and the profit of manufacturers of new energy vehicles decreases with the increase of the coefficient of the investment cost of motor recycling sustainable development. The profit of motor manufacturers decreases with the increase of R&D cost coefficient of motor environmental protection capability, and the profit of new energy vehicle manufacturers decreases with the increase of sustainable investment coefficient of motor recycling.

2.3 Government Subsidy Strategy

In order to incentivize the respective R&D behaviors of new energy vehicle supply chain players, governments often adopt different subsidy strategies.

(1) Motor Manufacturers' Subsidy Strategy

In order to improve the environmental protection capability of new energy vehicles, motor manufacturers need to invest higher R&D costs to improve the change of motor production materials. In order to incentivize motor producers, the government will subsidize them according to their environmental protection ability. Therefore, this section follows this approach to set the subsidy.

The optimal solution is derived in the same way as:

$$\pi_b^B(\omega_b, g_b) = (\omega_b - c)(1 - p_b + k_1 g_b + k_2 \tau_b) - \lambda_1 g_b^2 + s g_b \tag{5}$$

$$\omega_b^* = (\delta_3(2\delta_2\lambda_1 + sk_1) - 2ck_1^2\lambda_2)/(2\Delta) \tag{6}$$

$$g_b^* = (\delta_3\mu s + k_1\lambda_2\delta_1)/\Delta \tag{7}$$

$$p_b^* = (\mu s k_1[\delta_4(A + \delta_4) - 6\lambda_2])/(2\Delta) + p_n^* \tag{8}$$

$$\tau_b^* = ((sk_1 + 2\delta_1\lambda_1)\delta_4\mu)/(2\Delta) \tag{9}$$

Where
$\delta_1 = 1 - \mu c, \delta_2 = 1 + \mu c, \delta_3 = 4\lambda_2 - (A + k_2)^2, \delta_4 = A + k_2, \Delta = 2\mu\delta_3\lambda_1 - k_1^2\lambda_2.$
Substituting Eqs. (6)-(9) into Eq. (5) and Eq. (2), respectively, yields the most profitable as:

$$\pi_b^{B*} = (\delta_3 s^2 \mu + 2\delta_1\lambda_2(sk_1 + \delta_1\lambda_1)) / (2\Delta), \pi_b^{M*} = \delta_3\lambda_2\mu^2(sk_1 + 2\delta_1\lambda_1)^2 / (4\Delta)^2 \quad (10)$$

Proposition 3 The environmental protection capability of the electrodes is higher in the b-strategy than in the no-subsidy strategy; at the same time, the wholesale price of the motors is higher in the b-strategy. Compared to the no-subsidy strategy, the level of the motor's environmental capacity increases when the government imposes a subsidy only on the motor producer. There is a direct link between the level of consumer demand for environmentally friendly cleanliness and the cost of motor development.

(2) Subsidy strategy for new energy vehicle manufacturers

New energy vehicle manufacturers need to invest a large amount of money in the research and development of recycling technology and laddering utilization, which will reduce their willingness to recycle. Therefore, the government needs to provide subsidies to automobile manufacturers to incentivize them.

$$\pi_m^M(p_m, \tau_m) = (p_m - \mu\omega_m + A\tau_m)(1 - p_m + k_1 g_m + k_2\tau_m) - \lambda_2\tau_m^2 + s\tau_m \quad (11)$$

$$\omega_m^* = (\delta_3\lambda_1(\delta_4 s + 2\delta_2\lambda_2) - 2ck_1^2\lambda_2^2) / (2\lambda_2\Delta) \quad (12)$$

$$g_m^* = (\delta_3\mu s + k_1\delta_1\lambda_2) / \Delta \quad (13)$$

$$p_m^* = p_n^* + (s(4\lambda_1 k_2(\delta_3 + 2\lambda_2) + A\lambda_2(K_1^2 - 2\mu\lambda_1))) / (2\lambda_2\Delta) \quad (14)$$

$$\tau_m^* = (\mu\lambda_1(s(\delta_3 + 4\lambda_2) + 2\delta_1\delta_4\lambda_2) - sk_1^2\lambda_2) / (2\lambda_2\Delta) \quad (15)$$

Substituting Eqs. (12)-(15) into Eqs. (1) and (11) yields the respective optimal profits as:

$$\pi_m^{B*} = \frac{\lambda_1(s\delta_4 + 2\delta_1\lambda_2)^2}{4\lambda_2\Delta} \quad (16)$$

$$\pi_m^{M*} = \frac{4\mu^3\lambda_1^2\lambda_2\delta_3(A\delta_1 s + 4s^2 + k_2\delta_1 s + \lambda_2\delta_1^2) + s^2k_1^4\lambda_2^2 - s^2\lambda_1\mu\delta_3(4k_1^2\lambda_2 + 3\mu\lambda_1\delta_4^2)}{4\lambda_2\Delta^2} \quad (17)$$

Comparing the decisions of new energy vehicle manufacturers under n-strategy and m-strategy, the following conclusions are obtained.

Proposition 5 Compared with the n-strategy, the motor environmental protection ability is higher under the m-strategy and the waste motor recycling rate is higher under the b-strategy. This suggests that no matter what strategy the government adopts, those who do not receive direct subsidies will also improve their own R&D and accordingly increase the motor environmental protection or the recycling rate of used motors. Proposition 5 also shows the effectiveness of government subsidies. The fact that λ is 1 does not affect the calculation results. The overall profits of the supply chain under the three strategies are calculated as follows:

$$\pi_n^* = \frac{\delta_1^2\Delta_1 + \delta_1^2\delta_6\mu^2}{\Delta_1^2} \tag{18}$$

$$\pi_b^* = \frac{(2\delta_1^2 + \delta_6 s^2\mu + 2s\delta_1 k_1)2\Delta_1 + \delta_6(2\delta_1 + sk_1)^2\mu^2}{4\Delta_1^2} \tag{19}$$

$$\pi_m^* = \frac{(2\delta_1 + \delta_4 s)^2\Delta_1 + \delta_3\mu s[4\delta_1(\delta_1 + \delta_4)\mu + (16 - 3\delta_4^2)\mu s - 4sk_1^2] + k_1^4 s^2}{4\Delta_1^2} \tag{20}$$

Which is $\Delta_1 = 2\mu(2 + A + k_2)(2 - A - k_2) - k_1^2, \delta_6 = (2 + A + k_2)(2 - A - k_2)$.

Comparing the overall profit of the supply chain under both subsidy strategies with the no-subsidy strategy, the following conclusions are made.

Proposition 6 The overall profit of the supply chain under both subsidies is higher than the no-subsidy strategy. This indicates that government subsidies can effectively increase the overall profit of the supply chain. However, from the government's point of view, due to the influence of the budget, the government has to take into account the consumer's travel demand, the environment and social welfare to make the appropriate subsidy strategy.

In this study, the social welfare is composed of the total profit π of the supply chain, the consumer surplus CS and the government subsidy expenditure GS. The total profit of the supply chain π is the sum of the profits of motor manufacturers and new energy vehicle manufacturers. The government subsidy expenditure GS depends on the government subsidy method. As a result, the social welfare under each strategy is:

$$SW_n^* = \frac{\delta_1^2[\delta_6\mu(2 + \mu) + 2\mu^2 - k_1^2]}{\Delta_1^2} \tag{21}$$

$$SW_b^* = \frac{\mu^2(2\delta_1 + sk_1^2)(2 + \delta_6) + (2\delta_6\mu - k_1^2)[4(1 + \mu c)^2 - 2\delta_6\mu s^2]}{4\Delta_1^2} \tag{22}$$

$$SW_m^* = \frac{k_1^2(2\delta_1 + s\delta_6)^2 + \Delta_2^2 + 2\mu^2\Delta_3 2k_1^2 c}{4\Delta_1^2} \tag{23}$$

Which is $\Delta_2 = 2\delta_1\delta_6\mu + (8 - \delta_6^2)s\mu - sk_1, \Delta_3 = (2\delta_1 + s\delta_6)(3s\delta_6 + 4c\delta_6^2 + 6\delta_1 - 16c)$

The impact of subsidies on social welfare is an important element that the government needs to consider. Therefore, referring to the way Chen et al [9] studied the government as a subject, this paper takes the subsidies of new energy vehicle manufacturers as an example to analyze the impact of government subsidies on social welfare and make corresponding numerical analysis. It shows that government subsidies also have a promoting effect on social welfare. In particular, China is now in the high incidence of waste motor recycling, the government should subsidize the waste motor recycling accordingly to improve the environmental benefits as far as the finance allows.

3 Numerical Analysis

The direct comparison of the environmental protection capability, the recycling rate of used motors under the two subsidy strategies and the social welfare under the three strategies in the above section is complicated, so this section discusses them in the form of numerical analysis[10]. In order to analyze the propositions and inferences more intuitively, to verify the validity of the model and to make in-depth observations, let c = 0.35, s = 0.2; μ = 2.5.

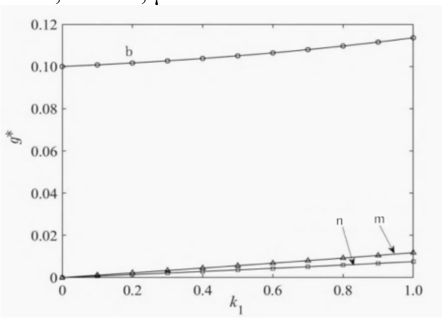

Fig. 1. g varies with k1

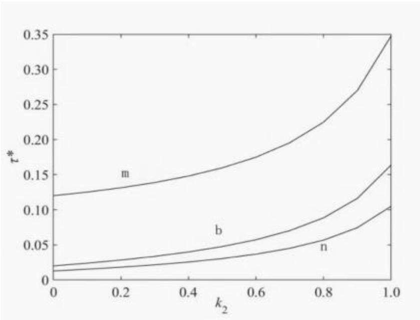

Fig. 2. t varies with k2

From Figures 1, and 2, we can see that: 1) No matter how to take the values of A and k1 in the range of (0, 1), the recycling rate of used motors is always the highest under the subsidy strategy of new energy automobile manufacturers, followed by the subsidy strategy of electric motor manufacturers, and the government subsidy directly to automobile manufacturers will increase the R&D investment in recycling of used motors and increase the recycling rate, which is also conducive to the protection of the environment. 2) Under any strategy, τ increases with the increase of k2, i.e., with the increase of consumers' sensitivity to motor recycling, enterprises will improve the recycling rate of used motors. That is, with the increase of consumers' sensitivity to motor recycling, enterprises will increase the recycling rate of used motors. Consumers pay more and more attention to the enterprise's environmental behavior, and gradually become the key factor of whether to buy their products.

From Figures 3, and 4, we can see that: 1) social welfare increases significantly regardless of subsidy strategy; 2) social welfare increases with the increase of k1; 3) as shown in Figure 3, the size of social welfare under the two subsidy strategies is affected by A and k2, and the social welfare is higher under strategy b than that under strategy m when the values of A and k2 are small. As shown in Fig. 4, as A and k2 increase simultaneously, the social welfare of the m-strategy is higher than that of the b-strategy in some cases. For large values of A and k2, social welfare is higher in the m-strategy than in the b- strategy.

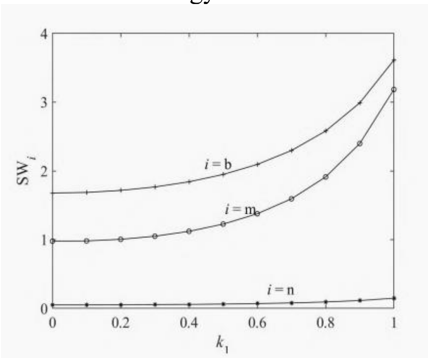

Fig. 3. The impact of government subsidies on social welfare under three strategies

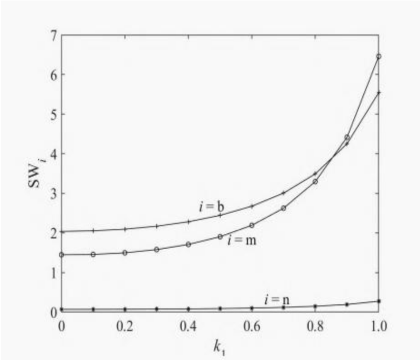

Fig. 4. The impact of government subsidies on social welfare under three strategies

4 Concluding

In this paper, we compare and analyze the effects of the no-subsidy strategy, the motor manufacturer's subsidy strategy, and the new energy vehicle manufacturer's subsidy strategy on the main decisions of a supply chain consisting of motor manufacturers and new energy vehicle manufacturers, taking into account the environmental protection capability of motors and the recycling efforts of motors by the motor manufacturers and the vehicle manufacturers, respectively. The study shows that under the no-subsidy strategy, the motor recycling rate decreases with the increase of the wholesale price of motors and increases with the increase of the range of motors. Compared with the no-subsidy strategy, the government's subsidy strategy can effectively increase the environmental protection capability of motors, the recycling rate of used motors, and the profits of supply chain companies. The environmental friendliness of motors and the profitability of motor manufacturers increase with the increase in consumer demand for environmental friendliness. At the same time, government subsidies are effective in increasing social welfare, and the order of social welfare is similar to the order of environmental performance under both subsidy strategies. As the range of electric motors gradually meets consumer demand, the number of new energy vehicles increases, and the number of used electric motors increases, the government should shift the focus of subsidies to new energy vehicle manufacturers, which is conducive to the utilization of resources and the development of the environment.

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