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Research on the Development Path of New Energy Vehicles in the Post Subsidy Era

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Abstract: This paper establishes a tripartite evolutionary game model based on the mutual influence and restriction among the government, automobile enterprises and consumers. Through the visual analysis of the behavior path of the three parties under different scenarios, the impact of different policies on new energy vehicle industry is explored. The results show that under the background of post subsidy era, the government, enterprises and consumers will finally reach the game equilibrium (no support, R&D and purchase) in the development of new energy vehicle industry. The government's R&D subsidies for the new energy vehicle industry are necessary in the short term. The R&D investment of automobile enterprises in new energy vehicles should be within a reasonable range, the excessive R&D investment will reduce their price competitiveness.

Keywords: New energy vehicles; Post-modern subsidy; Tripartite evolutionary game; Scenario analysis

1 Introduction

The development of modern industry has brought many conveniences to human life. However, the characteristics of high pollution and high energy consumption of traditional industries such as steel and coal make the problems of environmental pollution and resource shortage increasingly prominent. As the pearl of the traditional industrial system, traditional fuel vehicles generally use fossil fuels such as gasoline and diesel as the power source, which will emit waste gases such as carbon dioxide during vehicle operation, this is one of the important reasons for air pollution, global warming and acid rain. As an effective way to solve the above problems, new energy vehicles (NEV) are favored by governments and automobile enterprises all over the world. In recent years, governments and auto companies have issued a timetable for the suspension of production and sales of fuel vehicles, and issued relevant policies to vigorously support the development and consumption of new energy vehicles. Obviously, it has become a general trend for new energy vehicles to replace traditional fuel vehicles.

China's new energy vehicle market has experienced a long subsidy stage, and has successively issued a series of subsidy support policies, which effectively promoted the development of the new energy vehicle market, making China surpass the United States as the world's largest new energy vehicle market for the first time in 2015. However, excessive policy stimulus inevitably breeds industry chaos such as deception and abuse of subsidies, which deviates from the original policy objectives and is not conducive to the long-term development of the new energy vehicle industry. Since 2017, the subsidy amount of new energy vehicles has been reduced by 20% compared with previous years, and the local financial subsidy shall not exceed 50% of the central single vehicle subsidy. Many policies show that new energy vehicles have entered the

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era of "post subsidy". However, at a time when the scale and development momentum of China's new energy vehicle industry are irresistible, the way to optimize the subsidy management policy and formulate a reasonable industrial development strategy is still a major issue to be solved.

Through the analysis of the interactive relationship among government, enterprises and consumers, this paper discusses the behavior patterns of each subject with the help of system dynamics theory. The dynamic evolution path is visualized, and the impact of different policies on the behavior patterns of game subjects is analyzed. It has a certain reference value for the government to formulate policies which encourage enterprises to develop independently, achieve technological breakthroughs and realize the healthy development of new energy vehicle industry.

2 The tripartite game model

The game among government, enterprises and consumers exists in the whole process of the development of new energy vehicle industry. The government pursues the maximization of the overall social welfare. It should not only consider the economic development, but also pay attention to the environmental and social benefits brought by the industrial development of NEV, and formulate policies from the overall perspective to decide whether to support and subsidize NEV industry. At the same time, the government must also consider the reactions of enterprises and consumers in formulating policies. Based on the principle of profit maximization, enterprises choose between producing new energy vehicles and traditional vehicles. The decisions will be affected by government policies and consumer demand. On this basis, the government, enterprises and consumers make decisions according to the goal maximization principle, and the balance can be reached through multiple games, so as to establish the evolutionary game model of the government, enterprises and consumers. The relevant parameters set and their meanings are explained in the table 1.

Table 1: Parameter setting

Parameter	Meaning description
V_1	Social welfare benefits obtained by the government from the production of traditional fuel vehicles by enterprises
V_2	Social welfare benefits obtained by the government from enterprise production of NEV(V_2>V_1) NEV(V_2>V_1)
A	Government regulatory benefits (including reputation, market order, social welfare, etc.)
S_e	Government R&D subsidies for NEV manufacturers
S_c	Government preferential policies and subsidies for consumers purchasing NEV
H	Significant benefits brought by NEV as a strategic emerging industry
R_1	Long term sales profit brought by enterprise R&D of high-performance NEV
R_2	Short term sales profit brought by enterprise production of general technology NEV(R_1-C_1>R_2)
R_3	Profit from sales of traditional energy vehicles(R_1-C_1>R_3-C_2)
C_1	R&D cost invested by enterprises in high-performance NEV
C_2	R&D cost invested by enterprises in traditional energy vehicles(C_1>C_2)
C_g	Cost of government regulation of industry market
U_0	Utility of consumers' purchase of general technology NEV
U_1	Utility of consumers buying traditional energy vehicles(U_0<U_1)
ΔU_1	The utility gap between consumers' purchase of high-performance NEV and ordinary technology NEV
ΔU_2	Consumer utility gap caused by enterprise investment in R&D of traditional fuel vehicles (ΔU_1>0,ΔU_2>0,ΔU_1>ΔU_2)
K	Taxes that consumers need to pay to the government when buying traditional energy vehicles

According to the above parameter setting, the tripartite evolutionary game payoff matrix in the new energy vehicle market can be constructed, which as shown in table 2.

Table 2: Evolutionary game payoff matrix

Government	enterprise	Purchase of NEV(z)	Purchase of traditional vehicles(1-z)
support(x)	research and development (y)	V_1+A-C_g-S_e-S_c+H R_1+S_e-C_1 U_0+ΔU_1+S_c	V_2+A-C_g+K R_3-C_2 U_1+ΔU_2-K
	no research and development (1-y)	V_1+A-C_g-S_c+H R_2 U_0+S_c	V_2+A-C_g+K R_3 U_1-K
No support(1-x)	research and development (y)	V_1+H R_1-C_1 U_0+ΔU_1	V_2 R_3-C_2 U_1+ΔU_2
	no research and development (1-y)	V_1+H R_2 U_0	V_2 R_3 U_1

Assuming that E_s and E_{ns} represent the expected return of the local government's strategy of supporting and not supporting the new energy vehicle industry respectively, $\overline{E_1}$ refers to the average expected return after the government makes a decision, it can be obtained by calculation:

$$\begin{cases} E_s = yz(V_1 + A - C_g - S_e - S_c + H) + y(1-z)(V_2 + A - C_g + K) \\ +(1-y)z(V_1 + A - C_g - S_c + H) + (1-y)(1-z)(V_2 + A - C_g + K) \\ E_{ns} = yz(V_1 + H) + y(1-z)V_2 + (1-y)z(V_1 + H) + (1-y)(1-z)V_2 \\ \overline{E_1} = xE_s + (1-x)E_{ns} \end{cases} \tag{1}$$

The replication dynamic equation of local government groups is :

$$F(x) = dx/dt = x(E_s - \overline{E_1}) \tag{2}$$

Assuming that E_r and E_{nr} represent the expected returns of automobile enterprises choosing R&D and not R&D strategies respectively,$\overline{E_2}$ is the average income of new energy vehicle enterprise behavior. Then we have the following equation.

$$\begin{cases} E_r = xz(R_1 + S_e - C_1) + x(1-z)(R_3 - C_3) + (1-x)(1-z)(R_3 - C_2) \\ E_{nr} = xzR_2 + x(1-z)R_3 + (1-x)zR_2 + (1-x)(1-z)R_3 \\ \overline{E_2} = yE_r + (1-y)E_{nr} \end{cases} \tag{3}$$

The replication dynamic equation of new energy vehicle enterprise group is:

$$F(y) = dy/dt = y(E_r - \overline{E_2}) \tag{4}$$

Assuming that E_b and E_{nb} represent the expected benefits of consumers choosing new energy vehicles and traditional energy vehicles respectively, $\overline{E_3}$is the average income of consumer behavior. Then we have equation (5).

$$\begin{cases} E_b = xy(U_0 + \Delta U_1 + S_c) + x(1-y)(U_0 + S_c) + (1-x)y(U_0 + \Delta U_1) + (1-x)(1-y)U_0 \\ E_{nb} = xy(U_1 + \Delta U_2 - K) + x(1-y)(U_1 - K) + (1-x)y(U_1 + \Delta U_2) + (1-x)(1-y)U_1 \\ \overline{E_3} = zE_b + (1-z)E_{nb} \end{cases} \tag{5}$$

The replication dynamic equation of consumer groups is:

$$F(z) = dz/dt = z(E_b - \overline{E_3}) \tag{6}$$

Bring equations (1), (3) and (5) into equations (2), (4) and (6) respectively to obtain the replication dynamic equations of the government, automobile enterprises and consumers. A three-dimensional dynamic system can be obtained by sorting out equations (2), (4) and (6), which as shown in equation (7).

$$\begin{cases} F(x) = dx/dt = x(E_s - \overline{E_1}) = x(1-x)[-S_e xy - (S_c + K)z + A - C_g + K] \\ F(y) = dy/dt = y(E_r - \overline{E_2}) = y(1-y)[S_e xz + (R_1 - R_2 + C_2 - C_1)z - C_2] \\ F(z) = dz/dt = z(E_b - \overline{E_3}) = z(1-z)[(K - U_1)x + (\Delta U_1 - \Delta U_2)y + U_0 - U_1] \end{cases} \tag{7}$$

3 Simulation analysis of the tripartite evolutionary game in NEV industry

Through the analysis, we know that the stability of the equilibrium point of the tripartite evolutionary game requires the corresponding parameters to be within a certain value range. By visualizing the evolutionary game process of government, enterprises and consumers, the economic meaning behind the choice of tripartite behavior strategies could be explored. The long-term development path of NEV industry could be optimized.

Generally speaking, the development history of NEV industry is short. The available data are scattered, and the data released by all parties are inconsistent, so it is difficult to collect on the whole. Therefore, combined with the actual situation of China's NEV industry and referring to the experience of parameter assignment in relevant literature [9, 10], this paper assigns the corresponding parameters. The initial assignment of parameters satisfying the stability of equilibrium solution is shown in table 3.

In the tripartite game between the government, NEV car enterprises and consumers, the subtle changes in the behavior of each game subject will change the behavior path of other subjects, and even may completely change the equilibrium strategy of the subject in some cases. Therefore, studying the evolution path of each subject under different scenarios can not only visually describe the evolution process of equilibrium results, but also explore the impact of different policies on the long-term development of NEV, then provide guidance for policy formulation.

Changes in government subsidies will inevitably affect the R&D decisions of NEV enterprises. By adjusting the government's R&D subsidies to NEV, we can analyze the impact of government subsidies on the R&D decisions of NEV enterprises. When the government's R&D subsidy to NEV declines from 1 to 0, the evolution results of enterprise R&D decisions are shown in Figure 1. In Figure 1, the vertical axis represents the behavior probability of NEV enterprises choosing the "R&D" strategy. The horizontal axis represents the time process of evolution (the time t here has no specific unit, but only represents the speed of the evolution of behavior subjects). The six red to blue rays represent the evolution path of vehicle enterprise behavior when the government subsidy S_e is 1,0.8, 0.6, 0.4, 0.2 and 0 respectively. As shown in the figure, when the government subsidy S_e gradually decreases from 1 to 0, the decision-making curve of car enterprises tends to 1 more and more slowly. This shows that with less and less government subsidies, the speed of car enterprises investing in the research and development of NEV is also slower and slower.

Under the background of the current decline of NEV subsidies, it can still be seen that government subsidies play a strong role in promoting automobile enterprises to develop high-performance NEV. Therefore, in the formulation and implementation of subsidy policies, the government should change the direction of subsidies to NEV enterprises, from simply subsidizing NEV producing enterprises to subsidizing NEV R&D enterprises. The corresponding supervision and management should be strengthened, so as to avoid the occurrence of "compensation fraud". In this way, we can better guide enterprises to actively invest in the research and development of new high-performance NEV, and avoid the waste of resources caused by blind subsidies.

The change of government subsidies will not only affect the R&D decision of NEV enterprises, but also indirectly affect the sales price of NEV and consumers' purchase confidence, and ultimately affect

Table 3: Evolutionary game payoff matrix

parameter	V_1	V_2	A	S_e	S_c	H	R_1	R_2	R_3	C_1	C_2	C_g	U_0	U_1	ΔU_1	ΔU_2	K
value	5	12	4	1	1	2	16	3	2	10	1	10	2	4	2	1	0.5

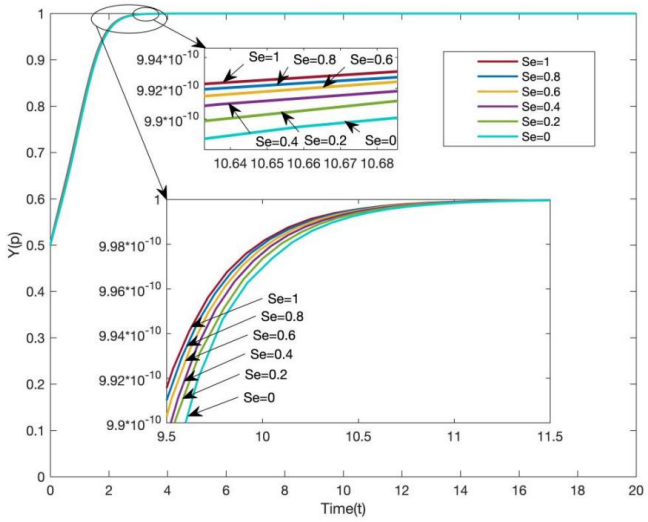

Figure 1: The influence of government support on the decision-making of automobile enterprises

consumers' decision whether to buy NEV. When the government's R&D subsidy to NEV declines from 1 to 0, the evolution results of consumer purchase decision are shown in Figure 2. In Figure 2, the vertical axis represents the behavior probability of consumers choosing the "purchase" strategy, the horizontal axis represents the time process of evolution. The six red to blue rays represent the evolution path of consumer behavior when the government subsidy S_e changes. As can be seen from Figure 2, when the government subsidy S_e gradually decreases from 1 to 0, the speed of consumer decision curve tends to 1 is slower and slower. This shows that the lower the government subsidy, the more hesitant consumers are when buying NEV. The consumers tend to choose negative strategies.

It can be seen from the evolution results that the government's R&D subsidies to NEV enterprises may play a guiding role in policy and represent the future automobile trend. On the one hand, the increase of R&D subsidies is conducive to automobile enterprises to reduce production costs and make more concessions on prices. On the other hand, R&D subsidies, as a "signal transmission", enhance consumers' confidence in the safety and endurance of new energy vehicles, and guide consumers to accept new energy vehicles faster. Therefore, in the long run, the government's reasonable R&D subsidies to NEV enterprises will have a strong positive effect on the development of NEV industry. At the beginning of this year, in order to alleviate the downward pressure on the economy, the state introduced a number of measures to promote the consumption of new energy vehicles. At the same time, the state has extended the implementation of financial subsidies and preferential tax policies to help industries tide over the difficult period of the epidemic. Governments at all levels have also issued many supporting policies around the consumption of new energy vehicles. In terms of expanding consumption, Shanghai, Beijing, Guangzhou, Tianjin, Shenzhen, Hangzhou, Hainan and other automobile purchase restriction cities have successively relaxed the incremental index of automobile / new energy vehicles. These policies have greatly increased consumers' confidence in the NEV market and promote consumers making decisions to buy NEV.

4 Conclusions

Based on bounded rationality, this paper establishes a game model. The evolutionary game theory is used to analyze the evolution process of government, automobile enterprises and consumer behavior in the post subsidy era of new energy vehicles. The government, enterprises and consumers will finally reach a game equilibrium (no support, R&D and purchase) in the game of NEV. This means that the government will gradually withdraw from the NEV market, and the development of NEV industry will be mainly determined by market subjects such as enterprises and consumers. However, in the short term, the government's R&D subsidies for automobile enterprises are also important, which plays a strong role in promoting automobile

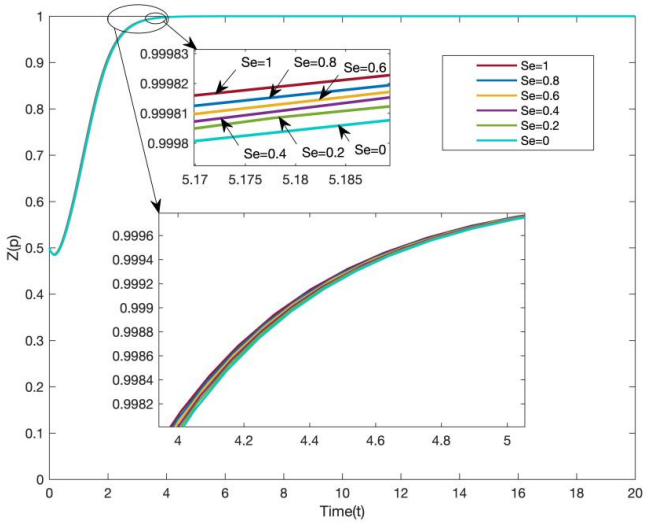

Figure 2: The influence of government support on the decision-making of automobile enterprises

enterprises to develop high-performance NEV.

In addition, reasonable subsidies will give consumers a policy oriented role, enhance consumers' confidence in buying cars, and promote the healthy development of NEV industry. The R&D investment of NEV vehicle enterprises should be within a reasonable range. The research shows that there is a positive correlation between the R&D investment of the enterprise and the government subsidy.

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