Government Subsidies and Manufacturer Investment Decisions in the Electric Vehicle Industry: An Evolutionary Game Analysis

Liu Cao * and Qingmei Tan

College of Economics and Management, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu, 210061, China
*Caoliu0813@126.com

Abstract. This study analyzes the interaction between government subsidy policies and electric vehicle (EV) manufacturers' investment decisions using an evolutionary game theory model. The government can choose to provide subsidies or not, while EV manufacturers decide whether to invest in production based on the subsidies offered. The model shows that government subsidies can encourage investment by manufacturers, but the optimal subsidy level depends on the strategic behaviors of both parties. Numerical simulations reveal that balanced subsidy policies, considering both production costs and social benefits, lead to a stable equilibrium. This research provides insights into the design of effective subsidy policies to promote the growth of the EV industry.

Keywords: Electric vehicles, government subsidies, investment decisions, evolutionary game theory.

1 Introduction

With the increasing severity of global environmental issues, the environmental pollution and carbon emissions caused by traditional gasoline vehicles have become a major focus of societal attention. In this context, the promotion of electric vehicles (EVs) has emerged as a key strategy for addressing climate change and driving energy transition worldwide[1]. As a clean energy transportation solution, electric vehicles not only help reduce greenhouse gas emissions and decrease air pollution, but they also promote the optimization of energy structures. However, despite the significant environmental and sustainability advantages of electric vehicles, their market adoption still faces numerous challenges, including high production costs, insufficient consumer awareness, and inadequate charging infrastructure[2].

The government plays a crucial role as an important driver in the electric vehicle (EV) industry[3]. By providing financial subsidies, tax incentives, and policy support, the government can effectively encourage EV manufacturers to innovate and invest in production, thus accelerating the widespread adoption of electric vehicles. However, designing a reasonable subsidy policy that balances the interests of all parties and maximizes social benefits remains a pressing issue. The game between the government and

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manufacturers, and how their policy choices influence market development, warrants further investigation[4].

While existing studies have explored the impact of government subsidies on the electric vehicle (EV) market, few have focused on the dynamic interactions between government policies and manufacturers' investment decisions through a game-theoretic lens [5]. Specifically, limited attention has been given to how government subsidy policies influence manufacturers' investment strategies and the long-term implications of these strategies for social welfare and market development. This study addresses this gap by constructing an evolutionary game model to analyze the interplay between government subsidy policies and manufacturers' investment decisions. By examining how manufacturers respond to various subsidy policies and how these responses shape broader economic and social outcomes, the study provides a nuanced understanding of the strategic behaviors of both parties. Compared to prior research, this study advances the literature by offering a dynamic and integrated framework that balances production costs with social benefits, thereby identifying optimal subsidy policies. This contribution not only enhances theoretical insights into the strategic interaction between governments and manufacturers but also provides practical guidance for designing effective subsidy mechanisms to accelerate the development of the EV industry.

2 Assumptions and Research Design

2.1 Basic Assumptions

Strategic Decisions. The strategy choice of the manufacturer is made under bounded rationality, where the government's strategy selection is provided as a subsidy with probability x and the probability of no subsidy is $1-x$ ($0 \le x \le 1$). The manufacturer's strategy selection in the subsidy space is investment with probability y ,and the alternative is no investment, with probability $1-y$ ($0 \le y \le 1$).

Strategic Decisions. The basic revenues of the government and EV manufacturers are denoted as A and I , respectively. When the government provides subsidies, the government bears a subsidy cost recorded as C_g ,As a key participant in market economic activities, EV manufacturers can obtain revenue aC_g ($0 \le a \le 1$) due to the improved fiscal and policy environment created by government subsidies. When EV manufacturers choose an investment strategy, the government further introduces supportive measures to provide financial capital assistance F to EV manufacturers.

Revenue and Costs. From the government's perspective, providing subsidies and facilitating investment in the EV industry can result in additional regional economic benefits ΔA_1 .Meanwhile, such measures also improve social welfare and enhance societal benefits ΔA_2, where $\Delta A_2 \le \Delta A_1$, At the same time, the EV manufacturers gain additional economic benefits ΔI_1.

The investment costs incurred by EV manufacturers without receiving subsidies are C_1,which may include risks associated with investment failures, temporary capital shortages, and other uncertainties. Thus, the investment cost incurred by EV manufacturers without government subsidies is greater than that with subsidies. The investment cost for EV manufacturers with subsidies is denoted as C_2 ($C_1 \le C_2$).

From this, the payoff matrix for the evolutionary game model based on the strategy sets of the government and EV manufacturers can be derived, as shown in Table 1.

Table 1. Pure strategy game benefit matrix between government and EV manufacturers

Both sides of the game		EV Manufacturers	
		Invest	Do Not Invest
Government	Provide Subsidies	$A+\Delta A_1-C_g-F$ $I+aC_g+F+\Delta I_1-C_1$	$A-C_g$ $I+A+aC_g$
	Do Not Provide Subsidies	$A+\Delta A_2$ $I+\Delta I_1-C_2$	A I

Based on the payoff matrix, this paper constructs replicator dynamic equations for the two groups—government and EV manufacturers—under the influence of subsidy policies to reveal their behavioral evolutionary patterns and stable strategies.

2.2 Replicator Dynamic Equation for the Government and EV

To explore how the government and EV manufacturers adjust their strategies over time, we use replicator dynamic equations. These equations measure how the likelihood of each party choosing a particular strategy changes based on its relative success compared to alternatives. Essentially, if a strategy yields higher payoffs, it becomes more popular in subsequent interactions.

The government's decision revolves around whether to provide subsidies or not. The key factor influencing this choice is the balance between the costs of subsidies and the economic and social benefits they generate. If the benefits outweigh the costs, the government is more likely to adopt the subsidy strategy. Conversely, if the costs are too high, the government may opt not to provide subsidies.The replicator dynamic equation for the government is:

$$F(x)=\frac{dx}{dt}=x(U_{11}-U_1)=x(1-x)\left[y(\Delta A_1-\Delta A_2-F)-C_g\right] \tag{1}$$

Manufacturers decide whether to invest in production or refrain from doing so. This decision depends on the expected returns from investment versus the associated costs. Subsidies lower investment costs, making investment more appealing if the additional revenues outweigh the remaining costs. Without subsidies, higher costs might deter investment. The replicator dynamic equation for manufacturers is:

$$F(y)=\frac{dy}{dt}=y(U_{21}-U_2)=y(1-y)\left[x(F+C_2-C_1)+\Delta I_1-C_2\right] \tag{2}$$

Together, these equations demonstrate how both parties' strategies evolve dynamically, converging toward a stable equilibrium where payoffs are optimized for each side. In the established model, let $F(x)$ and $F(y)$ equal zero. The four pure strategy equilibria for the strategic choices of the government and EV manufacturers are obtained as $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$, $E_4(1,1)$, and a mixed strategy equilibrium $E_5(x^*,y^*)$.where $E_1(0,0)$ represents the strategy (do not provide subsidies, do not invest), $E_2(0,1)$ represents the strategy (do not provide subsidies, invest), $E_3(1,0)$ represents the strategy (provide subsidies, do not invest), and $E_4(1,1)$ represents the strategy (provide subsidies, invest). The mixed strategy equilibrium is denoted as $E_5(x^*,y^*)$,where $x^*=\dfrac{C_2-\Delta I_1}{F+C_2-C_1}$, $y^*=\dfrac{C_g}{\Delta A_1+\Delta A_2-F}$.According to evolutionary game theory, an Evolutionary Stable Strategy (ESS) must be a pure strategy equilibrium. Thus, it is necessary to determine whether E_1-E_4 are ESSs. Therefore, this paper substitutes the four possible evolutionary stable strategies into each equilibrium point. The matrix of behavioral strategies and expressions is shown in Table 2.

Table 2. Model Parameters and Definition

Equilibrium Point	Determinant Expression	Trace Expression
$E_1(0,0)$	$-C_g(\Delta I_1-C_2)$	$-C_g+(\Delta I_1-C_2)$
$E_2(0,1)$	$\left[(\Delta A_1-\Delta A_2-F)-C_g\right]-\Delta I_1+C_2$	$\left[(\Delta A_1-\Delta A_2-F)-C_g\right]-\Delta I_1+C_2$
$E_3(1,0)$	$-C_g\left[(F+C_2-C_1)+\Delta I_1-C_2\right]$	$-C_g+\left[(F+C_2-C_1)+\Delta I_1-C_2\right]$
$E_4(1,1)$	$-\left[(\Delta A_1-\Delta A_2-F)-C_g\right]$ $\{-[(F+C_2-C_1)+\Delta I_1-C_2]\}$	$-\left[(\Delta A_1-\Delta A_2-F)-C_g\right]$ $\{-[(F+C_2-C_1)+\Delta I_1-C_2]\}$

Based on Table 2, the stability of the system can be further analyzed, with the results shown in Table 3.

Table 3. Relationship Between Parameters and the Area of S_1

Parameter	Trend of Change	Trend of S_2 Change
ΔA_1	↑	↑
ΔA_2	↑	↑
ΔI_1	↑	↑
C_1	↑	↓
C_2	↑	↓
F	↑	*

Based on the analysis of the replicator dynamic equations and the stability of system evolution, the evolutionary game phase diagram of EV manufacturers' investment under the influence of government subsidies is obtained, as shown in Figure 1.

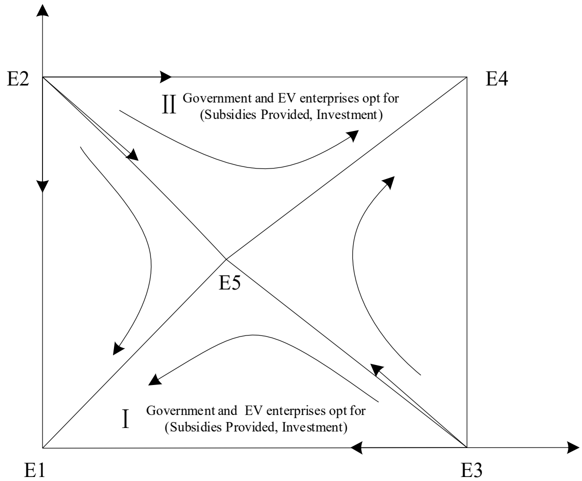

Fig. 1. Behavioral Evolution Diagram of Government Subsidies and Manufacturer Investments

In the evolutionary game phase diagram, if the initial state of the game participants is located in Region I, the system evolves towards the stable equilibrium strategy E_1 (no subsidies, no investment). If the initial state is in Region II, the system evolves towards the stable equilibrium strategy E_4 (provide subsidies, invest). As the area of Region I S_1 increases, the stability of E_1 also grows. Conversely, as the area of Region II S_2 expands, the stability of E_4 gradually increases.

It is calculated that the probability of the evolutionary game system stabilizing at E_4 (provide subsidies, invest) is $S_2 = 1 - \frac{C_2 - \Delta I_1}{F + C_2 - C_1} - \frac{C_g}{\Delta A_1 + \Delta A_2 - F}$ According to guidance, the key parameter changes are related to the size of S_1.

3 Research Conclusions and Policy Suggestion

The government's strategic choice is directly influenced by economic returns, with the probability of adopting a subsidy strategy positively proportional to economic gains. This indicates that increased economic benefits serve as a positive incentive for the government to implement subsidy strategies. The investment decisions of EV manufacturers are influenced not only by internal factors such as investment costs and economic returns but also by the government's subsidy support. The greater the financial support provided through subsidy policies, the more likely the economically driven EV manufacturers are to choose investment strategies, which in turn increases the government's probability of selecting a subsidy strategy.The investment decisions of EV manufacturers are constrained by costs. In the presence of subsidies, the probability of EV manufacturers choosing an investment strategy increases as profit margins expand.The strategic choices of EV manufacturers are directly related to the expected economic benefits obtained after the implementation of subsidy policies. The manifestation of the subsidy's effect promotes an increase in the probability of both the government choosing the subsidy strategy and the EV manufacturers opting for the investment strategy. The magnitude of economic returns affects the evolutionary speed and stable outcomes of both parties.

The findings offer actionable guidance for designing effective subsidy policies in different contexts. Policymakers should balance subsidy costs with economic and social benefits. For developed economies, this means prioritizing incentives for advanced technology and infrastructure, while emerging markets should focus on reducing consumer costs and supporting local manufacturing. Additionally, dynamic adjustments to subsidy levels are essential—higher subsidies can address initial market barriers, while mature markets may benefit from targeted support for innovation and infrastructure expansion.

Subsidy policies should align with local regulatory frameworks and market conditions. In regions with strict environmental regulations, subsidies can support emission reduction goals, whereas in less regulated areas, they can help establish industry standards and incentivize private investment. Over time, transitioning from direct subsidies to market-based incentives, such as carbon credits, ensures long-term sustainability while achieving broader environmental and economic objectives.

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