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The Influence of Government on Automobile Enterprise`s Production Methods: An Evolutionary Game Based Study

Abstract. *With environmental protection and energy efficiency increasingly becoming the central issues of global concern, government policies have had a significant impact on the automotive industry, particularly on corporate production methods. This paper aims to analyse the interactions and strategic choices between governments and automotive production companies through the framework of game theory, as well as how these interactions drive the evolution of production methods in the automotive industry. The research first constructs a theoretical framework, considering government regulation, corporate costs, and reputation acquisition as the main variables. Then, using game models, it analyses the strategic behaviour of different entities under the guidance of government policies during industrial transformation. The findings reveal whether automotive enterprises will transition to new energy production methods under government policies that enforce rewards or penalties. In the process of numerical simulation, we present the results of changes in choices for both sides with the modification of some key parameters, providing references for further research.*

Keywords: *automotive enterprises, government policy, evolution of production methods, new energy vehicles, evolutionary game.*

JEL Classification: F426, F272.

1. Introduction

Climate change (Lu and Wang, 2023) and resource depletion (Day and Garth, 2017) have caused global concerns, forcing governments and industries to take action to mitigate these long-term challenges. Against this backdrop, the automotive

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industry, as a significant source of global energy consumption and carbon emissions, faces unprecedented transformation pressure (Yao et al., 2024). In particular, the promotion and popularisation of new energy vehicles are considered one of the key measures to address the above issues (Mester et al., 2023). With the continuous revision and introduction of new environmental policies by governments, including financial subsidies (Zhu and Li, 2023), tax incentives (Georgescu, 2020), production quotas (Dzhalladova et al., 2023), and emission penalty mechanisms, whether enterprises decide to transition to new energy vehicle (Perotti et al., 2023), production has become an important game-theoretic node (Hashai and Adler, 2021) (Levy et al., 2003).

This paper aims to analyse how government reward and penalty clauses impact automotive enterprises' transformation decisions between traditional and new energy production modes. The game of interest involves not only the influence of corporate costs on policies, but also misjudged rewards and penalties by the government, the impact of social reputation on the decisions of governments and enterprises, and the strategic interaction between enterprises and governments.

From the perspective of game theory, this paper explores the probability and potential evolutionary paths of enterprises adopting new energy vehicle transformation strategies under different government reward and penalty policies. It is hypothesised that enterprises will consider government incentives, the cost of transformation, and the social reputation gained after transformation when making decisions. Ultimately, the purpose of this paper is to provide empirically supported insights through in-depth analysis to help enterprises, governments, and stakeholders better understand the dynamics of industrial transformation under policy reward and penalty mechanisms. Simultaneously, the findings will also provide references for policymakers to formulate or adjust relevant policies to promote the sustainable development of the new energy vehicle industry.

2. Literature review

In the manufacturing process of automobile enterprises, enterprises have both the characteristics of the pursuit of profit (Zhang et al., 2024), but also have the side of social and environmental responsibility (Tian and Chen, 2016). The government is not only responsible for the supervision and management of automobile enterprises manufacturing, but also to promote the development and popularisation of new energy vehicle applications (Zhang et al., 2022). With the progress of the times update, new energy vehicles also gradually into the people's field of vision (Zhang and Cai, 2020). Traditional energy vehicles are no longer suitable for the low carbon development of society, and accelerating the development of new energy vehicles is the current trend in the automotive market (Shuai et al., 2021).

Reading the literature found that the role of the government in the development of new energy vehicles has an important impact (Awaga et al., 2020). For example, Hua et al. confirmed that the implementation of new energy vehicles plays an important role in realising energy saving and emission reduction through the siting problem of charging stations, and that the implementation of the development of new energy vehicles is one of the most important initiatives to ensure energy security and solve environmental problems (Nwilaty et al., 2023). At the same time, government participation (Zhao and Johnson, 2010) can promote the development of new energy vehicles into the market (Wang et al., 2022). Promoting the automotive industry to develop new energy key technologies how the government establishes effective incentives and guarantee mechanisms is the key (Yang and Wu, 2023). The government's incentive and subsidy policy are not only for the development of the industry (Zhao et al., 2024), but should also focus on the development of technological innovation (Li et al., 2022) of individual enterprises (Wang and Lee, 2023), for example, Lu et al. (2023) investigated that the interaction between government and business can influence governance effectiveness and promote environmental protection awareness. Gao and Teng (2021) examined how the government-business relationship affects the development of business innovation. Straka (2023) argued that the issue of energy security is very important for the development of enterprises, and how to ensure that economy and security go hand in hand during the development of new energy vehicles is one of the issues that enterprises need to consider. Zhang and Cai (2020) argued that the government should adopt different subsidy strategies at different stages of the development of new energy vehicles (Asmussen and Fosfuri, 2019). Scholars have made suggestions on how the government can better promote the development of new energy from the perspective of new energy. Du and Chen (2023) believed that resource utilisation is the main reason for low productivity of enterprises, and enterprises should actively solve the problem of resource allocation to jointly promote the development of new energy automobile industry and achieve economic prosperity and ecological balance.

3. Model construction

The reward and punishment policies of the government play a crucial role in the transition of automotive enterprises to the production of new energy vehicles. The following variables are relevant to the relationship between government incentives and disincentives policies and the transformation of automotive enterprises.

Table 1. Parameters symbols and descriptions

Symbol	Descriptions
G_0	Government income.
C_1	Operational cost with a reward-oriented implementation by the government.
A	Government rewards.
T_1	The reputation that sustainable development brings to the government.
π_0	Corporate income.
c_1	Transformation manufacturing cost for enterprises.
t_1	The reputation brought by sustainable development to enterprises.
θ	Probability of erroneous rewards.

Symbol	Descriptions
T_2	Reputation damage due to erroneous rewards.
c_2	Not transformation manufacturing cost for enterprises.
C_2	Operational cost with a punishment-oriented implementation by the government.
φ	Probability of erroneous punishments.
P	Amount of punishment.
T_3	Reputation damage due to erroneous punishments.

Source: Authors' own creation.

3.1 Government's gaming strategy

Table 2. Parameters symbols and descriptions

		Enterprises	
		New Energy	**Traditional**
Government	Rewards	$G_0 - C_1 - A + T_1$	$G_0 - C_1 - \theta A - T_2$
		$\pi_0 - c_1 + A + t_1$	$\pi_0 - c_2 + \theta A$
	Punishments	$G_0 - C_2 + \varphi P - T_3$	$G_0 - C_2 + P$
		$\pi_0 - c_1 - \varphi P$	$\pi_0 - c_2 - P$

Source: Authors' own creation.

Based on the assumptions above, the evolutionary game analysis of the government is shown as follows.

The payment when the government chooses the reward strategy:

$$W_1 = y\left(G_0 - C_1 - A + T_1\right) + \left(1-y\right)\left(G_0 - C_1 - \theta A - T_2\right) \tag{1}$$

The payment when the government carries out the punishment strategy:

$$W_2 = y\left(G_0 - C_2 + \phi P - T_3\right) + \left(1-y\right)\left(G_0 - C_2 + P\right) \tag{2}$$

The average payment from the government:

$$\overline{W} = xW_1 + \left(1-x\right)W_2 \tag{3}$$

Therefore, the dynamic differential equation for the government is shown as follows:

$$\frac{dx(t)}{dt} = x\left(W_1 - \overline{W}\right) = x\left(1\text{-}x\right)\{y[\left(1-\phi\right)P + \left(\theta-1\right)A + T_1 + T_2 + T_3] + C_2 - C_1 - A\theta - P - T_2\} \tag{4}$$

and

$$F\left(x\right) = x\left(1\text{-}x\right)\{[\left(1-\phi\right)P + \left(\theta-1\right)A + T_1 + T_2 + T_3]y + C_2 - C_1 - A\theta - P - T_2\} \tag{5}$$

so

$$F'(x)=(1-2x)\{[(1-\varphi)P+(\theta-1)A+T_1+T_2+T_3]y+C_2-C_1-A\theta-P-T_2\} \tag{6}$$

According to the principle of stability: if $F'(x^*)<0$, Then it indicates that x^* is in a stable state.

(1) When $y=\frac{-(C_2-C_1-A\vartheta-P-T_2)}{(1-\phi)P+(\theta-1)A+T_1+T_2+T_3}$, $\frac{dx(t)}{dt}$ always for 0, Indicates that x does not change with time.

(2) When $y>\frac{-(C_2-C_2-A\theta-P-T_2)}{(1-\phi)P+(\theta-1)A+T_1+T_2+T_3}$, $F'(x)<0$, $x=1$ is an evolutionary stable state. It implies that after continuous imitation and learning, the proportion of rewards chosen by the government tends to be 100%.

(3) When $y<\frac{-(C_2-C_2-A\theta-P-T_2)}{(1-\phi)P+(\theta-1)A+T_1+T_2+T_3}$, $F'(x)<0$, $x=0$ is an evolutionary stable state. It implies that after continuous imitation and learning, the proportion of punishments chosen by the government tends to be 100%.

3.2 Automobile enterprise's gaming strategy

Payments when automobile enterprises produce new energy:

$$U_1=x[\pi_0-c_1+A+t_1]+(1-x)(\pi_0-c_1-\varphi P) \tag{7}$$

The payment when the automobile enterprises do not produce new energy:

$$U_2=x[\pi_0-c_2+\theta A]+(1-x)(\pi_0-c_2-P) \tag{8}$$

The average payment from the automobile enterprises:

$$\bar{U}=yU_1+(1-y)U_2 \tag{9}$$

Therefore, the dynamic differential equation of the production enterprise is shown as follows:

$$\frac{dy(t)}{dt}=y(U_1-\bar{U})=y(1-y)\{[(1-\theta)A+(\phi-1)P+t_1]x+(1-\phi)P-c_1+c_2\} \tag{10}$$

and

$$F(y)=y(1-y)\{[(1-\theta)A+(\varphi-1)P+t_1]x+(1-\varphi)P-c_1+c_2\} \tag{11}$$

so

$$F'(y)=(1-2y)\{[(1-\theta)A+(\varphi-1)P+t_1]x+(1-\varphi)P-c_1+c_2\} \tag{12}$$

According to the principle of stability: if $F'(y^*)<0$, Then it indicates that y^* is in a stable state.

(1) When $x=\frac{-[(1-\phi)P-c_1+c_2]}{(1-\theta)A+(\phi-1)P+t_1}$, $\frac{dy(t)}{dt}$ always for 0, Indicates that y does not change with time.

(2) When $x > \frac{-\left[(1-\phi)P - c_1 + c_2\right]}{(1-\theta)A + (\phi-1)P + t_1}$, $F'(y) < 0$, $y = 1$ is an evolutionary stable state. It implies that after continuous imitation and learning, the proportion of enterprises producing new energy among automobile enterprises tends to 100%.

(3) When $x < \frac{-\left[(1-\phi)P - c_1 + c_2\right]}{(1-\theta)A + (\phi-1)P + t_1}$, $F'(y) < 0$, $y = 0$ is an evolutionary stable state. It implies that after continuous imitation and learning, the proportion of the enterprises that choose not to produce new energy among automobile enterprises tends towards 100%.

3.3 Stability analysis of system evolution game

By combining equation (4) with equation (10), the differential equation set (13) can be obtained, which can represent the entire system's game evolutionary process:

$$\begin{cases} \frac{dx(t)}{dt} = x(1\text{-}x)\left\{\left[(1-\phi)P + (\theta-1)A + T_1 + T_2 + T_3\right]y + C_2 - C_1 - A\theta - P - T_2\right\} \\ \frac{dy(t)}{dt} = y(1-y)\left\{\left[(1-\theta)A + (\phi-1)P + t_1\right]x + (1-\phi)P - c_1 + c_2\right\} \end{cases} \tag{13}$$

When $\frac{dx(t)}{dt} = 0$, $\frac{dy(t)}{dt} = 0$, the possible equilibrium points of the system can be obtained as $(0,0)$, $(0,1)$, $(1,0)$, $(1,1)$, $\left(\frac{-\left[(1-\phi)P - c_1 + c_2\right]}{(1-\theta)A + (\phi-1)P + t_1}, \frac{-\left(C_2 - C_1 - A\theta - P - T_2\right)}{(1-\phi)P + (\theta-1)A + T_1 + T_2 + T_3}\right)$. To determine which point is the evolutionarily stable state ESS, according to the method created by Friendman in 1991 for calculating the local stability of the system (1991), the Jacobian matrix of the evolutionary system equation set can be analysed.

In equation system (13), partial derivatives are taken for two equations x and y, respectively, to obtain the Jacobian matrix, as shown in (14):

$$J = \begin{vmatrix} \begin{matrix}(1\text{-}2x)\{[(1-\phi)P + (\theta-1)A + T_1 \\ + T_2 + T_3]y + C_2 - C_1 - A\theta - P - T_2\}\end{matrix} & x(1\text{-}x)\left[C_2 - C_1 - A\theta - P - T_2\right] \\ y(1-y)\left[(1-\phi)P - c_1 + c_2\right] & \begin{matrix}(1-2y)\{[(1-\theta)A + (\phi-1)P \\ + t_1]x + (1-\phi)P - c_1 + c_2\}\end{matrix} \end{vmatrix} \tag{14}$$

Bring the local equilibrium points A, B, C, D, and E into the Jacobian matrix and find out det(J) as well as tr(J) to search for the system's evolutionary stable point (ESS).

(1) When x=0, y=0, the determinant and trace of the matrix J.

$$\begin{cases} \det J = \left(C_2 - C_1 - A\theta - P - T_2\right)\left[(1-\phi)P - c_1 + c_2\right] \\ \operatorname{tr} J = \left(C_2 - C_1 - A\theta - P - T_2\right) + \left[(1-\phi)P - c_1 + c_2\right] \end{cases} \tag{15}$$

In this case, only when $\left(C_2-C_1-A\theta-P-\mathrm{T}_2\right)<0$, $\left[(1-\phi)\mathrm{P}-\mathrm{c}_1+\mathrm{c}_2\right]<0$ can satisfy the stable point condition, this is $\left(C_2-C_1\right)<A\theta+P+T_2$, $(1-\phi)P<\left(c_1-c_2\right)$,as the government tends to choose to punish enterprises to obtain more fines, $\left(C_2-C_1\right)$,automobile enterprises will be unwilling to transform new energy production, obtain more financial saving benefits, $\left(C_2-C_1\right)$, at this time the corresponding evolutionarily stable strategy is (government punishment, enterprises unwilling to transform). Additionally, θ as increases, it will lead to the increase of $\left(C_2-C_1\right)$, the government will worry about the occurrence of rewards for the automobile enterprises that are unwilling to transform into new energy, and they are more inclined to choose to punish enterprises. θ as increases, this will lead to the enterprise being wrongly punished for implementing the transformation into new energy, causing automobile enterprises to be more inclined to adopt a production strategy without transforming into new energy.

(2) When x=0, y=1, the determinant and trace of the matrix J.

$$\begin{cases}\mathrm{detJ}=\left(C_2-C_1-\mathrm{A}-\phi P+T_1+T_3\right)(-1)\left[(1-\phi)P-c_1+c_2\right]\\ \mathrm{trJ}=\left(C_2-C_1-\mathrm{A}-\phi P+T_1+T_3\right)-\left[(1-\phi)P-c_1+c_2\right]\end{cases} \tag{16}$$

It is known that only when condition $\left(C_2-C_1-\mathrm{A}-\phi P+T_1+T_3\right)<0$, $\left[(1-\phi)P-c_1+c_2\right]>0$ are met can the stable point condition be met. At this point, there is $\left(C_2-C_1\right)<\mathrm{A}+\phi P-T_1-T_3$, $\left[(1-\phi)P\right]>c_1-c_2$, it follows that the government's revenue from choosing fines is greater than the revenue from choosing rewards, and the car company's revenue from not transitioning to new energy production is less than the revenue from transitioning to new energy production. Moreover, the larger φ , the more, will lead to an increase in $\left(C_2-C_1\right)$,meaning the government can obtain more revenue from penalising companies for not transitioning to new energy production, thus leaning more towards choosing to punish companies; while on the auto company side, as φ increases, it will lead to the cost of transitioning to new energy manufacturing and the cost of not transitioning becoming similarly high, so the company will temporarily choose not to transition to new energy. There is the possibility of being wrongly penalised, leading car companies to prefer to adopt a strategy of transitioning to new energy production. This state can achieve equilibrium in the short term, but given the reality, under government function overlap due to unclear definitions of functions and unclear distribution of benefits, it is difficult for different government departments to reach a balance where one side fines and the other does not. Therefore, in the long term, this equilibrium state will evolve towards (reward, car company transitions) or (punishment, car company does not transition).

(3) When x=1, y=0, the determinant and trace of the matrix J.

$$\begin{cases} \det J = (-1)(C_2 - C_1 - A\theta - P - T_2)\left[(1-\theta)A + t_1 - c_1 + c_2\right] \\ trJ = (-1)(C_2 - C_1 - A\theta - P - T_2) + \left[(1-\theta)A + t_1 - c_1 + c_2\right] \end{cases} \tag{17}$$

Similarly, it can be inferred that only when the conditions are met can $(C_2 - C_1 - A\theta - P - T_2) > 0$, $\left[(1-\theta)A + t_1 - c_1 + c_2\right] < 0$ satisfy the stable point condition. At this point, there is $(C_2 - C_1) > A\theta + P + T_2$, $\left[(1-\theta)A + T_1\right] < c_1 - c_2$, it follows that the government's revenue from choosing rewards is greater than the revenue from choosing to punish, especially in terms of gaining a lot of social reputation; when a car company's revenue from not transitioning to new energy is less than from transitioning, the corresponding ESS is (reward, non-transitioning to new energy). Furthermore, the larger θ ,the more it will lead to an increase in $(C_2 - C_1)$,meaning the government can obtain more revenue from rewarding green manufacturing companies, thus leaning more towards choosing to reward companies; as θ increases, will see the cost of transitioning to new energy manufacturing and the cost of not transitioning get closer together, so companies will temporarily choose to transition to new energy to gain more revenue. Considering the reality, where rewarding the transition to new energy involves overlapping functions of many government departments, the choice of stable strategy will evolve in the direction of (reward, transition to new energy) or (punishment, non-transition to new energy).

(4) When x=1, y=1, the determinant and trace of the matrix J.

$$\begin{cases} \det J = (-1)(C_2 - C_1 - A - \phi P + T_1 + T_3)(-1)\left[(1-\theta)A + t_1 - c_1 + c_2\right] \\ trJ = (-1)(C_2 - C_1 - A - \phi P + T_1 + T_3) + (-1)\left[(1-\theta)A + t_1 - c_1 + c_2\right] \end{cases} \tag{18}$$

In this case, only when $(C_2 - C_1 - A - \phi P + T_1 + T_3) > 0$, $\left[(1-\theta)A + t_1 - c_1 + c_2\right] > 0$. In order to meet the stable point condition, there are $(C_2 - C_1) > A + \phi P - T_1 - T_3$, $\left[(1-\theta)A + T_3\right] > c_1 - c_2$, at which point it follows that the government's revenue from penalising is greater than from rewarding $(C_2 - C_1)$, so the car company will choose to transition to new energy and gain more financial savings; $(c_1 - c_2)$, at this point, the corresponding ESS is (reward, transition to new energy). Moreover, as φ grows larger, it will lead to an increase in $(C_2 - C_1)$, meaning that the government penalising new energy-transitioning companies incorrectly will affect its reputation, thus more inclined to choose to reward companies; while on the company side, as θ increases, it will lead to the possibility of serious penalties for not implementing a transition to new energy, causing companies to tend more toward adopting a strategy of transitioning to new energy production.

(5) However, at point E, since there is always $trJ = 0$, there is no stable point.

4. Evolutionary Game Simulation Analysis of Government Rewards/Punishment and Car Company Transitioning Behaviours

4.1 Simulation Analysis of Evolutionary Game Equilibrium Points

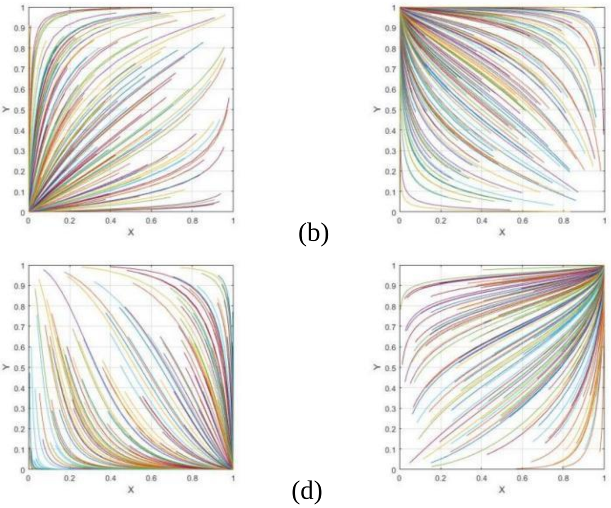
First, set the basic parameters for Evolutionarily Stable Strategy (ESS) at (0,0) and verify through simulations. On this basis, adjust and set values according to the conditions of evolutionary stability, and analyse other possible ESS via simulations. Since the conditions for distinguishing equilibrium between (1,1) and (0,0), as well as (1,0) and (0,1), are unique, and the other equilibrium conditions are numerous, they will not be verified one by one due to space limitations. Only one condition of each type of equilibrium will be listed, and the others are analogously determined. Randomly select 150 sets of initial probabilities to observe the evolutionary trajectories of the participating entities. The simulation parameter settings and results are as follows.

When the model parameters are set to the following values: C_2 =0.5; C_1 =4; A =1; st =0.5; P =0.5; f =1; c_1 =5; c_2 =1; T_1 =1; T_2 =1; T_3 =1; t_1 =1. Government regulation incurs high costs, leading to the tendency to penalise companies to reduce operational costs; transition to new energy production is expensive for companies, inclining them to choose not to transition to new energy to save costs. At this time, (Penalty, No Transition to New Energy) is the ESS (Evolutionarily Stable Strategy) point. When the initial value of the sharing probability for A-class and B-class enterprises is fixed at 0.2, the system cost coefficients are set to 0.2 and 0.7 respectively, and the evolutionary results are shown in Figure 1 (a).

When the model parameters are set to the following values: C_2 =1; C_1 =8; A =1; st =0.5; P =0.5; f =1; c_1 =1; c_2 =8; T_1 =1; T_2 =1; T_3 =1; t_1 =1.The cost of government incentives is high, leading to a tendency to penalise companies to lower operational costs; the cost of not transitioning to new energy is high for companies, leading them to prefer transitioning to new energy to decrease costs. At this time, (Penalty, Transition to New Energy) is the ESS point. The evolutionary results are shown in Figure 1 (b).

When the model parameters are set to the following values: C_2 =7; C_1 =2; A =2; st =0.5; P =0.5; f =1; c_1 =6; c_2 =1; T_1 =1; T_2 =1; T_3 =1; t_1 =1.The cost of government incentives is low, leading to a tendency to reward companies for reducing operational costs; the cost of transitioning to new energy is high for companies, leading them to prefer not to transition to new energy to cut costs. At this time, (Reward, No Transition to New Energy) is the ESS point. The evolutionary results are shown in Figure 1 (c).

When the model parameters are set to the following values: C_2=7; C_1=2; A=2; st =0.5; P =0.5; f =1; c_1 =2; c_2 =7; T_1 =6; T_2 =1; T_3 =6; t_1 =1.The cost to the government for offering rewards is low, leading to a preference for rewarding companies to reduce operational costs; companies face higher costs if they do not switch to new energy manufacturing; thus, they tend to choose to transition to new energy to save costs, improve their social image and potentially receive government rewards. At this point, (Reward, Transition) is the ESS point. The evolutionary results are shown in Figure 1 (d).



(a) (b) (c) (d)

Figure 1. Evolutionary equilibrium
Source: Authors' own creation.

4.2 Analysis of factors influencing evolutionary game equilibrium

Based on evolutionary stability at (1,1), further simulation analysis is conducted on factors such as rewards for companies (A), penalties (P), government social reputation ($T_1;T_2;T_3$), company social reputation (t_1), government operational costs ($C_1;C_2$), company operational costs ($c_1;c_2$),the impact of erroneous rewards (θ),the impact of erroneous penalties(ϕ).Changes in evolutionary equilibrium trends with varying strategy judgment policies are examined for possible variable influences, with parameter values and simulated change diagrams shown below:

(1) Impact of government rewards on the evolutionary game

By setting varying amounts of government rewards values of A chosen as 1, 5, and 10, under the condition of other factors remaining constant, simulation graphs like those below can be obtained. Compared to automotive companies, the impact of the reward amount is greater on the government; with increasing rewards, government costs increase, and there is a slower shift toward reward strategy. However, the government gains a higher reputation and, from a long-term perspective, ultimately still chooses a reward policy. Stimulated by the rewards, companies accelerate their transition to new energy as the incentive increases.

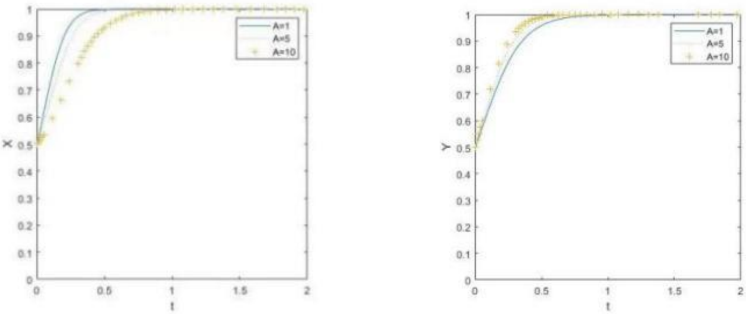


Figure 2. Government and corporate strategy evolution trajectories under different intensities of government rewards
Source: Authors' own creation.

(2) Impact of government penalties on the evolutionary game

By setting varying amounts of government penalties, the values of P chosen as 1, 5, and 10, under the condition of other factors remaining constant, simulation graphs like those below can be obtained.

As indicated by Figure 3, as the penalty amount increases, the government gains more revenue indirectly from fines, ultimately leading the government to choose penalty strategies rather than rewards. On the corporate side, penalties instil fear of being wrongly fined, and the risk of high fines coupled with the pressure of transformation costs shift companies from willing transition to new energy rapidly to not transitioning at all.

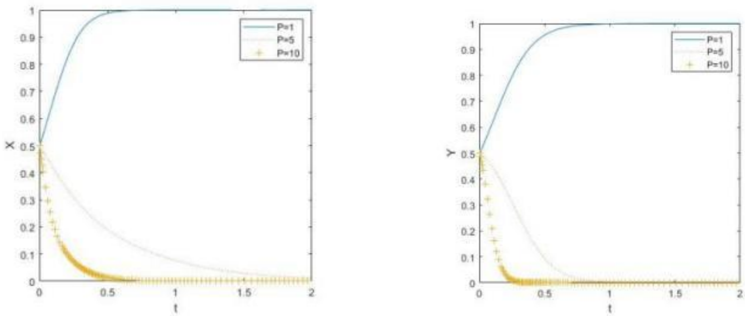


Figure 3. Government and corporate strategy evolution trajectories under different intensities of government penalties
Source: Authors' own creation.

(3) Impact of government operational costs on the evolutionary game

As can be seen from Figure 4, the government's implementation of the incentive policy slows down as the operating costs of the incentive strategy rise, but from a sustainable long-term perspective, the government ultimately still implements the incentive policy. Because the government's operating cost increase cannot directly affect enterprises, it basically has no effect on enterprises' new energy transformation strategies. As the operating cost of the government's penalty strategy increases, the more the government tends to adopt the incentive strategy. Because the government's operating cost increase cannot directly affect enterprises, it still has little impact on the transition to new energy strategies of automotive companies.

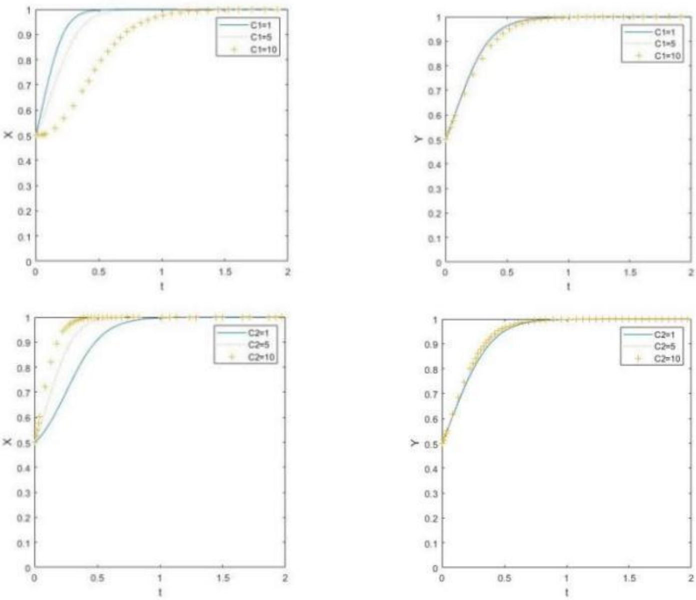


Figure 4. Government and corporate strategy evolution trajectories under different government operational costs
Source: Authors' own creation.

(4) Impact of change in government social reputation on the evolutionary game

As in Figure 5, an increase in government social reputation T_1 speeds up the adoption of reward policies by the government, while increases in T_2 and T_3 slow down the implementation of rewards. Nonetheless, the government eventually chooses to reward, and as the company's reputation directly affects the enterprise, it has no impact on the automotive company's strategy to transition to new energy.

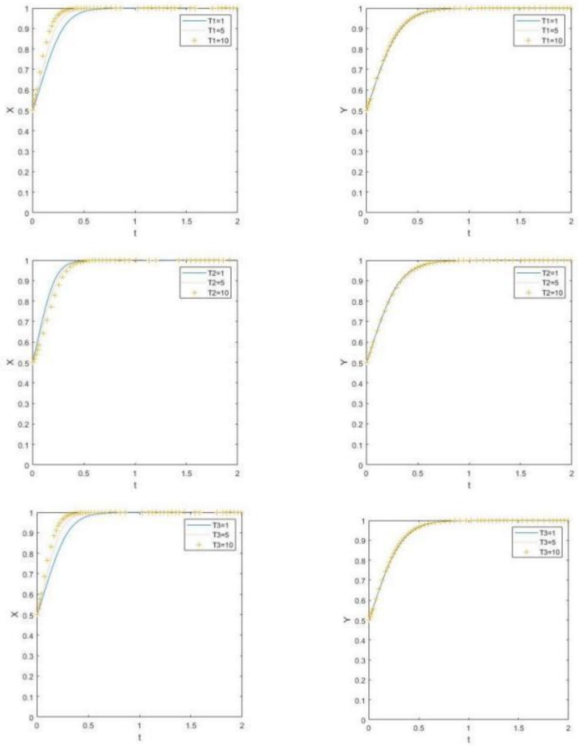


Figure 5. Government and corporate strategy evolution trajectories under different corporate social reputation values
Source: Authors' own creation.

(5) Impact of change in company social reputation on the evolutionary game

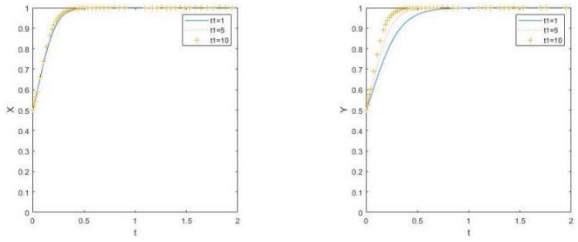


Figure 6. Government and corporate strategy evolution trajectories under different government social reputation values
Source: Authors' own creation.

Figure 6 indicates that an increase in social reputation (t_1) for the company results in more attention and increased pressure, slowing down the pace of transition, but ultimately the company will transition to new renewable energy. Relative to the government, the company's reputation has a smaller impact on governmental decisions; thus, it does not affect the government's choice of reward policies.

(6) Impact of Company Green Manufacturing Costs on the Evolutionary Game

The Figure 7 shows that as the cost of switching to new energy (c_1) for the company increases, the government tends to choose reward policies to strengthen automotive companies' transition to new energy, but the intensity of this measure varies slightly. Companies also significantly choose not to transition to new energy with the increasing cost (c_1). With rising costs (c_2) of not transitioning to new energy, the government tends towards reward measures but with minimal change in intensity; automotive companies, with an increase in cost (c_2), tend to significantly choose transitioning to new energy production.

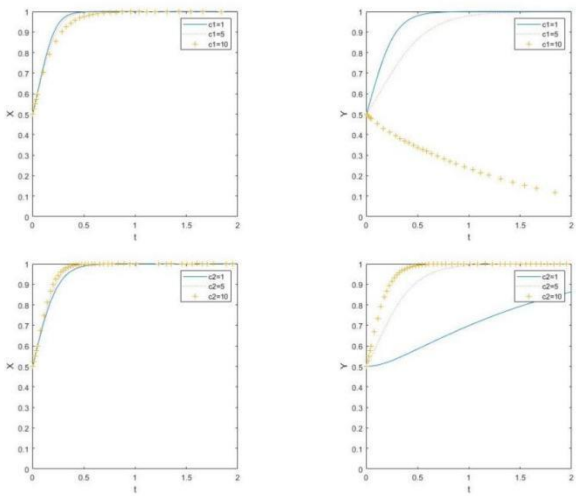


Figure 7. Government and corporate strategy evolution trajectories under different corporate manufacturing costs

Source: Authors' own creation.

(7) Impact of Erroneous Rewards on the Evolutionary Game

The Figure 8 indicates that as the likelihood of erroneous government rewards θ increases , despite the small specific reward values, the government still tends to choose reward policies, And with the improvement of θ enterprises, Enterprises will choose to transform into new energy models for production, but due to the small reward value, the impact on the transformation of enterprises into new energy is not significant.

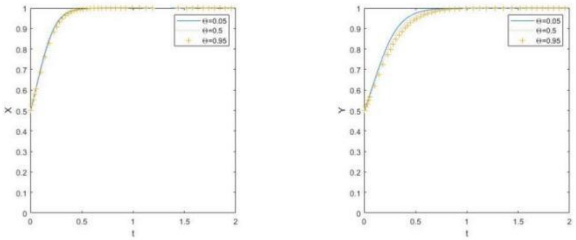


Figure 8. Government and corporate strategy evolution trajectories under different probabilities of erroneous rewards
Source: Authors' own creation.

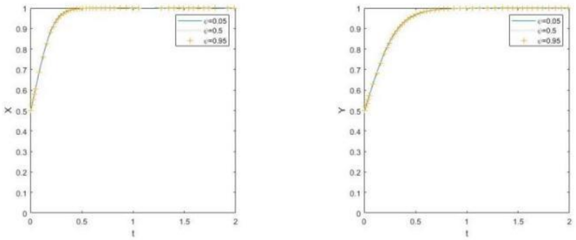


Figure 9. Government and corporate strategy evolution trajectories under different penalty probabilities for errors
Source: Authors' own creation.

(8) Impact of erroneous penalties on the evolutionary game

As shown in Figure 9, as the probability of government penalty for errors ϕ increases, the government's choice of reward policies does not fluctuate; similarly, as ϕ increases, the corporate decision to transition to producing new energy does not fluctuate either.

5. Conclusions

The simulation analysis results show that the intensity of government's reward and penalty policies has expanded, highlighting the government's determination in the transformation of the automotive industry towards new energy development. At the evolutionary equilibrium points (0,0) and (1,1), it can be concluded through parameter adjustment that an increase in corporate rewards will to some extent enhance the willingness of automotive companies to transition to new energy production, while an increase in government penalties significantly reduces the decision-making willingness of companies to make such a transition.

Moreover, changes in the government's operational costs have virtually no impact on reward and penalty decisions, merely slowing down the implementation of reward policies, but the effect on corporate decisions is minor. Variations in social reputation value have some accelerating or decelerating effects on government decisions, but they do not affect the decisions of automotive companies regarding whether to transition to new energy manufacturing. Companies are most sensitive to the costs of transitioning to new energy vs. not transitioning. In addition, both government mistakes in rewards and penalties have a relatively small impact on both the government itself and corporations.

In summary, from the government's perspective, the optimal decision plan is to reduce operational costs through fewer errors in rewards and penalties, thus improving government reputation, while giving reward policies to companies; from the perspective of automotive companies, the best decision plan is to reduce the operational costs of transitioning to new energy through technological innovation, expand the popularity of new energy production, and thereby enhance corporate social reputation.

Lastly, the main contributions of this study include: combining rewards and penalties into one model, expanding the scope of previous studies on the evolutionary game between government and enterprises that only measured from the perspective of either rewards or penalties; introducing the factor of erroneous judgments in rewards and penalties, which makes the model assumptions more closely aligned with real situations; and through simulation analysis of different parameters, proposing the variability factors that influence the government's reward and penalty strategies and automotive companies' decision-making strategy toward new energy transition, impacting the results of the evolutionary game.

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