Contemporary Mathematics
http://ojs.wiserpub.com/index.php/CM/

UNIVERSAL WISER PUBLISHER

Research Article

Analysis of Interested Subjects in New Energy Vehicle Industry-Based on Game Theory Perspective

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Received: 15 November 2024; **Revised:** 5 December 2024; **Accepted:** 6 December 2024

Abstract: This paper analyzes the stakeholders of the new energy vehicle industry strategic choices in market competition using Nash equilibrium and cooperative game theory from game theory, employing mathematical models. First, This paper constructs a game model containing multiple competitors to determine the optimal strategy of the industry in the non-cooperative situation. Secondly, the cooperative game theory is introduced to analyze the distribution of various stakeholders in the new energy vehicle industry under the condition of cooperation, and to discuss how to achieve win-win results through cooperation.Verifying the model's effectiveness through empirical analysis, we suggest competitive strategies to be employed in the tripartite game. Our research demonstrates that game theory can provide a scientific basis for the new energy vehicle industry to devise effective competitive tactics in the intricate market environment.

Keywords: game theory, nash equilibrium, cooperative game, firm competition, market strategy

MSC: 91A10, 91A12, 91A80, 91B26, 91B76

1. Introduction

As the largest carbon emitter in the world, China's share of carbon emissions from the production or use of automobiles cannot be ignored. According to the International Energy Agency (IEA), carbon emissions from the transportation sector account for more than 10% of the country's total emissions [1]. Therefore, in order to reduce China's overall carbon emissions, it is necessary to reduce carbon emissions from automobiles, especially fuel vehicles. In this context, vigorously developing the new energy automobile industry has become an imminent problem that needs to be solved in China. This is not only of great significance for coping with global warming and energy crisis and promoting the transformation and development of the automobile industry, but also plays a positive role in promoting people to form a green and low-carbon lifestyle [2, 3].

The development strategy of China's new energy automobile industry originated from the proposal of "863 plan" in 2001, which aimed to promote the research and development and industrialization of new energy vehicles through scientific and technological innovation [4]. Subsequently, the state has launched a number of policies to promote the development of the new energy vehicle industry, such as the "Energy Saving and New Energy Vehicle Industry Development Plan (2012-2020)" and the "New Energy Vehicle Recommended Vehicle Model Catalog for Popularization

DOI: https://doi.org/10.37256/cm.5420246081

and Application", etc. [5, 6]. After more than 20 years of development, China's new energy vehicle industry has taken shape and achieved some success, but it still needs to go through a long journey in realizing a mature market [7, 8].

As the world's largest automobile consumer, China is facing the dual challenges of environmental degradation and rapid depletion of fossil energy. Environmental pollution is a growing problem, especially in large cities, where air quality and residents' health are seriously affected [9, 10]. Meanwhile, the rapid depletion of fossil energy not only exacerbates the energy security problem, but also has a negative impact on economic development [11]. Therefore, accelerating the cultivation and development of the new energy vehicle industry will help to alleviate the pressure on resources and the environment and promote the sustainable development of the automobile industry [12, 13].

In recent years, China's new energy vehicle industry has been booming, and in 2015, China's new energy vehicle sales surpassed the United States for the first time, becoming the world's first (China Association of Automobile Manufacturers, 2015). According to the China Association of Automobile Manufacturers, China's new energy vehicle production reached 517,000 units and sales reached 507,000 units in 2016, with year-on-year growth of 51.7% and 53% respectively (China Association of Automobile Manufacturers, 2016). This achievement not only reflects the effectiveness of national policies, but also the market's recognition and support for new energy vehicles [14, 15].

However, despite the remarkable progress, China's new energy vehicles are still in their infancy and face many challenges. Firstly, the technology is immature, and new energy vehicles still need to be improved in terms of range and charging speed [16, 17]. Secondly, the infrastructure is not perfect, the construction of charging piles and other supporting facilities lags behind, affecting the consumer experience [18]. Finally, the market recognition is low, and consumer awareness and acceptance of new energy vehicles still needs to be improved [19]. In this context, national policy subsidies are still the main driving force for the rapid development of the new energy vehicle industry [20].

2. Core theoretical foundations

2.1 *Equilibrium theory and game theory*

Equilibrium theory refers to the understanding of the interplay between output, consumption and value through the entire macroeconomic framework, the relationship. The core theory of this doctrine is that commodities have a relatively equilibrium price system in this macroeconomic framework, and that each consumer achieves the highest possible consumption benefits by choosing a product under the constraints of the established value of the commodity and the cost of the capital; that each firm will, at the established market price, the Each firm will determine its level of output by the supply of that product to maximize the revenue of their respective firms; the demand and supply of products in each market are in equilibrium. However, when there are externalities in the market, when the interests of consumers and the benefits of corporate producers are optimized, the market efficiency is not optimal, which can easily lead to market failure. In the case of new energy vehicles, government subsidies for consumers in the sales of new energy vehicles are advanced by the enterprises in advance, and then the enterprises apply for subsidies from the relevant departments based on the sales vouchers. Therefore, government subsidies for consumers ultimately flow to new energy vehicle manufacturers. However, when the government subsidies are completely withdrawn from the market, the government's intervention disappears, and in the absence of policy support and government subsidies and dividends, compared with the development of mature traditional fuel vehicles, consumers for the shortcomings of new energy vehicles and personal utility, greatly reducing the desire to buy new energy vehicles. The producers of new energy vehicles will not have the desire to produce new energy vehicles or promote the development of new energy vehicles considering the factors of technological innovation, production costs, and consumer demand, which will ultimately lead to the predicament of "market failure".

Game theory is the specific guiding theory of this paper, as a rigorous and quantifiable interactive decision-making theory, naturally applicable to the study of competitive action programs between multiple parties. In the theoretical development of game theory, a variety of game models have emerged, including static game with complete information, dynamic game with complete information, static game with incomplete information and dynamic game with incomplete information, according to which four equilibrium states can be obtained. The incomplete static game is a more mature game in the development process of game theory, which should be more widely used. There are two kinds of situations in the incomplete information static game: one is that all participants in the game choose at the same time, and there is no time sequence; the other is that each participant in the game chooses the action of each participant in the time sequence, but each participant doesn't know the specific action of other participants, i.e., the participant who chooses later doesn't know that the participant who chooses first doesn't know that the participant who chooses first chooses. In the other case, there is a temporal sequence of the actions of the participants in the game, but each participant does not know the specific actions of the other participants, that is, the participants who choose later do not know the specific programs and actions taken by the participants who choose first, therefore, the approximation of the existence of the sequence is regarded as the simultaneous actions of the participants. The main goal of studying static games with incomplete information is to reveal economic activities, but in many static game relationships there are also incomplete information characteristics. An in-depth exploration of such incomplete information static games is both for the purpose of optimizing the game-related theories and is also necessary for solving practical problems.

3. Three-way game modeling of government, consumers and enterprises

3.1 *Model design*

The development of new energy vehicles will help China get rid of its dependence on dollar-denominated oil, ease energy tension, reduce carbon emissions and the problems of extreme weather and environmental degradation they cause, and at the same time help China's automobile industry to achieve a bend in the road. Therefore, the government attaches great importance to the development of the new energy vehicle industry and has introduced a series of policies to promote the progress of the new energy vehicle industry.

Therefore, the government is an indispensable parameter to establish the game model. Enterprises and consumers are the main producer and the main consumer, so the three-party game model is established for the government, consumers and enterprises. The government's subsidy policy and tax policy are two important policies implemented by the government for the new energy automobile industry and the traditional automobile industry.

Promoting the progress of new energy vehicles requires the joint efforts of all fields. In this, the government, enterprises and consumers play a key role. Therefore, in order to deeply analyze the competitive relationship between the government, enterprises and consumers, we can make the following assumptions without changing the core of the problem:

Assumption 1 The parties involved in the game include the government, automobile manufacturers, and consumers, all of whom are groups with limited rationality, and who are constantly searching for the best strategy in multiple rounds of the game.

Assumption 2 The government subsidizes it with a subsidy ratio of $P1$ and a non-subsidy ratio of 1-P_1;

Suppose the proportion of consumers who buy new energy vehicles in case 3 is P_2, and the proportion of those who do not buy new energy vehicles but buy traditional fuel vehicles is 1-b.

Assumption 3 The proportion of car companies that choose to develop and produce high-quality new energy vehicles is c, and the proportion that do not develop is 1-c.

Where $a, b, c \in [0, 1]$, affected by time, are time functions.

Based on the above inferences, we can predict that the potential scenarios for firms in the competition include: first, they may choose to build traditional fuel vehicles, which produce large amounts of exhaust and become a dominant factor in urban air pollution, and thus must accept higher social obligations and run counter to their advocated green concepts, and thus suffer from multifaceted constraints from the government; and second, they may choose to secondly, they can choose to develop new models with clean energy, which is good for the environment and supported by the government, and be encouraged to develop this industry, while enjoying a series of preferential policies such as direct financial subsidies, exemption of purchase tax and so on. In addition, there are two types of choices for customers: either they refuse to buy a new energy vehicle or they decide to buy such a new vehicle. In this triangle, the government not only acts as a policy maker, but also performs regulatory duties. Similarly, there are two courses of action that the government will take to deal with the conflict between these three parties: one is to provide financial assistance to the new energy vehicles by allowing customers to pay for them at the selling price minus the subsidy, which the government then passes on to the manufacturers of the new energy vehicles in the form of a direct subsidy; and the other is to forgo any form of subsidy for the new energy vehicles. However, because the government represents the public interest, it has a greater responsibility to protect the environment, and the costs incurred usually far exceed the amount of subsidies granted to promote the development of the new energy vehicle industry. Therefore, we have designed the following parameters for the different stakeholders, as shown in Table 1 below:

Table 1. Parameter design table

Parameter categories	Parameter code	Parameter explanation
Government subsidies cost	H_1	Government subsidies for enterprise support
	H_2	Government subsidies to consumers Costs
Revenue	S_1	Costs for enterprises to develop new energy vehicles
Parameter categories	S_2	Cost of developing traditional cars
Government subsidies	S_3	Cost of environmental management without government support for enterprises
Cost	P_1	Profit of producing new energy vehicles
	P_2	Revenues from the production of conventional automobiles
	P_3	Total benefits of consumers using new energy vehicles
	P_4	Total benefits of consumers using traditional cars
	P_5	Long-term social benefits to the government from new energy vehicles

3.2 *Model solution*

Different strategies chosen by the government, firms and consumers produce different benefits, and their benefit matrices are shown in Table 2:

Table 2. Three-part benefit matrix for government, business and consumers

Government	Enterprises	Purchase of new energy vehiclesb	Purchase of conventional vehicles $1-b$
Government subsidizeda	Production of new energy vehiclesc	$P_1 - S_1 + H_1$	$-S_1 + H_1$
		$P_3 + H_2$	0
		$P_5 - -H_1 - H_2$	$-H_1$
	Manufacture of conventional automobiles $1-c$	$P_2 - S_2$	$-S_2$
		0	0
		$-S_3 - H_2$	$-S_3$
Government does not subsidize $1-a$	Manufacture of new energy vehiclesc	$P_1 - S_1$	$-S_1$
		P_3	0
		0	0
	Production of conventional cars $1-c$	$P_2 - S_2$	$-S_2$
		P_4	0
		$-S_3$	$-S_3$

Based on the above parameter assumptions and benefit matrix, the utility functions of the government, consumers and firms are counted as U_1, U_2 and U_3 respectively.

The government utility function is:

$$U_1 = a\{b[c(P_5 - H_1 - H_2) + (1-c)(-S_3 - H_2)] + (1-b)[c(-H_1) + (1-c)(-S_3)]\}$$

$$+ (1-a)b[c*0 + (1-c)(-S_3)] + (1-b)[c*0 + (1-c)(-S_3)] \quad (1)$$

Derived by taking the partial derivative of U_1 with respect to a:

$$F(a) = bcP_5 - bH_2 - cH_1 \quad (2)$$

From Equation (2), the government supports the development of the new energy vehicle industry only when $bcP_5 - bH_2 - cH_1 > 0$. The proportion of consumers choosing to buy new energy vehicles, the proportion of enterprises producing new energy vehicles, and the social benefits obtained by the government after implementing the new energy vehicle industry policy are all influencing factors for the government to provide subsidies for new energy vehicles.

The utility function of consumers is.

$$U_2 = b * \left\{ a[c(P_3 + H_2) + (1-c)*0] + 1 - a[c(P_3) + (1-c)*0] + (1-c)*0 \right\} \quad (3)$$

Derived by taking the partial derivation of U_2 with respect to b:

$$F(a) = acH_2 + c(P_3 - P_4) \quad (4)$$

From Equation (4), when $acH_2 + C(P_3 - P_4) > 0$, consumers will choose to buy new energy vehicles. The total utility of consumers to buy new energy vehicles, the utility of buying traditional cars and the government subsidies to consumers are three factors that constrain consumers consumers to buy new energy vehicles.

The utility function of the enterprise is:

$$U_3 = c\{a[b(P_1 - S_1 + H_1) + (1-b)(H_1 - S_1)] + (1-a)[b(P_1 - S_1) + (1-b)(-S_1)]\}$$

$$+ (1-c)\{a[b(P_2 - S_2) + (1-b)(-S_2)] + (1-a)[b(P_2 - S_2) + (1-c)(-S_2)]\} \quad (5)$$

Deriving U_3 about c yields:

$$F_{(C)} = aH_1 + b(P_{1\_}P_2) - (S_1 + S_2) \quad (6)$$

From Equation (6), when $aH_1 + b(P_1 - P_2) - (S_1 + S_2) > 0$, the enterprise will choose to produce new energy vehicles. The government subsidy for new energy vehicles, the total revenue and cost of new energy vehicles, the total revenue and cost of conventional vehicles, and the probability of government subsidy, and the proportion of new energy vehicles purchased by consumers are all related to whether the enterprise decide to produce new energy vehicles are related.

3.3 *Analysis of the equilibrium of the game among the three parties' interests*

As can be seen from the formula (2), the government's original purpose of subsidizing the new energy vehicle market is to reduce the cost and risk of car companies, increase the research and development of car companies to produce high-quality new energy vehicles and the willingness of consumers to buy new energy vehicles. Therefore, only when the revenue is large enough can it cover the other expenses. In addition, the government's utility in the new energy vehicle industry is proportional to the product of b and c, and inversely proportional to each. We can see that when the government subsidizes the new energy vehicle industry, it needs to subsidize both consumers and firms. This way the government will get the boost in social welfare due to the greening of the new energy vehicle industry. Subsidizing consumers or businesses alone will reduce social welfare. It is worth noting that because the government will consider the input-output ratio, in practice, the government will prioritize subsidies to large enterprises and may ignore small and micro enterprises, which also exacerbates the imbalance in the development of automobile enterprises.

As can be seen from formula (4), U_2 is positively correlated with $P_3 - P_4$, which means that the greater the utility consumers get from buying high-quality new energy vehicles developed by automobile enterprises, the more they recognize the high-quality automobiles developed and produced by automobile enterprises, and the more consumers are willing to buy new energy vehicles developed by automobile enterprises, which promotes the good development of the new energy automobile market. At the same time, we can see that the utility of consumers in the formula U_2 and H_2 are positively correlated, it is easy to see that the government for the car companies and consumers to subsidize an important reason is to reduce the cost of consumers to buy new energy vehicles, to enhance the willingness of consumers to buy new energy vehicles.

According to Equation (6), if both a and b are 0, the company's benefit will show a negative value, which means that the company, as a social organization, needs to take responsibility for public welfare and social environment protection in the process of manufacturing traditional vehicles. At the same time, due to the social nature of the company, it is enforced to carry out this obligation instead of just focusing on profit maximization. There are three key influences on whether a company chooses to produce electric vehicles: first, financial support from the government. The subsidy provided by the government is a key driver for the company to develop EVs, and the higher the amount, the higher the chances of the company producing EVs as H_1 rises and improves the company's efficiency; secondly, the magnitude of the increase or decrease in revenues generated by the company's production of EVs in comparison to conventional cars is positively proportional to its efficiency, and only if this magnitude is greater than 0 will the company consider whether to go into production of EVs; the last factor is the cost of producing EVs, which is the amount of revenue required to produce them. The last element is the cost of producing electric vehicles, there is an inverse relationship between cost and revenue, so many companies will control the cost to ensure profitability.

3.4 *Behavioral strategies of game subjects*

The behavioral strategy model based on the previous assumptions is shown in the game tree in Figure 1. Firstly, the government (G) will decide to provide a subsidy (H) to consumers (C) who have already purchased new energy vehicles. Consumers have two choices: to purchase a new energy vehicle (Y) or to insist on purchasing a conventional vehicle (N), and if they still choose to purchase a conventional vehicle, the amount of subsidy $H_1 = 0$. Based on the assumption of self-confirming expectations, it is difficult for new energy vehicle manufacturers (E) to observe and confirm the actual demand of consumers before completing the production decision, and therefore, automobile companies will According to its own expectations of market demand to decide its production, so its actual production of products may be the same as the final actual demand of consumers, or contrary, may produce various types of results as shown in Figure 1:

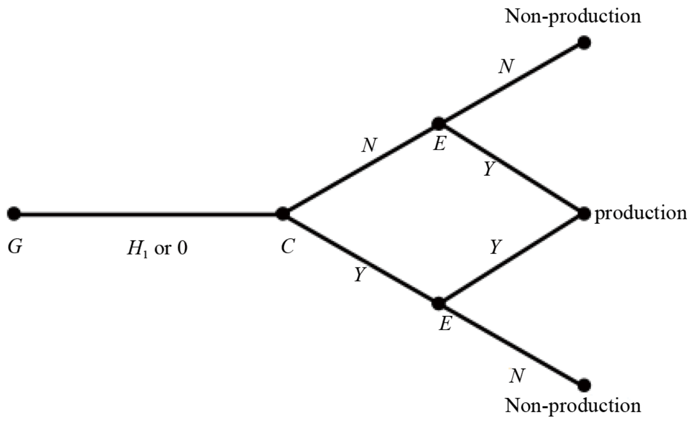

Figure 1. "Government-consumer-automobile company" tripartite game tree

There are four possible sets of behavioral strategies for consumers and producers: (Y, Y), (Y, N), (N, Y) and (N, N). Consumers' objective is to maximize utility, and the utility of consumers who buy new energy vehicles is denoted as Un, and the utility of consumers who buy conventional vehicles is denoted as Ut.

The following discusses the impact of the size of Un and Ut on the equilibrium outcome of the game. When $Un < Ut$, the utility level of purchasing traditional cars is higher than the utility brought by purchasing new energy cars, and consumers are more inclined to purchase traditional cars. At this time, the optimal response of the enterprise aiming at profit maximization is to produce traditional cars, and the strategy choice of the consumer-automobile enterprise is (N, N). The profit brought by producing traditional cars is $P2-S2$, and in the case of consistent expectations, there will no longer be enterprises in the market that have the will to produce new energy cars, which in turn will cause the government's industrial policy failure, and the government will make adjustments to its industrial policy. At this time, the government needs to pay the more expensive pollution control cost $S3$.

When $Un > Ut$, the utility level of purchasing new energy vehicles is higher than the utility brought by purchasing traditional vehicles, and consumers are more inclined to purchase new energy vehicles. At this time, the optimal choice of the enterprise is to produce new energy vehicles, and the strategy choice of the consumer-producing enterprise is (Y, Y). Then the enterprise's revenue should be the profit $P1-S1$ brought by the production of new energy vehicles, at this time the government's expenditure is $H1+H2$, that is, the government provides subsidies for new energy vehicle consumers and automobile enterprises, at this time the government to achieve the goal of its industrial policy, and the government, consumers and automobile manufacturers to achieve the optimal equilibrium results.

When $Un = Ut$, the utility of purchasing new energy vehicles is the same as that of traditional vehicles, and there is no difference between purchasing new energy vehicles and traditional vehicles, and the optimal strategies of consumers and automobile enterprises at this time are any one of (Y, Y) and (N, N). The equilibrium results of the game at this time will not be repeated.

4. Conclusions and recommendations

4.1 *From the government perspective*

Whether the government chooses to support new energy vehicles depends on the total utility it obtains. The total utility obtained is negatively correlated with the support cost and subsidy cost paid in the support process. It is positively correlated with the improvement of social image and the increase of social welfare in the process of support. The government restricts the enterprises producing traditional vehicles and punifies the consumers purchasing new energy vehicles, which is conducive to increasing the total utility obtained by the government and thus more conducive to the promotion of new energy vehicles.

4.2 *From the enterprise perspective*

Whether an enterprise chooses to produce new energy vehicles depends on the total utility it obtains. The size of the total utility it obtains is positively correlated with the government subsidy it obtains; It is positively correlated with the income obtained by consumers buying new energy vehicle enterprises; It is negatively correlated with the production cost paid by enterprises in the process of automobile production; In addition, the stronger the government's restrictions on traditional automobile production are, the more conducive it is for enterprises to adjust the direction of industrial development and turn to the new energy automobile industry.

4.3 *From the consumer perspective*

Whether consumers choose to buy new energy vehicles depends on the total utility they obtain. The size of the total utility obtained is positively correlated with the size of the government subsidy obtained at the time of purchase; it is positively related to the purchase income obtained by it; is negatively correlated with the extent to which the government punishes the purchase of conventional cars.

5. Conclusions and recommendations

Under the background of green and low-carbon, this paper analyzes the impact of policy changes on the behavior of consumers, enterprises and the government from their perspectives by constructing a three-party game model. It is found that: the government's subsidy is conducive to stimulating consumers to buy new energy vehicles; the more the government punishes enterprises for producing traditional vehicles, the more conducive to the transformation of enterprises to produce new energy vehicles; the higher the utility of consumers to buy new energy vehicles, the more they tend to buy new energy vehicles. Based on the above conclusions we put forward the following recommendations:

1. Reform automobile industry policies to reduce costs and increase revenues.

At this stage, the subsidization of new energy vehicles is disorganized, and this subsidy information has stimulated many automobile companies to overly devote themselves to the research and manufacturing of new energy vehicles, which has led China's electric vehicle market into a period of "sloppy development". Some companies do not even really understand and master the core technology to start production in a hurry, which directly affects the market a variety of electric vehicle models of uneven quality. Therefore, the future national subsidy strategy must be changed accordingly: from focusing on "quantitative" to "quality", the government should focus more on the industry's technical specifications, product specifications set, while further clarifying the details of the amount of subsidies for various types of models. No longer only the size of the enterprise as a basis for judgment, but to focus on observing the progress of its technology, for the lack of innovation ability of enterprises to be eliminated, and then moderately increase the production of high-precision products to promote industrial transformation and upgrading, and help have the strength of the scale of the electric vehicle enterprises.

2. The government should increase the strength of consumer subsidies.

In the long run, it is the optimal strategy for automobile enterprises to continuously invest in research and development of high-quality new energy vehicles. China's new energy vehicle industry has entered the growth period, enterprises should get rid of the mentality of relying excessively on government subsidies during the start-up period, improve the past development mode in a timely manner, formulate a new strategy, adapt to the changes, increase the research and development of new energy vehicles and innovations, and improve the performance of new energy vehicles as well as the user experience. Secondly, China's new energy automobile industry is in the growth period, the market prospect is good, for the investment opportunity period. Vehicle enterprises should combine their own advantages, take a variety of means to social financing, for their own to crack the technical problems, research and development of new batteries, optimize the fast charging technology, realize the key chip self-sufficiency and other key areas to provide sufficient funds. In addition, the government should continue to introduce and improve the development of new energy vehicles supporting policies to the market to send a signal to further develop new energy vehicles, to give car companies to develop and produce high-quality new energy vehicles confidence, to solve the worries of car companies to develop and produce high-quality new energy vehicles. For example, it should further guide new energy vehicle enterprises to carry out mergers and reorganization, and emphasize subsidies for cutting-edge technologies and bottleneck solutions for new energy vehicles.

This paper establishes a tripartite evolutionary game model of the government, car companies and consumers, and analyzes the three possible scenarios under the equilibrium outcome according to behavioral finance, and gives some suggestions accordingly. However, there are some shortcomings in this study. On the one hand, the assumptions of the empirical study are too idealized, the development environment of new energy automobile industry is more complex and changeable, and the influence of the external environment and peer competition is not analyzed. On the other hand, the article is relatively simple in terms of the introduction of variables, and does not take into account variables such as the type of subsidies and the realization rate of corporate innovation.

Conflict of interest

The author declares no competing financial interest.

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