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Analysis of the Evolutionary Game of Key Participants' Behavior in the New Energy Vehicle Market

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ABSTRACT

This study aims to explore the strategic choices and evolutionary patterns of consumers, enterprises, and governments at different stages of the market development for NEVs (NEVs) by constructing an evolutionary game model involving these three key players. The goal is to provide a theoretical basis and policy recommendations for the healthy development of the NEV market. To address these issues, this research constructs a tripartite evolutionary game model to analyze the behavioral strategies and evolutionary patterns of governments, enterprises, and consumers in the NEV market. Firstly, it is assumed that there is information asymmetry among the three participants in the NEV market, and that all are bounded rationality groups. The participants' strategic choices will gradually evolve toward the optimal strategy. Based on this, a game model of the three participants—enterprises, consumers, and governments—was constructed, and different market environments were set to simulate the utility and dynamic changes of each participant under different strategies. The results show that in the initial stage, strong government incentive policies can effectively promote the initial development of the market, despite the low acceptance of NEVs by enterprises and consumers. In the development stage, with continuous policy support and the gradual maturation of the market environment, enterprises begin to shift towards NEV production, although consumer acceptance of NEVs still needs improvement. In the mature stage, with the maturity of product technology and the improvement of the market ecosystem, the behaviors of consumers and enterprises become stable, and the NEV market gradually enters a period of steady growth. Through this research, we hope to reveal the mechanism of government policy on market development, identify the optimal incentive measures, improve enterprises' technological innovation capabilities, and enhance consumers' purchase confidence, thereby jointly promoting the healthy and sustainable development of the NEV market. With concerted efforts, the NEV market can play a greater role in the construction of a green economy, achieving a win-win situation for both economic and environmental benefits.

KEYWORDS

Game Theory; Evolutionary Game; NEVs

1. INTRODUCTION

Globally, the problems of environmental pollution and resource scarcity are becoming increasingly severe, and the development of green and low-carbon energy has become an important means for countries to achieve sustainable development goals. As a representative of green and low-carbon energy, NEVs (NEVs) can reduce greenhouse gas emissions and dependence on fossil fuels, gradually becoming the focus of attention for governments, enterprises, and consumers. Against this backdrop, China's NEV market has experienced rapid development.

In recent years, the Chinese government has vigorously promoted the development of the NEV industry through a series of policy measures. These measures include financial subsidies, tax incentives, and the construction of charging facilities, effectively incentivizing enterprise R&D investment and production enthusiasm, while also enhancing consumers' willingness to purchase. Data shows that China has become the world's largest NEV market, with both sales and ownership ranking first globally. As of 2023, the penetration rate of NEVs in China reached 31.6%, and it is expected to reach 40% in 2024. However, despite significant achievements, the NEV market still faces many challenges, such as immature technology, high costs, and inadequate supporting facilities.

The purpose of this study is to deeply analyze the behavioral strategies and evolutionary patterns of consumers, enterprises, and governments in the NEV market by constructing a tripartite evolutionary game model, thereby providing theoretical basis and policy recommendations for further promoting the development of the NEV market. The study simulates the utility and dynamic changes of each participant under different strategies by setting different market environments, exploring the stability of the market in the initial, development, and maturity periods, and analyzing the key influencing factors at each stage.

Through this research, we hope to enhance enterprises' technological innovation capabilities and increase consumers' purchase confidence, thereby jointly promoting the healthy and sustainable development of the NEV market. With concerted efforts, the NEV market can play a greater role in the construction of a green economy, achieving both economic and environmental benefits.

2. LITERATURE REVIEW

The rapid development of the new energy vehicle (NEV) industry globally has become a key area in addressing climate change and promoting sustainable development. The Chinese government actively promotes the development of the NEV industry through policy tools such as financial subsidies, aiming to reduce greenhouse gas emissions and promote a transition to a green, low-carbon economy (Hu & Zhu, 2022) [1]. However, as subsidy policies gradually phase out, the healthy development of the NEV industry faces new challenges.

Government subsidy policies are crucial in driving the development of the NEV market. Research indicates that government financial incentives can effectively reduce the purchase costs for consumers, enhancing the market competitiveness of NEVs (Cao, Yang, & Junjie, 2016) [2]. Government subsidies not only directly influence consumer purchase decisions but also indirectly promote corporate investment in research and development (R&D) and technological innovation in the NEV sector. However, as the market matures, subsidy policies need to be more precise to avoid over-reliance on policies and to stimulate intrinsic innovation motivation within enterprises (Hu & Zhu, 2022).

Technological innovation by enterprises is the source of core competitiveness in the NEV industry. Companies seek a balance between government policies and market demands to achieve long-term sustainable development (Ji, Huang, & Zhong, 2020; Liu et al., 2024) [3, 4]. Technological innovation includes breakthroughs in core technologies such as battery technology and drive systems, as well as innovations in cost control, supply chain management, and market positioning. Enterprises need to flexibly adjust their technological innovation strategies in a constantly changing market environment to adapt to policy changes and market demands.

Consumer behavior research reveals the decision-making factors for consumers when purchasing NEVs, including price, performance, brand influence, and environmental awareness (Chen, 2021; Sun & Lü, 2018; Wu et al., 2024) [5-7]. Consumer perceptions and attitudes significantly impact the market acceptance of NEVs. Studies show that consumer acceptance of NEVs is influenced by multiple factors, including vehicle performance, cost-effectiveness, charging convenience, and environmental concern. Additionally, consumer purchasing behavior is affected by social norms and personal values.

Although existing literature provides valuable insights into the development of the NEV industry, there are still some research gaps. Firstly, existing studies mostly focus on the short-term effects of subsidy policies, with insufficient exploration of their long-term effects and market dependency. Secondly, the coordination mechanism between enterprise technological innovation and market demand has not been fully studied. Furthermore, the dynamic evolution process of consumer behavior requires more attention. Future research should focus more on these areas to provide more comprehensive and in-depth theoretical support and policy recommendations.

A comprehensive analysis of existing literature reveals a complex interplay between government subsidy policies, enterprise technological innovation, and consumer behavior. Government subsidy policies have played a crucial role in driving the NEV market, but as the market matures, more precise and sustainable policy design is needed. Enterprise technological innovation is the core of industry competitiveness and needs to be flexibly adjusted in a constantly changing market environment. Consumer behavior is influenced by multiple factors, and its dynamic evolution significantly impacts market development. Future research needs to delve deeper into these areas to promote the healthy development of the NEV industry.

3. CONSTRUCTION OF THE TRIPARTITE EVOLUTIONARY GAME MODEL

3.1. Model Assumptions

Assumption 1: The key participants in the evolutionary game model of the NEV market development include consumers, enterprises, and governments. It is assumed that information asymmetry exists, and each participant in the game is a bounded rationality group. Participants find it difficult to choose the optimal strategy in one game, and their strategic choices will gradually evolve toward the optimal strategy over time.

Assumption 2: In the NEV market, consumers' strategy set is (buy electric vehicle, buy fuel vehicle). Consumers buy vehicles to meet daily travel needs. If consumers choose to buy NEVs, the utility of using NEVs is U1, and the total cost of using NEVs (including purchase, maintenance, operation, etc.) is C1. If the government incentivizes NEVs, consumers can receive corresponding government subsidies S. Since the residual value of electric vehicles is significantly lower than that of fuel vehicles, Ut is introduced to describe the cumulative residual value loss of electric vehicles after a certain period. With technological maturity, new NEV products will have higher residual value at the end of the period. If consumers choose to buy traditional fuel vehicles, the utility of using fuel vehicles is U2, and the total cost of using fuel vehicles (including purchase, maintenance, operation, etc.) is C2, and carbon tax Cc needs to be paid. In the initial stage of the NEV market, the utility of using electric vehicles is lower than that of using fuel vehicles, and the high cost of electric vehicles is higher than the total cost of fuel vehicles. However, as the market develops, the utility of using electric vehicles U1 will gradually increase until it exceeds U2, and the total cost of electric vehicles C1 will gradually decrease until it is lower than C2.

Assumption 3: In the NEV market, the strategy set of enterprises is (produce electric vehicles, produce fuel vehicles). This study focuses on traditional automobile enterprises with mature fuel vehicle production lines. These enterprises aim to maximize net profit. If enterprises choose to transition to producing electric vehicles, they need to invest additional marginal costs C0, and the revenue from selling electric vehicles is R1. If the government incentivizes electric vehicle production, enterprises can receive government subsidies M1. If enterprises choose to continue producing fuel vehicles, they do not need to invest additional costs but need to pay environmental taxes C0, and the revenue from selling fuel vehicles is R2. As the NEV market matures and the penetration rate of electric vehicles increases, R1 will gradually increase, while R2 will gradually decrease.

Assumption 4: In the NEV market, the strategy set of the government is (incentivize the electric vehicle industry, not incentivize the electric vehicle industry). When the government chooses to incentivize the electric vehicle industry, it mainly achieves this through fiscal policies, providing financial subsidies M1 to enterprises producing electric vehicles and price subsidies S to consumers purchasing electric vehicles, incentivizing electric vehicles to align with sustainable development strategies, and obtaining social benefits Rz. Regardless of whether the government chooses to incentivize electric vehicles, due to the policy goals of sustainable development and the practical needs of environmental protection and energy shortages, it will impose environmental taxes on enterprises producing fuel vehicles and carbon taxes Cc on consumers purchasing fuel vehicles. Referring to the policy changes of the Chinese government, financial subsidies will gradually decrease as the market matures, but corresponding taxes will gradually increase.

Assumption 5: Suppose the probability that consumers choose to buy electric vehicles is x, then the probability of buying fuel vehicles is 1-x. Suppose the probability that enterprises choose to produce electric vehicles is y, then the probability of producing fuel vehicles is 1-y. Suppose the probability that the government chooses to incentivize electric vehicles is z, then the probability of not incentivizing is 1-z. The variables of the model are described in Table 1.

Table 1. Description of Related Variables

Variable	Description
x	Probability of consumers choosing to buy electric vehicles
y	Probability of automobile enterprises choosing to produce electric vehicles
z	Probability of the government choosing to incentivize the electric vehicle industry
R_z	Social benefits obtained by the government from incentivizing the electric vehicle industry
M_1	Government subsidies obtained by enterprises producing NEVs
M_2	Environmental taxes paid by enterprises producing traditional fuel vehicles
S	Government subsidies obtained by consumers purchasing NEVs
C_c	Carbon taxes paid by consumers purchasing traditional fuel vehicles
R_1	Revenue obtained by enterprises from selling NEVs
R_2	Revenue obtained by enterprises from selling traditional fuel vehicles
C_0	Marginal cost of enterprises producing NEVs
U_1	Utility obtained by consumers from purchasing NEVs
U_2	Utility obtained by consumers from purchasing traditional fuel vehicles
C_1	Purchase, maintenance, and operation costs of NEVs
C_2	Purchase, maintenance, and operation costs of traditional fuel vehicles
U_t	Cumulative residual value loss of NEVs after a certain period

2.1. Payoff Matrix

Based on the above assumptions, a game model of the three participants—enterprises, consumers, and governments—was constructed. The first row of functions in the cells represents the utility of the government, the second row represents the utility of the enterprises, and the third row represents the utility of the consumers. The payoff matrix for the different strategic behaviors of the three participants is shown in Table 2.

Table 2. Payoff Matrix

Enterprises	Consumers	Government	
		Incentivize	Not Incentivize
Produce Electric Vehicles	Buy Electric Vehicles	R_z-M_1-S	0
		$R_1+M_1-C_0$	R_1-C_0
		$U_1-C_1+S-U(t)$	$U_1-C_1-U(t)$
	Buy Fuel Vehicles	$R_z-M_1+C_c$	C_c
		$R_2+M_1-C_0$	R_2-C_0
		$U_2-C_2-C_c$	$U_2-C_2-C_c$
Produce Fuel Vehicles	Buy Electric Vehicles	R_z+M_2-S	M_2
		$-M_2$	$-M_2$
		$U_1-C_1+S-U(t)$	$U_1-C_1-U(t)$
	Buy Fuel Vehicles	$R_z+M_2+C_c$	M_2+C_c
		R_2-M_2	R_2-M_2
		$U_2-C_2-C_c$	$U_2-C_2-C_c$

4. TRIPARTITE EVOLUTIONARY GAME MODEL ANALYSIS

4.1. Expected Utility of the Three Participants

Based on the basic assumptions and payoff matrices of consumers, firms, and the government, the probability of consumers choosing to buy electric vehicles is denoted as x, and the probability of buying gasoline vehicles as 1-x. Let the expected utility of purchasing electric vehicles be E11, and that of gasoline vehicles be E12, with the total utility being E1. Therefore, the expected utilities and total utility for both strategies are as follows:

$$E_{11} = z[U_1 - C_1 + S - U(t)] + (1-z)[U_1 - C_1 - U(t)]$$

$$E_{12} = U_2 - C_2 - C_c$$

$$E_1 = xE_{11} + (1-x)E_{12}$$

For firms, the probability of producing electric vehicles is represented as x, and producing gasoline vehicles as 1−x. The expected utilities E21 and E22 and the total utility E2 are given as follows:

$$E_{21} = z + (1-x)z(R_2 + M_1 - C_0) + (1-x)(1-z)(R_2 - C_0)$$

$$E_{22} = (1-x)R_2 - M_2$$

$$E_2 = yE_{21} + (1-y)E_{22}$$

The government's probability of incentivizing NEVs is denoted as z, and not incentivizing as 1−z. The expected utilities E31 and E32, and the total utility E3 are defined as follows:

$$E_{31} = xy\ (R_z-M_1-S) + (1-x)\ y\ (R_z-M_1-C_c) + x\ (1-y)\ (R_z+M_2-S) + (1-x)\ (1-y)\ (R_z+M_2+C_c)$$

$$E_{32} = (1-x)yC_c + (1-y)xM_2 + (1-x)(1-y)(M_2 + C_2)$$

$$E_3 = zE_{31} + (1-z)E_{32}$$

4.2. Dynamic Replicator Equations for the Three Participants

The expected utility of consumers is simplified to the following expression:

$$E_{21} = U_1 - C_1 - U(t) + zS$$

$$E_{22} = U_2 - C_2 - C_c$$

$$E_2 = xE_{21} + (1-x)\,E_{22}$$

From $\mathrm{F(x)} = \frac{\mathrm{dx}}{\mathrm{dt}} = \mathrm{x(E_{11} - E_1)}$, the consumer's dynamic replicator equation can be derived:

$$F(x) = x(1-x)(U_1 - U_2 + C_2 - C_c)$$

For firms, the expected utility is simplified to the following expression:

$$E_{21} = xR_1 + (1-x)R_2 - C_0 + zM_1E_3$$

$$E_{22} = (1-x)E_2 - M_2$$

$$E_2 = y(xR_1 + (1-x)R_2 - C_0 + zM_1) - (1-y)\,M_2$$

From $\mathrm{F(y)} = \frac{\mathrm{dy}}{\mathrm{dt}} = \mathrm{y(E_{21} - E_2)}$, the firm's dynamic replicator equation can be derived:

$$F(y) = y(1-y)\,(xR_1 - C_0 + zM_1 + M_2)$$

For the government, the expected utility is simplified to the following expression:

$$E_{31} = R_z - yM_1 + xS + (1-x)\,C_c + (1-y)M_2$$

$$E_{32} = (1-x)C_c + (1-y)M_2$$

$$E_3 = zR_z - zyM_1 - zxS + (1-x)C_c + (1-y)\,M_2$$

From $\mathrm{F(z)} = \frac{\mathrm{dz}}{\mathrm{dt}} = \mathrm{z(E_{31} - E_3)}$, the government's dynamic replicator equation can be derived:

$$F(z) = zR_z(1-z)$$

4.3. Stability Analysis

We use the Jacobian matrix S to analyze the stability of the equilibrium points in the evolutionary system:

$$S = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

$$a_{11} = (1-2x)(U_1 - U_2 + C_2 - C_c)$$
$$a_{12} = 0$$
$$a_{13} = 0$$
$$a_{21} = y(1-y)R_1$$
$$a_{22} = (1-2y)(xR_1 - C_0 + zM_1 + M_2)$$
$$a_{23} = y(1-y)\, M_1$$
$$a_{31} = 0$$
$$a_{32} = 0$$
$$a_{33} = (1-2z)R_z$$

Where

$$S = \begin{bmatrix} (1-2x)(U_1 - U_2 + C_2 - C_c) & 0 & 0 \\ y(1-y)R_1 & (1-2y)(xR_1 - C_0 + zM_1 + M_2) & y(1-y)\, M_1 \\ 0 & 0 & (1-2z)R_z \end{bmatrix}$$

The eigenvalues are given by the diagonal elements a_{11}, a_{22}, a_{33},which are defined as:

$$\lambda_1 = (1-2x)(U_1 - U_2 + C_2 - C_c)$$
$$\lambda_2 = (1-2y)(xR_1 - C_0 + zM_1 + M_2)$$
$$\lambda_3 = (1-2z)R_z$$

According to the combinations of strategies chosen by the three participants, eight equilibrium points are obtained: (0, 0, 0), (1, 0, 0), (0, 1, 0), (0, 0, 1), (1, 1, 0), (1, 0, 1), (0, 1, 1), (1, 1, 1), and the eigenvalues corresponding to these points are listed in Table 3.

Table 3. Table of Eigenvalues

Equilibrium Points	$\lambda_1,\ \lambda_2,\ \lambda_3$
(0, 0,0)	$(U_1 - U_2 + C_2 - C_c,\ -C_0 + M_2,\ R_z)$
(1, 0, 0)	$(-U_1 + U_2 - C_2 + C_c,\ R_1 - C_0 + M_2,\ R_z)$
(0, 1, 0)	$(U_1 - U_2 + C_2 - C_c,\ C_0 - M_2,\ R_z)$
(0, 0, 1)	$(U_1 - U_2 + C_2 - C_c, -C_0 + M_1 + M_2, -R_z)$
(1, 1, 0)	$(-U_1 + U_2 - C_2 + C_c,\ -R_1 + C_0 - M_2,\ R_z)$
(1, 0, 1)	$(-U_1 + U_2 - C_2 + C_c,\ R_1 - C_0 + M_1 + M_2, -R_z)$
(0, 1, 1)	$(U_1 - U_2 + C_2 - C_c,\ C_0 - M_1 - M_2,\ -R_z)$
(1, 1, 1)	$(-U_1 + U_2 - C_2 + C_c, -R_1 + C_0 - M_1 - M_2, -R_z)$

In accordance with the industry lifecycle theory, this study divides the lifecycle of the new energy vehicle industry into initial, development, and maturity phases. It assumes that throughout the development of NEVs, the traditional gasoline vehicle industry remains in the maturity phase with its technological means and industrial ecosystem largely unchanged. Based on the research context mentioned above, the equilibrium points (0, 0, 1), (0, 1, 1) and(1, 1, 1) were selected for analysis at each respective stage.

Initial Phase: Equilibrium Point (0, 0, 1)

$$\lambda_1 = U_1 - U_2 + C_2 - C_c$$

$$\lambda_2 = -C_0 + M_1 + M_2$$

$$\lambda_3 = -R_z$$

The equilibrium point (0, 0, 1) reaches stability when the conditions $U_1-U_2+C_2-C_c<0$, $-C_0+M_1+M_2<0$, $-R_z<0$ are met. In the initial stage of new energy vehicle development, due to increasingly severe environmental issues and resource scarcity, governments strongly advocate for the promotion of green and low-carbon energy sources. Significant financial subsidies are provided to stimulate the development of the new energy vehicle industry. These subsidies help lower production costs for firms and offer price incentives for consumers with purchasing needs, thereby promoting industry growth from both supply and demand sides. Meanwhile, automobile firms, due to the nascent state of the new energy vehicle industry, unclear future prospects, and the sufficiently mature ecosystem of their traditional gasoline vehicle industry, opt to stick with the production and sales of gasoline vehicles. Consumers, perceiving NEVs as not yet adequately developed, choose not to purchase electric vehicles.

According to the inequality $U_1 - U_2 + C_2 - C_c < 0$, consumers will choose to purchase gasoline vehicles when the net utility derived from using gasoline vehicles (considering purchase, maintenance, and operational costs) exceeds that derived from using electric vehicles after accounting for corresponding costs; According to the inequality $-C_0 + M_1 + M_2 < 0$, if the financial subsidies firms receive for producing electric vehicles are less than the research and development costs for these vehicles, and the difference between the subsidy and costs is greater than the taxes required for producing gasoline vehicles, firms will opt to produce gasoline vehicles; According to the inequality $-R_z < 0$, The government will choose to incentivize the new energy vehicle industry when the social benefits derived from promoting NEVs are greater than zero.

Development Phase: Equilibrium Point (0, 1, 1)

$$\lambda_1 = U_1 - U_2 + C_2 - C_c$$

$$\lambda_2 = C_0 - M_1 - M_2$$

$$\lambda_3 = -R_z$$

When conditions $U_1 - U_2 + C_2 - C_c < 0$, $C_0 - M_1 - M_2 < 0$, $-R_z < 0$ are met, the equilibrium point (0, 1, 1) becomes stable. During the rapid growth phase of NEVs, the government will continue to provide corresponding policy support and financial subsidies, although the amount of these subsidies will show a decreasing trend. Due to the favorable policy environment and the golden period of market development, automotive companies will choose to enter the industry and transition from producing traditional gasoline vehicles to manufacturing new energy electric vehicles. During this time, the price of lithium carbonate, a key battery raw material, decreases, and the upstream battery companies' technological maturity leads to reduced production costs, thereby lowering the manufacturing costs for automotive companies. However, consumers, influenced by the brand effect of traditional gasoline vehicles and the immature supporting infrastructure and industrial ecosystem for electric vehicles, will not opt for electric vehicles but will continue to purchase established gasoline vehicles.

According to inequality $U_1 - U_2 + C_2 - C_c < 0$, consumers will opt to purchase gasoline vehicles when the net utility (utility minus the costs of purchase, maintenance, and operation) from using gasoline vehicles exceeds that from using electric vehicles. Per inequality $C_0 - M_1 - M_2 < 0$, when f the net benefit (financial subsidies minus the cost of research and development) for producing electric vehicles surpasses the taxes required for producing gasoline vehicles, companies will opt to produce electric vehicles. According to inequality $-R_z < 0$, the government will promote the new energy vehicle industry if the societal benefits from incentivizing the adoption of NEVs are greater than zero.

Maturity Phase: Equilibrium point (1, 1, 1)

$$\lambda_1 = -U_1 + U_2 - C_2 + C_c$$

$$\lambda_2 = -R_1 + C_0 - M_1 - M_2$$

$$\lambda_3 = -R_z$$

When conditions $-U_1 + U_2 - C_2 + C_c < 0,\ -R_1 + C_0 - M_1 - M_2 < 0,\ -R_z < 0$ is satisfied, the equilibrium point (1, 1, 1) becomes stable. In the maturity phase of new energy vehicle development, the government will gradually reduce financial subsidies. However, to meet sustainable policy needs, the government will not completely withdraw but will continue to levy environmental taxes on traditional gasoline vehicles and provide policy guidance at certain key industry junctures. As the industry chain and ecosystem fully mature, automotive companies see increased profitability; and as the products, support infrastructure, and user ecosystem for NEVs fully mature, offering more advanced and convenient features compared to traditional gasoline vehicles, consumers will opt for NEVs.

According to inequality $-U_1 + U_2 - C_2 + C_c < 0$, consumers will opt to purchase electric vehicles when the net utility (utility minus the costs of purchase, maintenance, and operation) from using electric vehicles exceeds that from using gasoline vehicles. According to inequality $-R_1+C_0-M_1-M_2<0$, if the net profit from producing NEVs is greater than the taxes required for producing gasoline vehicles, companies will continue to produce electric vehicles. Per inequality $-R_z<0$, the government will continue to incentivize the new energy vehicle industry if the societal benefits from promoting NEVs are greater than zero.

5. SIMULATION EXPERIMENT

5.1. Simulation Parameter Settings

To validate the effectiveness of the proposed evolutionary strategies, this study employs numerical simulations in MATLAB to analyze the strategic variations of the three stakeholders in different phases of the new energy vehicle market, as well as related sensitivity analyses. The parameter settings for the three phases were determined by integrating government policies, financial data from major automotive companies, and market survey results.

Table 4. Parameter Settings

Variable	Initial Stage	Development Stage	Maturity Phase
R_z	0.5	1.0	0.8
M_1	0.2	0.4	0.2
M_2	0.05	0.1	0.15
S	0.4	0.3	0.2
C_c	0.05	0.1	0.15
R_1	0.5	1.0	1.1
R_2	0.8	1.0	0.9
C_0	1.0	0.8	0.7
U_1	0.6	0.7	0.8
U_2	0.7	0.7	0.7
C_1	0.4	0.3	0.2
C_2	0.5	0.4	0.3
$U(t)$	0.2	0.2	0.2

5.2. Dynamic Evolution Process in the Initial Phase

The parameters during the initial stage meet the stability criteria defined by $-U_1+U_2-C_2+Cc<0$, $-R_1+C_0-M_1-M_2<0$, $-R_z<0$. The initial strategy point is set at (0.5, 0.5, 0.5). Using MATLAB, a simulation experiment of the initial phase parameter model was conducted. The dynamic evolution process of the three stakeholders during the initial phase is depicted in the following figure.

The simulation results confirm that (0, 0, 1) is an asymptotically stable equilibrium point during the evolution in the initial phase. As time progresses, the probability curve for the government converges towards 1, while the probability curves for enterprises and consumers converge towards 0. In the initial phase, the government strongly incentivizes and guides the development of NEVs. However, due to high transition costs, significant R&D challenges, and an immature upstream industry chain, enterprises are hesitant to enter the new energy market. Consumers, due to the immaturity of the products, which do not effectively replace traditional gasoline vehicles, also do not opt for electric vehicles. Moreover, during the evolution process, the potential consumer inclination towards NEVs remains lower than the production inclination of enterprises.

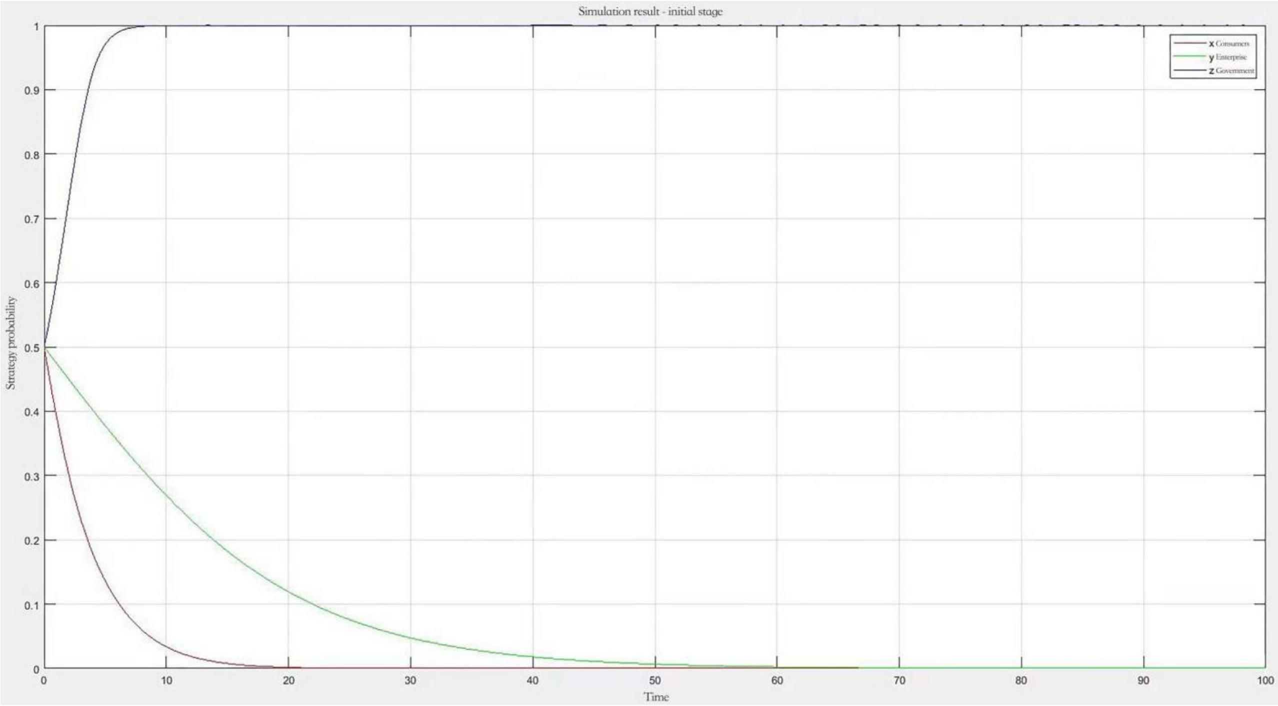

Figure 1. Evolutionary Game Diagram of Three Parties in the Initial Phase

5.3. Dynamic Evolution Process in the Development Phase

During the development phase, the values of the parameters meet conditions $U_1-U_2+C_2-Cc<0$, $C_0-M_1-M_2<0$, $-R_z<0$. The initial strategy point remains set at (0.5, 0.5, 0.5). Transitioning from the initial to the development phase, with an increase in government subsidies for enterprises and a reduction in vehicle manufacturing costs, a MATLAB simulation experiment was conducted to visualize the evolutionary process.

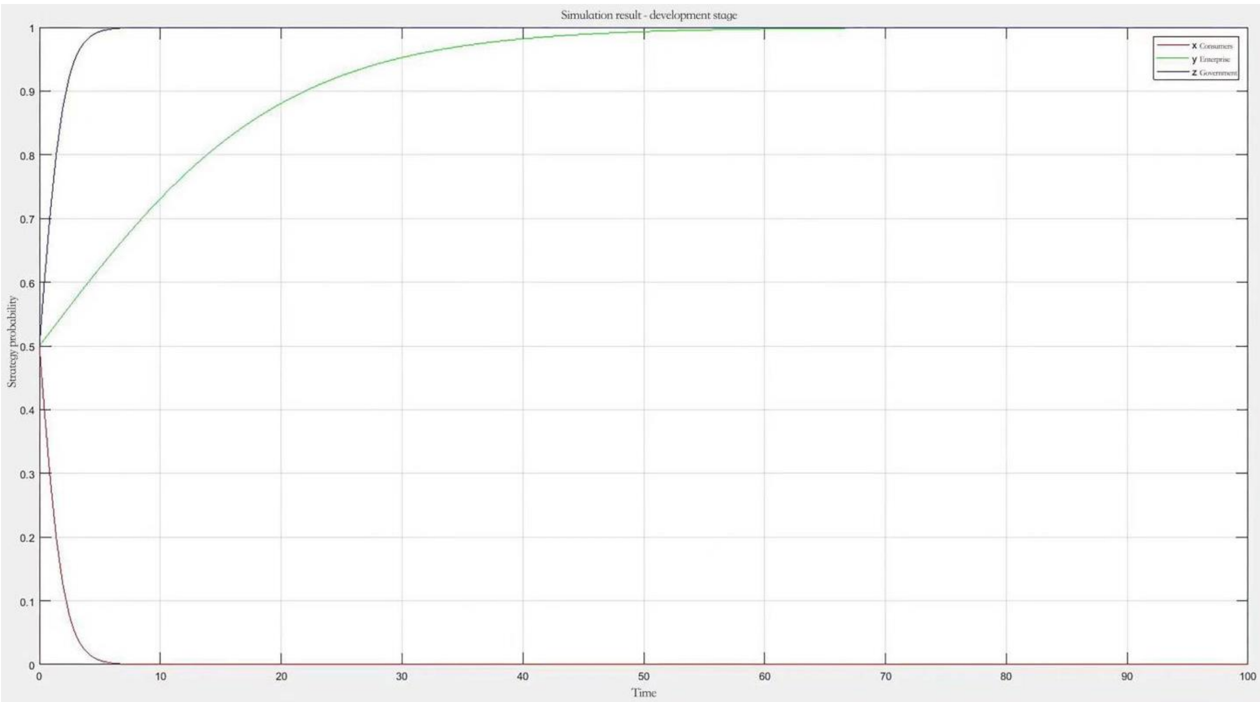

Figure 2. Evolutionary Game Diagram of Three Parties in the Development Phase

The simulation results confirm that (0, 1, 1) is an asymptotically stable equilibrium point during the development phase. As time progresses, the probability curves for both the government and enterprises converge towards 1, while the probability curve for consumers still converges towards 0. With the increase in government subsidies and the reduction in vehicle manufacturing costs, enterprises choose to enter the new energy vehicle market. However, due to the brand effect of traditional gasoline vehicles and the incomplete infrastructure for NEVs, consumers conservatively opt for gasoline vehicles.

5.4. Dynamics of Participants During the Maturity Phase

During the maturity phase, all parameter values meet the conditions $-U_1+U_2-C_2+Cc<0$, $-R_1+C_0-M_1-M_2 < 0$, $-R_z<0$. with the initial strategy set at (0.5, 0.5, 0.5). Simulation experiments conducted using MATLAB yielded the following results.

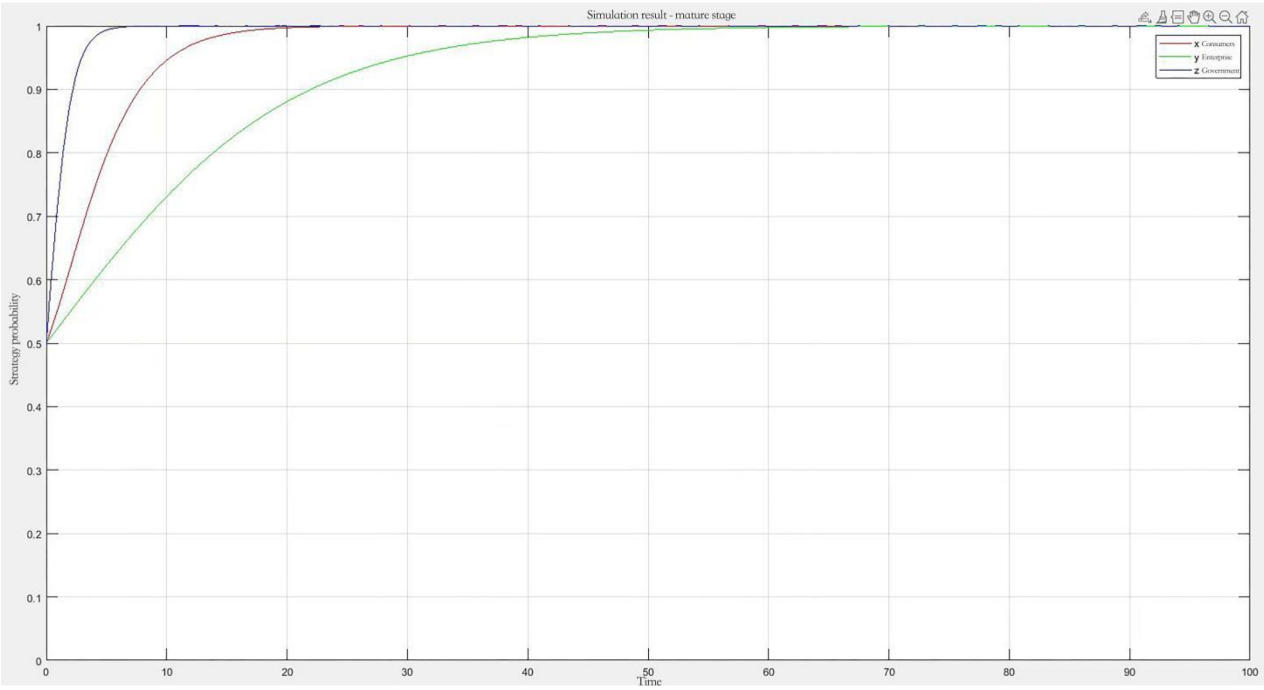

Figure 3. Evolutionary Game Diagram of Tripartite Interactions During the Maturity Phase

Simulation results confirm that (1, 1, 1) represents an asymptotically mature equilibrium point during the maturity phase, where the probability curves of the three participants converge to (1, 1, 1). In this phase, due to the maturation of electric vehicle products and their supporting infrastructure, the utility derived by consumers from using NEVs increases, surpassing that from traditional fuel vehicles. Correspondingly, the purchasing and daily operating costs decrease, generally being lower than those of traditional vehicles, leading consumers to gradually opt for NEVs. Furthermore, as the penetration rate of NEVs increases, the revenue from manufacturing and selling these vehicles will rise, and production costs will decrease with the maturation of the supply chain. The stable growth in net profits will provide sustained momentum for the industry's ecosystem. As the market matures and requires less aggressive incentives, government subsidies to businesses and consumers will decrease. However, promoting NEVs remains in line with sustainable development principles of green environmental protection and continues to generate social benefits; therefore, the government will not completely withdraw from the market.

5.5. Sensitivity Analysis

This study conducts a sensitivity analysis on consumer subsidies S, consumer carbon taxes C_c, business subsidies M_1, and environmental taxes for businesses M_2. These four parameters reflect the degree of government incentives for NEVs and are closely related to the utility of businesses and consumers.

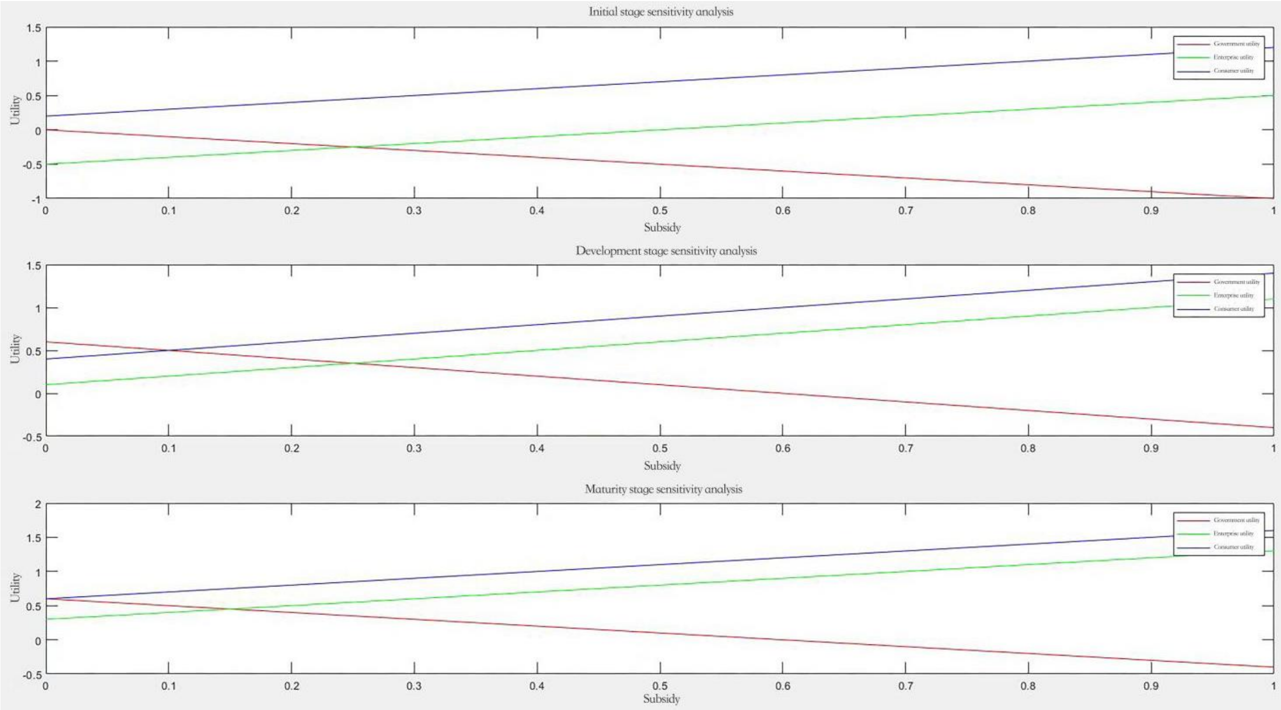

Figure 4. Sensitivity Analysis for S

The diagram illustrates the impact of changes in consumer subsidy S on the utility of the three participants at different stages. In the initial stage, as subsidy S increases, government utility gradually decreases due to the substantial funds required to support these subsidies, which puts financial pressure on the government, thereby reducing its utility. Business utility shifts from negative to positive; in the initial phase, as the market has not fully accepted NEVs, consumer subsidies can to some extent enhance consumers' willingness to purchase, thereby boosting business sales and utility. Consumer utility gradually increases as the subsidy reduces the purchase cost of electric vehicles, enhancing their willingness to buy and thus their utility.

In the development stage, government utility continues to decrease. Although the market's response to subsidies begins to manifest entering the development period, and the government's utility is significantly improved compared to the previous phase, the financial pressure of subsidies remains. Consumer utility significantly rises as subsidies further reduce the cost of electric vehicles, making consumers more willing to buy and significantly increasing their utility. The enhanced consumer purchasing willingness leads to increased business sales, thereby significantly boosting business utility.

During the maturity phase, the reduction in government utility slows down; as the market matures, the marginal effects of subsidies diminish, but financial pressures still exist. Business utility continues to improve, but as the market demand for NEVs stabilizes during this phase, the marginal utility of subsidy S in boosting sales further decreases. Consumer utility continues to increase, as the mature market and ongoing subsidies make consumers more inclined to purchase electric vehicles, thereby increasing their utility.

In summary, during the initial stage, increasing subsidy S helps promote the sales of electric vehicles, but it also increases the financial burden on the government. In the development stage, raising subsidy S helps further drive the development of the electric vehicle market, significantly enhancing the utility for both consumers and businesses. In the maturity stage, the promotional effect of increasing subsidy S on the electric vehicle market is limited; the government should consider gradually reducing subsidies to alleviate financial burdens. Subsidy S has the greatest impact on consumer utility by reducing the cost of purchasing vehicles, enhancing the willingness of consumers to buy electric vehicles, and thereby increasing consumer utility. Government utility decreases due to increased financial burdens, while business utility increases due to enhanced consumer willingness to buy. When formulating subsidy policies, it is necessary to balance the financial burden on the government with market incentives, gradually reduce dependency on subsidies, and enhance the market's self-development capabilities.

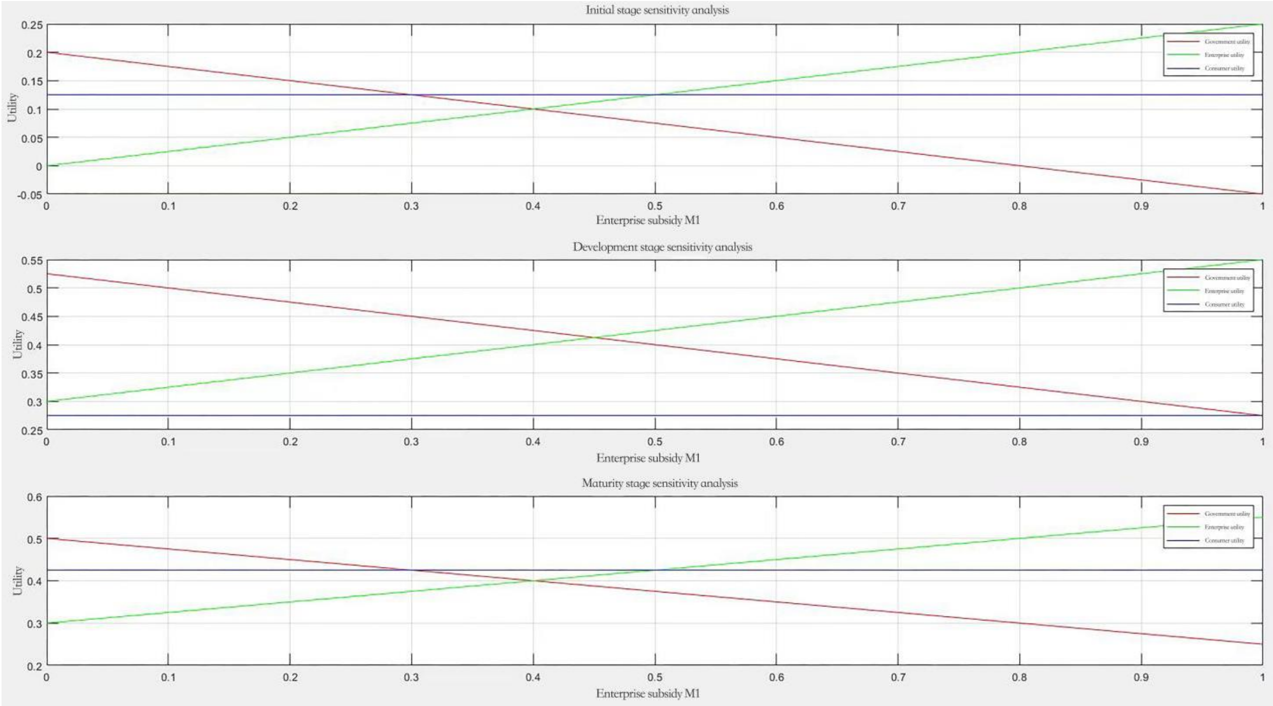

Figure 5. Sensitivity Analysis for M_1

The figure shows the impact of changes in enterprise subsidy M_1 on tthe utility of three stakeholders across different stages. In the initial stage, the government's utility decreases as M_1 increases, as the increase in subsidies raises government fiscal expenditure, thus lowering governmental utility; the utility of businesses increases with M_1. The subsidy directly enhances corporate revenues and reduces production costs, leading to an increase in utility; consumer utility remains unchanged, as the direct impact of corporate subsidies on consumers is minimal at this stage.

During the development stage, the utility of the government continues to decrease as the financial burden of increased corporate subsidies remains significant; however, the utility of businesses significantly increases. With rising market demand during this phase, the subsidies make businesses more competitive, noticeably enhancing their utility. Consumer utility remains unchanged, as the subsidies primarily improve the financial status of businesses, with little direct effect on consumers.

In the maturity stage, the decrease in government utility slows down. As the market matures and reliance on government subsidies decreases, fiscal pressure eases; business utility significantly increases. Businesses, being competitive in the maturity stage, further enhance their market share and utility through subsidies; consumer utility remains constant, with corporate subsidies having a minor direct impact on consumers.

In summary, during the initial phase, increasing the subsidy M_1 effectively promotes the production of electric vehicles but adds to the government's fiscal pressure. In the development stage, raising M_1 aids in advancing the electric vehicle market, significantly enhancing corporate utility. In the maturity stage, the effect of increasing M_1 in promoting the electric vehicle market is limited, and the government should consider gradually reducing subsidies to alleviate fiscal burdens. The subsidy M1 has the most substantial impact on corporate utility, with an increase markedly boosting this metric. Government utility decreases due to the subsidy increase, while consumer utility shows little change. Policy formulation needs to balance government fiscal expenditure and corporate development, progressively reducing corporate reliance on subsidies to promote market self-regulation.

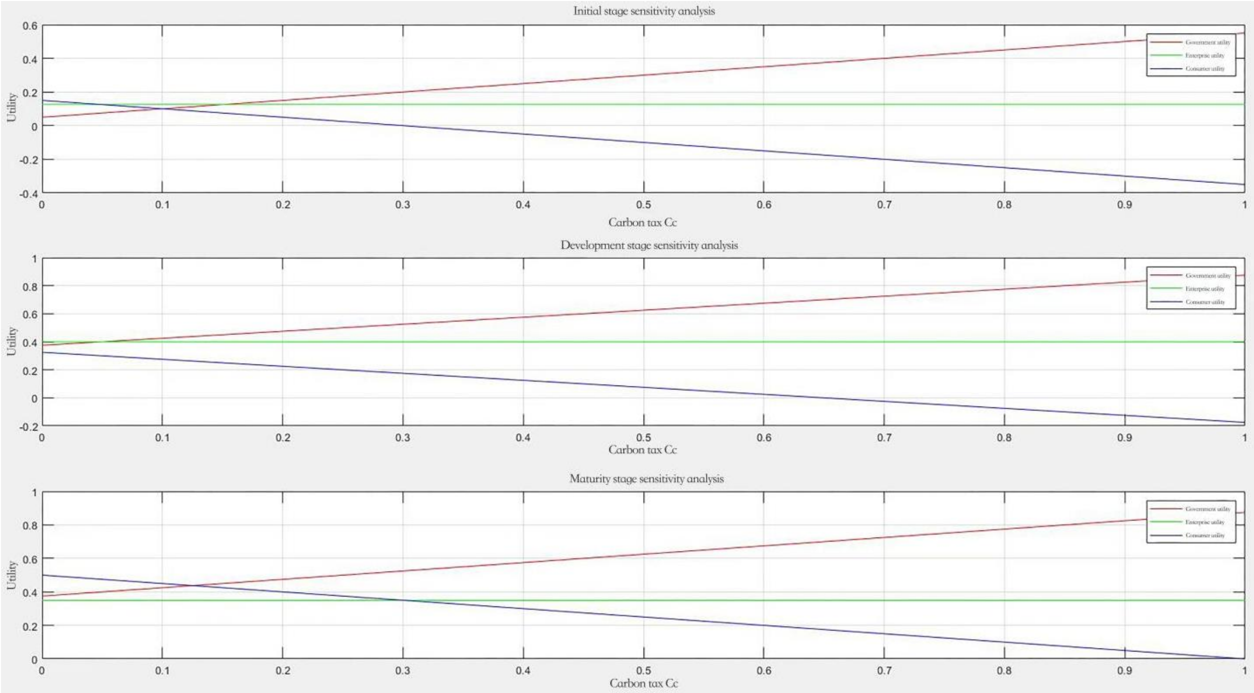

Figure 6. Sensitivity Analysis for C_c

The figure displays the effects of changes in the consumer carbon tax C_c on the utility of three stakeholders across different stages. In the initial phase, government utility increases with the rise in carbon tax C_c, The increase in carbon tax directly leads to higher tax revenue, which boosts government utility. Consumer utility significantly declines as the carbon tax increases. This is because the carbon tax raises the purchase and operational costs of traditional fuel vehicles, reducing the overall utility for consumers. However, corporate utility remains largely unchanged during this stage. This may be due to the fact that businesses have not fully expanded their investments and production of NEVs at this initial stage, and the impact of the carbon tax on their operations is limited.

In the development stage, government utility continues to rise with the increase in carbon tax C_c, further indicating that the government promotes environmental protection and increases fiscal revenue through the carbon tax policy. Consumer utility continues to decrease with the rise in carbon tax, reflecting the consumers' choice to reduce reliance on traditional fuel vehicles in response to high carbon taxes. However, corporate utility remains unchanged during this development stage. This may be due to businesses gradually adjusting their production and market strategies, transitioning towards NEVs, hence the carbon tax does not significantly impact their overall utility.

In the maturity stage, government utility significantly increases with the rise in carbon tax C_c, demonstrating the effectiveness of the carbon tax policy in steering the market towards NEVs. Consumer utility continues to decline with the increase in carbon tax during this stage, but the decline is smaller, indicating that consumers have adapted to the carbon tax policy and are gradually shifting towards purchasing NEVs. Corporate utility remains unchanged in the maturity stage, suggesting that businesses have fully adapted to market changes, and the production and sales of NEVs have become their main business, with the carbon tax having a minimal impact on their overall utility.

Overall, the increase in carbon tax C_c consistently positively affects government utility, while it has a negative impact on consumer utility. Corporate utility remains unchanged across all three stages, reflecting the businesses' adaptability to market changes and policies at different stages of development. By appropriately setting the level of carbon tax, the government can effectively guide the market through different development stages, promote the adoption of NEVs, reduce traditional fuel vehicles, and achieve environmental protection goals and sustainable market development.

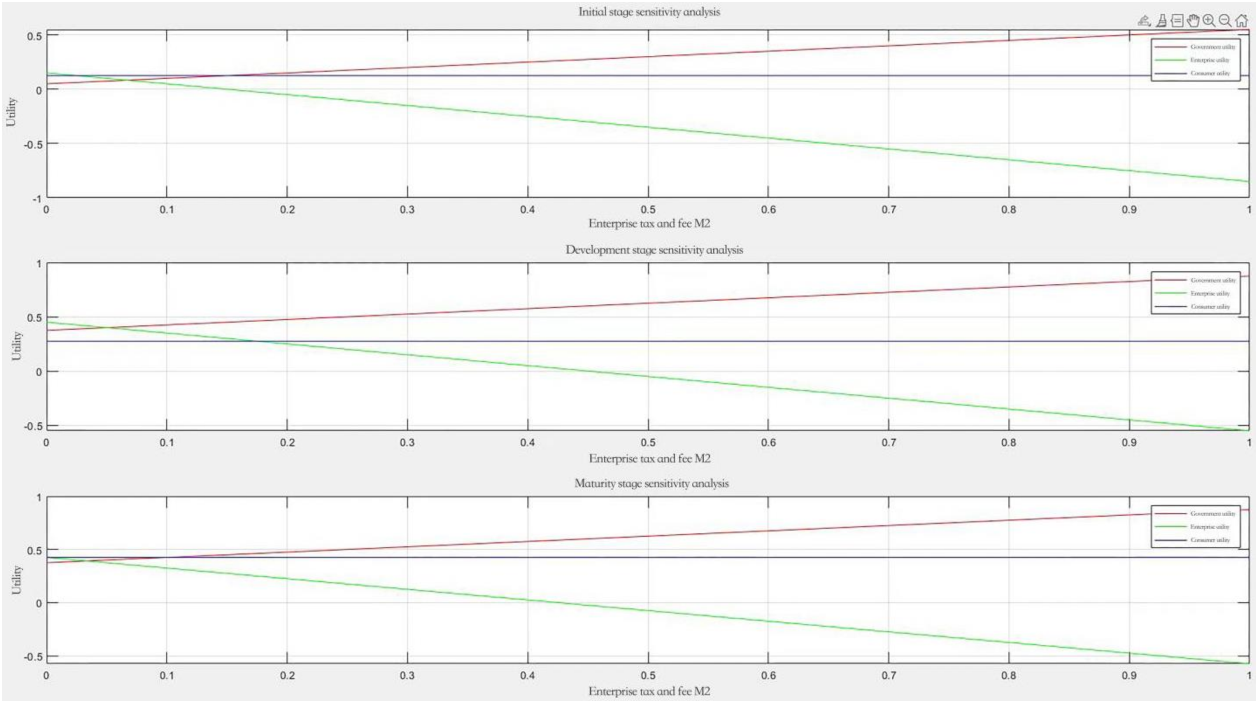

Figure 7. Sensitivity Analysis of M_2

The figure displays the impact of changes in the corporate environmental tax M_2 on the utility of three stakeholders across different stages. In the initial stage, government utility increases with the increase in M_2. This is because levying an environmental tax on companies producing petrol vehicles directly boosts government fiscal revenue and encourages companies to reduce the production of petrol vehicles, thereby achieving the goal of environmental protection. Corporate utility significantly decreases with the increase in M_2. As the environmental tax increases, the costs of producing petrol vehicles rise, and profits decrease, thus lowering corporate utility. Consumer utility remains largely unchanged in the initial stage, as M_2 is levied only on companies and does not directly affect consumers.

In the development stage, government utility continues to rise with the increase in M_2, further demonstrating the positive impact of the environmental tax on government utility. Corporate utility continues to decline significantly because, during this stage, companies may have begun transitioning but still partly rely on the production of traditional petrol vehicles, so the increase in environmental tax continues to diminish their utility. Consumer utility remains largely unchanged during this stage, as the environmental tax does not directly impact consumers.

In the maturity stage, government utility significantly increases with the rise in M_2. This indicates that the government's environmental tax policy effectively guides the market transition towards NEVs. Corporate utility continues to decline with the increase in M_2, but the decline is smaller, suggesting that companies have largely completed the transition to NEVs and their dependence on petrol vehicles has decreased, thus minimizing the impact of the environmental tax. Consumer utility remains essentially unchanged in the maturity stage, further proving that the environmental tax has limited direct impact on consumers.

Overall, the increase in the environmental tax M_2 consistently has a positive effect on government utility, while it has a negative impact on corporate utility. Consumer utility remains largely unchanged across all three stages, as M_2 is levied only on businesses and does not directly affect consumers. By appropriately setting the level of environmental tax M_2, the government can effectively guide companies to reduce the production of petrol vehicles, promote the development of NEVs, and achieve environmental protection and sustainable market development.

6. CONCLUSION

Through the analysis of the evolutionary game model, we constructed a game model involving consumers, enterprises, and governments in the NEV market, detailing their expected utilities and replicator dynamics equations. The simulation results indicate the stability of the NEV market at different stages and identify key equilibrium points. These results highlight the critical roles of government fiscal incentives, enterprise production decisions, and consumer purchase choices in NEV market development.

In the initial stage, strong government incentives drive market development, despite low confidence in NEVs from enterprises and consumers. Government subsidies and tax incentives help mitigate market uncertainties, attracting enterprise investment in NEV R&D and production, and encouraging consumer purchases. However, government incentives alone cannot sustain long-term market development, necessitating the gradual establishment of trust and reliance on NEVs by enterprises and consumers.

In the development stage, the market environment matures, and enterprises shift towards NEV production. Despite reduced government subsidies, enterprise utility remains stable due to accumulated technology and market experience, lowering production costs and enhancing competitiveness. Consumer acceptance of NEVs remains low, mainly due to brand effects and inadequate supporting facilities. The government should continue fiscal support while gradually reducing subsidies and investing in charging infrastructure and supporting services to improve the NEV experience for consumers.

In the mature stage, as product technology and market ecosystems mature, consumers increasingly prefer NEVs. Sensitivity analysis shows that changes in consumer subsidies significantly impact government and enterprise utilities, suggesting that optimizing subsidy policies can further enhance market structure. Reduced production costs and a stable market enter a growth period. The government can reduce direct subsidies, offering tax incentives and other measures to support long-term market stability.

Based on the simulation and sensitivity analysis results, the government should take specific measures at different stages:

Initial Stage:

(1) Provide substantial financial subsidies and tax incentives to reduce production and purchase costs.

(2) Increase public awareness and acceptance of NEVs.

(3) Promote the construction of charging facilities and supporting services to enhance the NEV experience.

Development Stage:

(1) Gradually reduce financial subsidies, maintaining moderate tax incentives to encourage enterprise innovation and cost reduction.

(2) Strengthen the construction of charging facilities and supporting services to enhance convenience.

(3) Guide interaction between enterprises and consumers to build market trust.

Mature Stage:

(1) Optimize subsidy policies, shifting to long-term and structural incentives such as tax incentives and green finance support.

(2) Continue improving charging facilities and supporting services to ensure stable market operation.

(3) Promote sustained enterprise investment in R&D and market expansion, enhancing product quality and competitiveness.

The government should adopt flexible policy combinations based on market development stages to achieve optimal incentives and balance fiscal conditions. In the initial stage, supply-side policies such as subsidies for NEV enterprises (M_1) and environmental taxes on fuel vehicle enterprises (M_2) significantly promote the market. These policies reduce NEV production costs, increase market supply, and enhance consumer and enterprise confidence. Despite increased fiscal expenditure, these policies are crucial for initial market development. In the development stage, demand-side policies such as consumer subsidies (S) and carbon taxes (C_c) effectively influence purchase choices, enhancing market demand and driving rapid growth. By increasing NEV market share, demand-side policies achieve rapid market expansion. In the mature stage, reducing subsidies and increasing carbon and environmental taxes maintain stable development. Mature markets reduce subsidy reliance, balancing fiscal conditions and guiding environmental protection.

Through the joint efforts of governments, enterprises, and consumers, the NEV market can achieve sustainable development, promoting a green economy. Future research can integrate actual market data to optimize model parameters, enhancing the practical value of the research.

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