The influence of the development of new energy vehicles on the environment from the game perspective

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Abstract. In order to alleviate environmental problems such as air pollution, this paper starts from the new energy automobile industry and analyzes the behavior strategies between the government and consumers, two stakeholders of new energy automobiles, through the dynamic game model. The following conclusions can be drawn from the utility function. First, theoretically, the government will not provide any financial subsidies for new-energy vehicles. Second, consumers' behavioral strategies are influenced by financial subsidies, vehicle purchase taxes, and the utility and cost of purchasing new energy vehicles or traditional vehicles. Therefore, the government should pay attention to the social level in order to achieve the maximum of social utility. On the one hand, the government should enhance the continuity of subsidy policies for consumers who buy new energy vehicles and strengthen the supervision of the implementation of subsidy policies. On the other hand, the government should play a positive role of its own credibility to the public and improve the awareness of environmental protection among car buyers. And consumers should constantly improve the sense of responsibility for environmental protection, so that the two can cooperate with each other and make contributions to environmental protection.

1. Introduction
With the aggravation of environmental problems such as global warming, air pollution and energy security, developing the new energy industry has become a more favorable measure to solve the current environmental crisis and alleviate the shortage of resources. In particular, the promotion of new energy vehicles is likely to make a significant contribution to improving air environment and saving energy at the present stage.

From the perspective of long-term interests, the transformation of the automobile industry to the direction of new energy vehicles through the optimization and upgrading of its own industrial structure will bring a lot of benefits in terms of social benefits and development costs. However, in the short term, the technological innovation and upgrading faced by the transformation process, as well as the acceptance degree and price tolerance of the majority of consumers to new energy vehicles, will bring resistance to new energy vehicle manufacturers. At present, the transformation of the automobile industry not only needs the efforts of the industry, but also needs more guidance and support from the government and consumers. Therefore, when studying the impact of the new energy automobile industry on environmental protection, this paper mainly starts from the government and consumers, and analyzes
their pursuit of interests and behavioral strategies through game theory, so as to put forward reasonable suggestions for improving air quality, mitigating natural resources and protecting the environment.

2. Literature Review

2.1. Environmental Impact of the Development of New Energy Vehicles
Referring to domestic and foreign literatures on the environmental impact of the development of new energy vehicles, most scholars have conducted researches from the perspective of lithium ion batteries for automobiles. Because lithium battery is the main power battery of new energy vehicles, its quality can affect the performance of new energy vehicles, and also determines the impact of the development of new energy industry on the air environment [1].

Then, Gordon et al. predicted the data through the model and concluded that the sharing of automatic electric vehicles, namely new energy vehicles, is expected to reduce energy consumption and air pollution related to transportation [2]. Therefore, the development and promotion of new energy vehicles can have a positive impact on the environment to a certain extent.

2.2. Study on New Energy Vehicles by Game Theory
Most domestic scholars mainly focus on the game analysis of financial subsidies to the relevant stakeholders of new energy vehicles, so as to study the problem of each subject to make the optimal strategy under the external conditions of interaction [3, 4].

Foreign scholars seldom study the game model among the stakeholders of new energy vehicles. By using a Stackelberg game model, Tushar et al. studied the energy exchange between a smart grid and a cluster of plug-in electric vehicles to optimize the tradeoff between the benefits of battery charging and the associated costs [5].

3. The Dynamic Game between Government and Consumers

3.1. Model Assumes
In this model, the game subjects involved in the environmental impact of the development of new energy vehicles are the government and consumers respectively. In order to simplify the discussion and analysis process, the following basic assumptions are made.

First, the players in the dynamic game process are rational. As a representative of a country, the government mainly pursues the maximization of social utility, while the consumer mainly pursues the maximization of personal utility.

Second, the government's policies are forward-looking and stable. The government's policy of providing subsidies to consumers who buy new energy vehicles is unlikely to change significantly in the next few years.

Third, there are only two categories of cars: traditional cars and new energy cars. Exhaust emissions from traditional vehicles pollute the atmosphere, while new energy vehicles do not pollute the environment. Consumers can only choose to buy new energy vehicles, or buy traditional cars if they do not buy new energy vehicles.

Fourth, consumers have the right to choose. The government will not interfere with consumers' purchase behavior of new energy vehicles, but consumers must accept the results of strategic behaviors.

3.2. Related Variables and Model Settings
For the government, there are two strategies: one is to subsidize the consumers who buy new energy vehicles; the other is not to subsidize the consumers who buy new energy vehicles. Suppose that the government gives a certain financial subsidy to consumers who buy new energy vehicles as \( S \), and the probability of making this strategy is \( P_1 \). However, the government should control the environmental pollution caused by not buying new energy vehicles. The governance cost is \( C_g \), and the probability of this strategy is \( (1 - P_1) \). Here, it is assumed that the social benefit obtained by the government from
consumers' purchase of new energy vehicles is R1. If consumers do not buy new energy vehicles, the social benefit is R2.

For consumers, there are also two strategies: one is to buy new energy vehicles; the other is to buy traditional cars without new energy vehicles. Assuming that the consumer's cost of purchasing new energy vehicles is C1, the total utility of using new energy vehicles is U1, and the probability of making this strategy is P2. The cost of buying a conventional car is C2, the total utility of using a conventional car is U2, and the probability of making this strategy is (1-P2). Because buying traditional cars will cause pollution to the environment, the vehicle purchase tax that needs to be paid is T. It is assumed that the utility obtained by the consumer does not change over time.

Since the research is dynamic game, there is game order in the game process between government and consumers. The government first decides whether to provide subsidies to consumers who buy new energy vehicles, and then consumers decide their purchase behavior according to the strategy made by the government, so as to construct the game tree between the government and consumers in the application of new energy vehicles, as shown in Fig. 1.

![Figure 1. The game tree between government and consumers.](image)

Based on the above analysis, the benefit matrix of the government and consumers is shown in Table 1.

| Number | Strategy Combination  | Government Benefit | Consumer Benefit |
|--------|-----------------------|--------------------|-----------------|
| 1      | (Subsidy, Purchase)   | R1 - S             | U1 - C1 + S     |
| 2      | (Subsidy, No Purchase)| R2 + T - Cg        | U2 - C2 - T     |
| 3      | (No Subsidy, Purchase)| R1                | U1 - C1         |
| 4      | (No Subsidy, No Purchase) | R2 + T - Cg    | U2 - C2 - T     |

3.3. Model Solution and Analysis

Through the game model analysis, it is known that the probability of government subsidies is P1, the probability of consumers to buy new energy vehicles is P2, and 0 ≤ P1, P2 ≤ 1. According to Table 1, the utility functions of the government and consumers can be obtained, and the specific process is shown below.

Firstly, the utility function of the government is solved, and then the strategic behavior of the government is analyzed.

The expected revenue when the government chooses the subsidy is:

\[ E(G)_{p,1} = P_2 \ (R_1 - S) + (1 - P_2) \ (R_2 + T - C_g) \]  (1)

The expected revenue when the government chooses not to subsidize is:

\[ E(G)_{p,1} = P_2 \ R_1 + (1 - P_2) \ (R_2 + T - C_g) \]  (2)
The utility function of the government is:

$$U(G) = P_1 [P_2 (R_1 - S) + (1 - P_2) (R_2 + T - C_g)] + (1 - P_1)[P_2 R_1 + (1 - P_2) (R_2 + T - C_g)]$$

(3)

Tidy:

$$U(G) = P_1[P_2(R_1 - R_2 + C_g -S -T) + R_2 + T - C_g]+(1 - P_1)[P_2(R_1 - R_2 + C_g -T)+R_2 + T - C_g]$$

(4)

Partial derivative of the utility function of the government with respect to subsidies can be obtained as follows:

$$\frac{\partial U(G)}{\partial P_1} = - P_2 S$$

(5)

When the partial derivative is greater than 0, in theory, the government will provide subsidies to consumers who buy new energy vehicles. However, at this point, $P_2 S < 0$ and $S < 0$ can be further known, that is, the government will not provide any financial subsidies for new-energy vehicles. As China's new-energy vehicle market is still in its infancy, its development in the next few years will still be restricted by many factors such as capital, technology and market. If the government does not actively intervene to a certain extent, such as providing financial subsidies to consumers who buy new energy vehicles, it will be difficult to quickly open up the domestic market of new energy vehicles in a short time, so that the air environment cannot be controlled from the source of exhaust emissions. Therefore, in combination with the current situation and existing rules and regulations, the Chinese government should consider the non-material effects of the subsidy strategy on the whole society at the present stage and provide certain financial subsidies to consumers who buy new energy vehicles.

Next, the utility function of the consumer is solved, and then the behavior strategy of the consumer is analyzed.

Consumers choose to buy new energy vehicles regardless of the expected benefits of traditional cars:

$$E(C)_{p_2} = P_1 (U_1 - C_1 + S) + (1 - P_1) (U_1 - C_1)$$

(6)

Consumers choose to buy traditional cars regardless of the expected benefits of new energy vehicles:

$$E(C)_{1-p_2} = P_1 (U_2 - C_2 - T) + (1 - P_1) (U_2 - C_2 -T)$$

(7)

The utility function of consumers is:

$$U(C) = P_2[P_1(U_1 - C_1 + S) + (1-P_1)(U_1 - C_1)] + (1-P_2)[P_1(U_2 - C_2 - T) + (1-P_1)(U_2 - C_2 -T)]$$

(8)

Tidy:

$$U(C) = P_2 (P_1 S + U_1 - C_1) + (1 - P_2) (U_2 - C_2 - T)$$

(9)

The partial derivative of the consumer's utility function with respect to the purchase probability can be obtained as follows:

$$\frac{\partial U(C)}{\partial P_2} = P_1 S + (U_1 - C_1) - (U_2 - C_2) + T$$

(10)

When the partial derivative is greater than 0, consumers will choose to buy new energy vehicles. $P_1 S + (U_1 - C_1) - (U_2 - C_2) + T > 0$, further, $(U_1 - C_1) - (U_2 - C_2) > 0$, that is, the difference between the utility and cost of consumers buying new energy vehicles is greater than the difference between the utility and cost of consumers buying traditional vehicles, which is also affected by financial subsidies and vehicle purchase taxes. The reason is that consumers first pursue the maximization of personal interests or the minimization of expenditure costs, and then consider the utility their strategic behaviors bring to the whole society. Without considering too much interference factors, on the one hand, when consumers need to pay the vehicle purchase tax of traditional non-energy vehicles, they tend to buy new energy vehicles. On the other hand, when the government provides financial subsidies for the purchase of new energy vehicles, consumers will also make the purchase of new energy vehicles strategy, to further improve the atmospheric environment quality.
4. Conclusion

From the perspective of game theory, this paper analyzes the impact of the development of new energy vehicles on the environment from the perspective of government and consumers through the dynamic game model, and draws the following two conclusions. First, according to the utility function of the government, in theory the government will not provide any financial subsidies for new-energy vehicles, but in reality this is not the case. Secondly, according to the utility function of consumers, consumers' behavioral strategies are affected by financial subsidies, vehicle purchase taxes, and the utility and cost of purchasing new energy vehicles or traditional vehicles.

Based on the solution and analysis of the above game model, relevant suggestions are given from the perspective of government and consumers. The government is mainly concerned with the whole level of the society and the ultimate goal is to achieve the maximum of social utility. In terms of policies, the government should enhance the sustainability of subsidy policies for consumers who buy new energy vehicles, provide more subsidy policies to consumers instead of automobile manufacturers, increase domestic demand through fiscal policies, and promote the implementation of double-cycle development. In terms of supervision, the government should strengthen supervision on the implementation of subsidy policies to prevent automobile manufacturers from damaging the legitimate rights and interests of consumers in the process of vehicle sales. In environmental protection publicity, the government should play an active role in promoting its credibility to the public, and improve the awareness of environmental protection among car-buying consumer groups. For car consumers, on the one hand, they should not only focus on the immediate interests, nor can they ignore the overall utility of the society. On the other hand, consumers should enhance their sense of responsibility for environmental protection and make contributions to improving air quality, mitigating natural resources and protecting the environment.

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