Optimal Control of Dual-Channel Supply Chain for New Energy Vehicles

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Abstract: This paper considers the decision-making problem under the integration transaction and the green innovation investment of new energy vehicle enterprises based on cooperative advertising, and uses the dynamic optimal control method to establish a dual channel supply chain consisting of two manufacturers and a retailer. Based on the integration transaction, the new energy vehicle supply chain cooperative green investment optimization model is established, This paper discusses the optimal equilibrium strategy of supply chain members in the case of manufacturer competition and cooperation by using differential game theory. The research finds that when the sum of the marginal profits of the network channels and traditional channels of the new energy vehicle manufacturer 1 is small and the quality advantage is not obvious, the green innovation efforts of the new energy vehicle manufacturer 2 will be higher than that of the manufacturer 1. In addition, the green innovation efforts of the new energy vehicle manufacturer 1 are higher than that of the manufacturer 2. The profit changes of the two manufacturers are related to the efficiency of green innovation and the marginal profits under the two channels. The two new energy vehicle manufacturers will choose cooperation only when there is a large difference in green innovation efficiency. After cooperation, the profits of manufacturers will increase and the profits of retailers will decrease.

Keywords: New Energy Vehicles; Optimal Control; Integral Trading; Green Investment; Competition and Cooperation

1. Introduction

With the increasingly serious environmental problems, fuel vehicles have not adapted to the trend of history, and new energy vehicles are entering the big stage of history. With the improvement of consumers' low-carbon awareness, consumers tend to buy products with a high degree of green. In order to increase the green goodwill of products, retailers usually carry out advertising; At the same time, in order to stimulate the development of new energy vehicles, China has formulated a "double points" policy. Under this policy, new energy vehicle enterprises must actively improve the quality of new energy vehicles in order to obtain corresponding points after selling new energy vehicles.

There are also some research on new energy vehicles based on point trading at home and abroad. Ma Liang et al. (2018) studied the technology innovation game competition of duopoly enterprises in the new energy vehicle industry. Li J, et al. (2020) discussed the influence of subsidy policy and double credit policy on the production decision of new energy vehicles and traditional vehicles.. Xie Jiaping et al. (2020) built a multi-level supply chain network for the sales of new energy vehicles and the recovery of power batteries to find the optimal conditions for the government to promote the balance between sales and recovery.

This paper the optimal equilibrium strategy of the dual-channel supply chain composed of two new energy vehicle manufacturers and one retailer under the integration transaction under the manufacturer competition model and cooperation model.

2. Problem Description and Basic Assumptions

This paper considers a two channel, two echelon supply chain consisting of two new energy vehicle manufacturers and one new energy vehicle retailer; Manufacturers carry out green innovation to make the green degree (i.e. quality) of new energy vehicles better. Retailers promote new energy vehicles through advertising efforts to form green goodwill. To facilitate the study, we propose the following assumptions:

(1) Suppose that the green innovation input level of the new energy vehicle manufacturer i at the t moment is $\frac{1}{2}n_1k_1^2$, The differential equation of the new energy vehicle quality $q_i(t)$ with the green innovation input within t is

$$\dot{q}_i(t)=k_i(t)-\delta q_i(t)i\in\{1,2\} \quad (1)$$

(2) Assuming that the retailer's advertising investment at any moment is $\frac{1}{2}n_2y^2$.

(3) There are two ways to sell new energy vehicles: traditional channels and online channels

$$D_{di}=(1-u)d_i+\alpha k_i(t)+\omega_1(k_i(t)-k_{3-i}(\mathrm{t}))+\tau q_i(t)-\eta q_{3-i}(t) \quad \textbf{(2)}$$

$$D_{ri}=ud_i+\alpha k_i(t)+\omega_1(k_i(t)-k_{3-i}(\mathrm{t}))+\beta y_i+\omega_2(y_i(t)-y_{3-i}(\mathrm{t}))+\tau q_i(t)-\eta q_{3-i}(t) \quad \textbf{(3)}$$

d_i is potential market capacity and D_{di} representing network channel demand; D_{ri} representing the needs of traditional channels; u represent the market share of traditional channels; α represents the impact coefficient of innovation on demand; β represents the impact coefficient of advertising on demand; τ represents the influence coefficient of quality on demand; ω_1 represent the innovation competition coefficient between companies; ω_2 represent the advertising competition coefficient between companies; η is the influence coefficient representing the product quality of other companies on demand. π_{ri} is margins of manufacturers in traditional channels, π_{di} is marginal profits of manufacturers in network channels, π_r is margins of retailers.

(4) Suppose that the green innovation efficiency of new energy vehicle manufacturer 1 is higher than that of new energy vehicle manufacturer 2 ($0<n_{m1}<n_{m2}$). $Q=\frac{n_{m1}}{n_{m2}}$.

3. Model establishment

3.1 Manufacturer's competition model

Under this model, the two new energy vehicle manufacturers and retailers make decisions with the goal of maximizing their own profits. The profit functions of two new energy vehicle manufacturers and retailers are as follows:

$$\max_{y_i}\Pi_r^1=\int_0^\infty e^{-pt}\sum_{i=1}^{2}(\pi_rD_{ri}-\frac{1}{2}(1-\varphi_i)n_ry_i^2)dt \quad \textbf{(4)}$$

$$\max_{k_i\varphi_i}\Pi_{mi}^1=\int_0^\infty e^{-pt}\ (\pi_{di}D_{di}+\pi_{ri}D_{ri}+h\theta(D_{di}+D_{ri})-\frac{1}{2}\varphi_in_ry_i^2-\frac{1}{2}n_{mi}k_i^2)dt \quad \textbf{(5)}$$

$$\dot{q}_i(t)=k_i(t)-\delta q_i(t)i\in\{1,2\}$$

ρ is discount rate, φ_r is proportion of advertising shared by manufacturers for retailers.

Proposition 1:

$$y_i = \frac{2(\beta+\omega_2)\ (\pi_{ri}+h\theta)\ +\beta\pi_r}{2n_r} \quad (6)$$

$$k_i = \frac{(h\theta+\pi_{ri}+\pi_{di})(\alpha+w_i)(\rho+\delta)+a\tau}{(\rho+\delta)n_{mi}} \quad (7)$$

$$\Pi_r^1 = \sum_{i=1}^{2}\left[\frac{\pi_r(\tau-\eta)}{\rho+\delta}q_i+\left(\pi_r\alpha+\frac{\pi_r(\tau-\eta)}{\rho+\delta}\right)\frac{(a-h\theta)(\alpha+\omega_i)(p+\delta)+a\tau}{(p+\delta)n_{mi}}+\frac{3\beta\pi_r c_i}{4\rho n_r}+\frac{ud_i\pi_r}{\rho}\right] \quad (8)$$

$$\begin{aligned}\Pi_{mi}^1 = &-\frac{b\eta}{\rho+\delta}q_{3-i}-\frac{\omega_2(\pi_{ri}+h\theta)c_{3-i}}{2n_r\rho}+\frac{(\pi_{di}+h\theta)d_i+(\pi_{ri}-\pi_{di})ud_i}{\rho}\\ &+\frac{a\tau}{p+\delta}q_i+\frac{(\rho+\delta)^2a^2(\alpha+w_1)^2+2(\rho+\delta)(\alpha+w_1)a^2\tau+a^2\tau^2}{2\rho n_{mi}(\rho+\delta)^2}\\ &-\frac{(\rho+\delta)^2ab(\alpha+w_1)\omega_1-(\rho+\delta)b\eta[(\alpha+\omega_1)b+a\omega_1]+b^2\eta^2}{\rho(\rho+\delta)^2n_{m(3-i)}}+\frac{c_i^2}{8\rho n_r}\end{aligned} \quad (9)$$

When the competition intensifies, the new energy vehicle manufacturer's green innovation investment, the retailer's advertising investment and the manufacturer's advertising share for the retailer increase; When the marginal profit of traditional channels of new energy vehicle manufacturers increases, the advertising share of retailers will increase, and the advertising investment of retailers will also increase.

3.2 Manufacturer's cooperation model

The two new energy vehicle manufacturers make decisions with the goal of maximizing the overall benefits of cooperation. The function of the retailer is shown in Formula 4. The overall profit of the two new energy vehicle manufacturers and the profit function of retailers are as follows

$$\max_{k_i\varphi_i}\Pi_{m_1+m_2}^2 = \int_0^\infty e^{-pt}\sum_{i=1}^{2}(\pi_{di}D_{di}+\pi_{ri}D_{ri}+h\theta(D_{di}+D_{ri})-\frac{1}{2}\varphi_i n_2 y_i^2-\frac{1}{2}n_1k_i^2)dt \quad (10)$$

Proposition 2:

$$y_i = \frac{2(h\theta+\pi_{ri})(\beta+\omega_2)-2\omega_2(\pi_{r(3-i)}+h\theta)+\beta\pi_r}{2n_r} \quad (11)$$

$$k_i = \frac{[(\alpha+\omega_1)(\rho+\delta)+\tau]a-[\omega_2(\rho+\delta)+\eta]b}{(\rho+\delta)n_{mi}} \quad (12)$$

$$\Pi_r^2 = \sum_{i=1}^{2}\left\{\begin{aligned}&\frac{\pi_r(\tau-\eta)}{\rho+\delta}q_i+\left(\pi_r\alpha+\frac{\pi_r(\tau-\eta)}{\rho+\delta}\right)\frac{[(\alpha+\omega_1)(\rho+\delta)+\tau]a-[\omega_1(\rho+\delta)+\eta]b}{(\rho+\delta)n_{mi}}\\ &+\frac{\beta\pi_r[2(h\theta+\pi_{ri})(\beta+\omega_2)-2\omega_2(\pi_{r(3-i)}+h\theta)+\beta\pi_r]}{4\rho n_r}+\frac{ud_i\pi_r}{\rho}\end{aligned}\right\} \quad (13)$$

$$\Pi_m^2 = \frac{a\tau}{p+\delta} q_i - \frac{b\eta}{p+\delta} q_{3-i} + \frac{[(\alpha+\omega_1)(\rho+\delta)+\tau]^2 a^2 - [\omega_1(\rho+\delta)+\eta]^2 b^2}{2\rho(\rho+\delta)^2 n_{mi}}$$
$$+ \frac{(h\theta+\pi_{ri})(\omega_2+\beta)[2(h\theta+\pi_{ri})(\beta+\omega_2)-2\omega_2(\pi_{r(3-i)}+h\theta)+\beta\pi_r]}{2\rho n_r}$$
$$+ \frac{[2(h\theta+\pi_{ri})(\beta+\omega_2)-2\omega_2(\pi_{r(3-i)}+h\theta)]^2+\beta^2{\pi_r}^2}{8\rho n_r} + \frac{(\pi_{di}+h\theta)d_i+(\pi_{ri}-\pi_{di})ud_i}{\rho}$$
$$- \frac{[\omega_1(p+\delta)+\eta]a\{[(\alpha+\omega_1)(\rho+\delta)+\tau]b-[\omega_1(\rho+\delta)+\eta]a\}}{\rho n_{m(3-i)}(p+\delta)^2} \quad (14)$$

Inference 1:

The corollary 1 When the value range Q is within a certain range（$Q_1 < Q < Q_2$）, make $\Pi_{m1}^2 - \Pi_{m1}^1 > 0$ and $\Pi_{m2}^2 - \Pi_{m2}^1 > 0$;two new energy vehicle manufacturers can choose to cooperate.

4. Example analysis

The following will carry out numerical simulation on relevant conclusions to more intuitively analyze and compare the impact of key parameters on the profits of all members of the supply chain, and set the basic parameters as $d_1 = d_2 = 100$, $\pi_r = 0.6$ (Wan Yuan), $\pi_{r1} = 0.9$ (Wan Yuan), $\pi_{d1} = 1$ (Wan Yuan), $\pi_{r2} = 0.8$ (Wan Yuan), $\pi_{d2} = 0.9$ (Wan Yuan), $h = 0.3$, $\theta = 0.4$ (Wan Yuan), $n_r = 1, n_{m1} = 0.9$, $n_{m2} = 1, u = 0.8$, $\rho = 0.2$, $\delta = 0.2$, $\alpha = 0.8$, $\omega_1 = 0.3$, $\omega_2 = 0.2$, $\beta = 0.7$, $\tau = 0.8$, $\eta = 0.5$, $q_{01} = 8$, $q_{02} = 6$

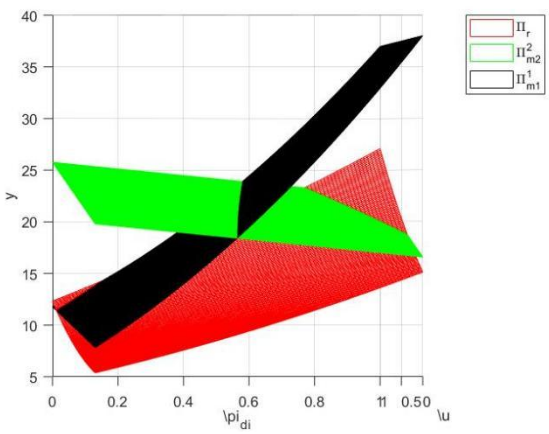

Figure 1Changes of members with A and B with μ and π_{d1}

It can be seen from Figure that the profit of retailers always decreases with the increase of the manufacturer's marginal profit in the network channel, and increases with the increase of the traditional market share. The profit of new energy vehicle manufacturer1 always increases with the increase; The change with is not static, and is related to the π_{d1}. When π_{d1} is small, the profit of new energy vehicle manufacturer 1 increases with the increase of traditional market share; when π_{d1} is large, the profit of new energy vehicle manufacturer 1 decreases with the increase of traditional market share.

5. Conclusion

We can draw the following conclusions: when the sum of marginal profits of new energy vehicle manufacturer 1's network channels and traditional channels is small and the quality advantage is not obvious, the green innovation efforts of new energy vehicle manufacturer 2 will be higher than that of manufacturer 1. In addition, the green innovation efforts of new energy vehicle manufacturer 1 are higher than that of manufacturer 2. When the green innovation efficiency of the two new energy vehicle manufacturers is significantly different, they will choose to cooperate. After cooperation, the profits of the manufacturers will increase and the profits of retailers will decrease.

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