Evolutionary Game Analysis of Government Regulation and Corporate Energy Conservation Promotion Strategies

Xizhe Wang, Zhaoxin Liu, and Zehao Wang

***Abstract*—This paper addresses the issue of energy conservation and emission reduction across society by examining the energy conservation knowledge promotion policies of energy sales enterprises. An evolutionary game model that includes both the government and an energy enterprise is developed to analyze the stability of the enterprise's energy conservation knowledge promotion and the government's regulatory strategies. Additionally, by incorporating numerical simulations of strategic changes, the stable evolutionary path is validated, and the specific factors influencing the enterprise's energy conservation knowledge promotion strategies are analyzed. The findings reveal that the awareness of corporate social responsibility is a crucial driver for energy production enterprises to promote energy conservation knowledge. When the energy sales enterprise's awareness of corporate social responsibility is sufficiently high, both the enterprise and the government achieve evolutionarily stable strategies, meaning that the enterprise actively promotes energy conservation knowledge and that government regulation is unnecessary. In other scenarios, stable strategies where the enterprise actively promotes energy conservation knowledge are not achievable. This study offers new insights into the promotion of energy conservation behavior in enterprises under government regulation.**

***Index Terms*—Energy conservation knowledge, Enterprise promotion, Government regulation, CSR.**

I. Introduction

CLIMATE phenomena such as global warming, rising sea temperatures, shrinking sea ice, and glacial melt are sounding a global red alert. Human activities are accelerating climate change at an alarming rate, placing the global climate system under severe and immediate threat. According to the 2023 World Meteorological Organization (WMO) report on the state of the global climate, 2023 was the hottest year on record, with global surface temperatures approximately 1.45°C higher than preindustrial levels. As climate change intensifies, the urgency of protecting the environment through energy conservation and reducing greenhouse gas emissions becomes increasingly critical.

Addressing the challenges posed by global climate change requires strengthened cooperation among governments, enterprises, and society, with each fulfilling its respective responsibilities. Governments, for example, can support research and innovation in green energy companies, fostering the application and development of renewable energy technologies [1]. Additionally, governments can enact and implement policies, regulations, and measures to monitor and manage corporate efforts to promote energy saving and environmental knowledge [2]. These efforts include establishing systems to oversee the corporate dissemination of energy-saving knowledge, encouraging companies to actively educate the public on energy-saving practices, and raising public awareness of green energy solutions [3]. Such initiatives help prevent corporate negligence or passive behavior in promoting energy conservation. Governments may also establish reward and punishment mechanisms to regulate corporate energy-saving practices [4].

Energy enterprises play a crucial role in achieving energy conservation and emission reduction goals. As significant contributors to energy consumption and carbon emissions, these companies bear responsibility for actively participating in energy-saving initiatives. Much of the existing research focuses on how energy companies can improve energy efficiency, restructure industries, adopt low-carbon technologies, and recycle energy [5]. Individuals and households also play a role by engaging in energy-saving behaviors; however, the lack of knowledge and skills related to energy efficiency limits their potential to engage in such practices [6]. Consequently, many scholars argue that strategic energy education and awareness campaigns are necessary to improve public energy literacy [7], [8]. Despite these efforts, empirical studies reveal that single interventions do not significantly reduce overall energy consumption [9]. Interventions that combine information dissemination with other strategies tend to be more effective than standalone efforts [10]. Therefore, a multifaceted approach is needed to complement government-driven efforts and create more comprehensive policies.

Within this context of government regulation and corporate social responsibility, several research questions arise:

From the government's perspective, should stricter regulation be imposed on companies responsible for promoting energy-saving knowledge?

From the perspective of corporate interests, should energy sales companies actively promote energy-saving knowledge?

How can government regulation and corporate promotion strategies be optimized to achieve maximum benefits?

These issues pertain to the government regulation of companies and corporate strategies for disseminating energy-saving knowledge. Research suggests that social incentives, driven by information dissemination, are often more effective than economic incentives in promoting energy-saving

Manuscript received November 10, 2024; revised July 10, 2025.

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behavior [11]. As large-scale energy service providers and suppliers, energy companies have extensive global customer bases, positioning them to play a significant role in disseminating energy-related knowledge. They can utilize various platforms, such as websites, apps, and social media, to promote energy-saving messages. However, the question remains whether these companies will willingly engage in such promotion. Energy-saving initiatives incur costs, including advertising and dissemination expenses. Some studies suggest that public investment in energy-saving education can result in substantial energy savings, viewing the cost of such promotion as a "social offset" investment [12]. However, the costs for energy companies come from within, as those focused on sales may experience reduced revenues due to lower energy consumption. As a result, energy-saving promotion by energy companies can be viewed as an integral aspect of their broader social responsibility.

Prior research also shows that corporate social responsibility can negatively affect short-term financial performance, reinforcing the notion that energy companies' promotion of energy-saving knowledge may impact profitability [13]. Government subsidies and incentives play crucial roles in motivating companies to fulfill their social responsibilities. However, it remains uncertain whether these subsidies can fully cover the costs of energy-saving promotion. Therefore, exploring how governments can design policies to encourage energy companies to engage in energy-saving initiatives is a valuable area for further research.

In this study, we employ an evolutionary game theory framework to examine the interaction between governments and corporations in energy-saving promotion strategies. The evolutionary game model simulates decision-making behaviors among multiple actors with limited resources, revealing the dynamic and evolving processes of competition and cooperation. This model is particularly well suited for analyzing the interrelationship among governments, companies, and society, offering insights into how optimal promotional and regulatory strategies can be identified within the context of energy conservation and emission reduction. The adoption of this game theory perspective is consistent with existing research on climate change and provides a solid foundation for analyzing how companies balance economic interests with social responsibility in this context. Through model analysis, we derive optimal strategies for both governments and companies, providing theoretical support for the transition to a greener, low-carbon economy [14, 15].

Building on previous research, this paper analyzes corporate energy-saving promotion strategies and government regulatory mechanisms. We first construct a relevant model and then use game theory analysis methods to determine corporate promotional strategies and government regulatory mechanisms, ultimately deriving general decision-making principles for corporate energy-saving knowledge dissemination under government regulation. Finally, we provide numerical examples to verify the results.

II. MODEL CONSTRUCTION

A. Model Description

This study examines an energy-saving knowledge promotion system involving a collaboration between a single energy sales company and a governmental authority. Both the energy sales company and the government agency operate under the assumption of bounded rationality, developing and implementing strategic promotion efforts to optimize their decision-making processes. The energy sales company is responsible for promoting energy-efficient technologies and practices to consumers, whereas the government agency's role is to encourage and regulate those initiatives through policy measures. Both entities aim to maximize their respective goals, which are often aligned with reducing overall energy consumption and promoting sustainable practices. The concept of bounded rationality, as introduced by Simon (1955), posits that decision-makers are constrained by limited information and cognitive capacity. This paper emphasizes how these two key players adapt their strategies in response to market environments and regulatory frameworks.

TABLE I: Variables and their definitions

Variable	Definitions
α_i	Positive or negative energy conservation knowledge promotion strategies of energy selling firms
x	The probability that an energy sales firm will choose a positive energy conservation knowledge promotion strategy
β	The government's strategy for regulating enterprises' energy saving publicity
y	Probability that the government will choose a strict regulatory strategy
c	Unit cost of energy production in energy selling firms
p	Energy price of the energy selling firm
C	Cost of corporate publicity
C_g	Cost of government regulation
C_c	Negative impact of negative publicity by firms, cost of government regulation
q_i	Energy use by society as a whole for different publicity strategies
A	Positive publicity, government incentives for firms
P	Negative publicity, government penalizes firms
R^g, R^f	Social benefits of positive publicity for government/firms

Energy-saving promotion systems have been increasingly discussed in recent literature, particularly in the context of interactions between businesses and governments. According to [14], government intervention through policy regulations can play a crucial role in encouraging energy-saving behaviors among both companies and consumers. Moreover, [15] demonstrate how energy sales companies benefit from aligning their promotion strategies with governmental energy policies, leading to mutually beneficial outcomes. As noted [16], [17], incorporating consumer preferences into decision-making models can provide insights into how firms and governments adjust their strategies in the face of uncertainty and limited information. The interaction between an energy sales company and a government, influenced by bounded rationality, can result in dynamic decision-making processes that ultimately optimize energy-saving outcomes through knowledge dissemination and behavioral incentives [18]. As shown in Table I, the key variables and their meanings in the model are as follows:

Energy sales companies produce energy products at a unit cost of c and sell them at a unit price of p. In regard to energy-saving knowledge promotion, these companies have two strategic options. They can choose to actively promote energy-saving knowledge, with the cost of such active promotion denoted by C_a. Alternatively, they can engage in passive promotion, with a lower cost denoted by C_p. Since active promotion involves additional efforts, such as distributing gifts or reposting promotional articles to increase the effectiveness and reach of the campaign, the cost of active promotion is assumed to be greater than that of passive promotion, i.e., $C_a > C_p$.

When energy sales companies adopt an active promotion strategy, the overall energy consumption of businesses, individuals, and society at large is denoted by E_a. Conversely, when companies opt for a passive promotion strategy, the total societal energy consumption is represented by E_p. Since active promotion increases awareness of energy conservation, it leads to a reduction in total energy usage. Hence, $E_a < E_p$, reflecting the positive impact of active— promotion on reducing energy consumption. Let q_a and q_p represent the probabilities of the company choosing active or passive promotion, respectively, where $q_a + q_p = 1$.

Interestingly, if energy sales companies engage in active energy-saving promotion, there are several benefits. First, it contributes to environmental protection, public health, and economic development, generating a societal benefit for the government, denoted by S. Second, active promotion reflects corporate social responsibility (CSR), enhancing the company's image and increasing consumer trust, which yields additional revenue for the company, denoted by R. On the other hand, if the company opts for passive promotion, it results in energy waste, leading to negative externalities for society. The government must then incur a cost, denoted by D , to mitigate the effects of this energy waste.

When overseeing companies' energy-saving knowledge promotion, the government also has two strategies. The government can either strictly regulate corporate energy-saving promotion efforts at a cost of G_s, or it can adopt a more lenient regulatory approach with zero cost, denoted by G_1. Let p_s and p_1 represent the probabilities of the government choosing strict or lenient regulation, respectively, where $p_s + p_l = 1$

Additionally, if the government enforces strict regulation and the company chooses to actively promote energy-saving knowledge, the company is rewarded with an incentive I. However, if the company engages in passive promotion under strict government regulation, it is fined an amount F . Notably, if no fines are imposed, then $F = 0$. Under lenient regulation, the government cannot accurately assess the company's promotional strategy; thus, no rewards or penalties are applied.

B. Sequence of Events

The sequence of events is assumed to follow the structure shown in Figure 1. In the first stage, the energy sales company determines its strategy for promoting energy-saving knowledge. In the second stage, the government determines its regulatory approach. If the government opts for strict regulation, it incurs a regulatory cost G_s. If the government chooses a loose regulatory approach, it does not acquire specific information about the company's energy-saving promotional strategy or actions.

In the third stage, the energy sales company sets the price p for its energy products and sells them on the market. Finally,

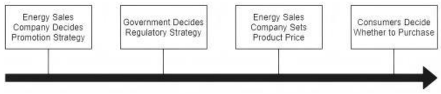


Fig. 1: Sequence of Events

informed consumers, aware of the available information regarding the energy products, decide whether to purchase the products on the basis of the company's pricing. For convenience, superscripts or subscripts f^+, f^- and f are used to represent the firm's positive (active) and negative (passive) promotional strategies, respectively. Similarly, g^s, g^l and g denote the government's strict and loose regulatory strategies, respectively.

Thus, the interactions between the firm and the government, along with the subsequent consumer decisions, follow this sequence, where the firm first chooses its promotion strategy, the government decides its regulatory action, and finally, the firm sets its product pricing for consumers, who make their purchasing decisions on the basis of the firm's actions and the prevailing regulatory environment.

III. Model Construction and Analysis

A. Model Construction

This section discusses the different promotion strategies of energy sales companies and the various regulatory strategies of the government. On the basis of the assumption outlined above, there are four possible strategy combinations between the energy sales company and the government, as shown in Table II.

We consider four possible scenarios for the company's strategies.

Scenario 1: PS and PL

When the company adopts an active promotion strategy, the expected payoff function is as follows:

$$\begin{aligned} U_{xp} = y\ \ (p-c)q_p - C_p + A + R^f \\ + [1-y]\ \ (p-c)q_p - C_p + R^f \end{aligned} \quad (1)$$

The first term on the right side of the equation represents the company's payoff when the government chooses a lenient regulatory strategy, and the second term represents the company's payoff when the government chooses a strict regulatory strategy. When the company adopts an active promotion strategy, its profit is expressed as $(p - c)q_p$, but the company must pay a certain promotional cost, C_p. Additionally, the company receives a reward, A, from the government for its active promotion efforts, which is also associated with positive social benefits: $p{-}c{\cdot}q_p{-}C_p{+}A{+}R_f$. Conversely, if the company adopts a passive promotion strategy, the company's profit is $p - c \cdot q_p - C_p$, and the government does not provide any reward for this strategy. In this case, the company's payoff is $p - c.\ q_p - C_p + R_f$.

Scenario 2: NS and NL

For passive promotion strategies, the payoff function is as follows:

$$\begin{aligned} U_{xn} = y\,[(p-c)q_n - C_n - P\,] \\ + [1-y]\,[(p-c)q_n - C_n] \end{aligned} \quad (2)$$

The first term on the right side of the equation represents the company's payoff when the government chooses a strict regulatory strategy, and the second term represents the

TABLE II: Promotion and Regulatory Strategies

Energy Sales Company	Government	
	S : Strict regulation (y)	L : Lenient regulation $(1-y)$
P : Active energy conservation knowledge promotion (x)	PS	PL
N : Passive energy conservation knowledge promotion $(1-x)$	NS	NL

company's payoff when the government chooses a lenient regulatory strategy. When the company adopts a passive promotion strategy, the company's profit is expressed as $(p-c)q_n$, and the company incurs a certain cost for passive promotion, C_n. Additionally, the government will impose a penalty, P , on the company for

passive promotion. As a result, the company's total payoff under strict government regulation is $p-c.\,q_n-C_n-P$. However, if the government adopts a lenient regulatory strategy, the company's payoff, regardless of whether it chooses active or passive promotion, is $p-c\cdot q_n-C_n$.

Thus, the overall expected payoff for the company is as follows:

$$\overline{U}_x = xU_{xp} + (1-x)U_{xn} \tag{3}$$

Accordingly, the replicator dynamic equation for the company's active promotion strategy is as follows:

$$F(x) = x \ \ U_{xp} - \bar{U}_x$$
$$= x(1-x)\ (p-c)(q_p-q_n) - C_p + R^f + C_n + Ay + Py \tag{4}$$

In other words, the company has two possible promotion strategies. Scenario 3: SP and SN When the government adopts a strict regulatory strategy for the company's energy conservation promotion, the government's expected payoff function is as follows:

$$U_{ys} = x(-C_g - A + R_g) + (1-x)(-C_g - C_c + P) \tag{5}$$

The first term on the right side of the equation represents the government's payoff when the company adopts an active promotion strategy, and the second term represents the government's payoff when the company adopts a passive promotion strategy. When the government adopts a strict regulatory approach, it incurs a regulatory cost, C_g, and it must also provide a reward, A, for the company's active promotion efforts. In return, the government gains a social benefit, R_g. Hence, the government's total payoff under strict regulation when the company chooses active promotion is $-C_g-A+R_g$. However, if the company adopts a passive promotion strategy, in addition to regulatory costs, the government must also bear the cost C_c for addressing the negative externalities caused by the company's passive promotion. In this case, the government's payoff is $-C_g-C_c+P$

Scenario 4: LP and LN

When the government adopts a lenient regulatory approach toward the company's energy conservation knowledge promotion, the government's expected payoff function is as follows:

$$U_{yl} = xR^g + (1-x)(-C_c) \tag{6}$$

The first term on the right-hand side of the equation represents the government's expected payoff when the company chooses an active energy conservation knowledge promotion strategy, whereas the second term corresponds to the government's expected payoff when the company adopts a passive promotional strategy. When the government applies lenient regulation, it does not incur any direct costs, but it does face certain consequences. Specifically, if the company opts for an active promotion strategy, the resulting positive promotion generates social benefits R^g for the government. However, if the company chooses a passive strategy, the government's lenient oversight leads to a lack of enforcement, requiring the government to bear the cost C_c of addressing the negative impacts caused by the company's passive promotion.

In summary, the government's average expected payoff function is as follows:

$$\overline{U}_y = yUU_{yp} + (1-y)U_{yn} \tag{7}$$

Given this, the replicator dynamic equation for the government's choice to strictly regulate the energy conservation promotion of energy sales companies is as follows:

$$F(y) = y \ \ U_{yp} - \bar{U}_y \tag{8}$$
$$= y(1-y)[-C_g - xA + (1-x)P]$$

$$\frac{dx}{dt} = x(1-x)\ (p-c)(q_p-q_n) - C_p + R^f + C_n + Ay + Py \tag{9}$$

Then:

$$\frac{dF(x)}{dx} = (1-2x)\ (p-c)(q_p-q_n) - C_p + R^f + C_n + Ay + Py \tag{10}$$

$$\frac{dy}{dt} = y(1-y)[-C_g - xA + (1-x)P] \tag{11}$$

Then:

$$\frac{dF(y)}{dy} = (1-2y)[-C_g - xA + (1-x)P] \tag{12}$$

B. Model Analysis

For the evolutionary stability analysis of the energy sales company's energy conservation promotion strategy, according to the differential equation stability theorem, the probability of the energy sales company choosing to actively promote energy conservation must satisfy the following conditions to be in a stable state: $F(x)=0$ and $\frac{dF(x)}{dx}<0$.

Let $y_0 = \dfrac{-R^f + C_p - C_n - (p-c)(q_p-q_n)}{A+P}$

then, $\dfrac{dF(x)}{dx} = (1-2x)(A+P)(y-y_0)$.

Proposition 1: a. When $y=y_0$, $F(x)=0$ always holds, indicating that the energy sales company cannot determine its promotional strategy.

b. When $y<y_0, x=0$ is the stable strategy, meaning that the energy sales company will opt for a passive energy conservation knowledge promotion strategy.

c. When $y>y_0, x=1$ is the stable strategy, meaning that the energy sales company will choose an active energy conservation promotion strategy.

Proposition 1 suggests that for energy sales companies, the decision to adopt an active energy conservation knowledge promotion strategy depends on the government's regulatory approach. Proposition 1(a) states that if the probabilities of the government choosing strict or lenient regulation are equal, the company's promotional strategy remains uncertain. Proposition 1(b) argues that if the likelihood of the government adopting lenient regulation is greater, the company is likely to choose a passive promotional strategy to reduce marketing costs. Conversely, Proposition 1(c) indicates that if the probability of the government enforcing strict regulation is greater, the company will opt for an active promotional strategy to avoid penalties. Importantly, the company's choice of promotional strategy is also influenced by the balance of costs and benefits.

For the evolutionary stability analysis of the government's regulation of energy conservation promotion by energy sales companies, similarly, the probability of the government choosing strict regulation must satisfy the following conditions to reach a stable state: $F(y) = 0$ and $\frac{dF(y)}{dy} < 0$.

$$\text{Let } x_0 = \frac{P - C_g}{A + P},$$

then

$$\frac{dF(x)}{dx} = (1 - 2y)(A + P)(x_0 - x) \tag{13}$$

Proposition 2:

a. When $x = x_0$, $F(y) = 0$ always holds, meaning that the government cannot determine its promotional strategy. b. When $x < x_0$, $y = 1$ is the stable strategy, indicating that the government will strictly regulate the company's energy conservation promotion.

c. When $x > x_0$, $y = 0$ is the stable strategy, indicating that the government will adopt lenient regulation regarding the company's energy conservation promotion.

Proposition 2 shows that the government's decision to strictly regulate the company's energy conservation promotion depends on the company's promotional strategy. Proposition 2(a) states that if the probabilities of the company choosing active or passive promotion are equal, the government's regulatory strategy is indeterminate. Proposition 2(b) suggests that if the probability of the company adopting passive promotion is high, the government will strictly regulate the company's energy conservation promotion. On the other hand, Proposition 2(c) states that if the probability of the company adopting active promotion is high, the government will choose a lenient regulatory approach since active promotion generates fewer negative externalities, and the government does not need to bear the cost of handling those externalities. For the evolutionary stability analysis of mixed strategies, the system of replicator dynamics leads to five equilibrium points in the system: $E_1(0, 0)$, $E_2(0, 1)$, $E_3(1, 0)$, $E_4(1, 1)$ and $E_5\,(x_0, y_0)$, where $E_1(0, 0)$, $E_2(0, 1)$, $E_3(1, 0)$ and $E_4(1, 1)$ are pure strategy equilibrium points and where $E_5\,(x_0, y_0)$ is a mixed strategy equilibrium point.

The Jacobian matrix for the system is as follows:

$$\begin{bmatrix} (1-2x)\begin{pmatrix} p-c\cdot(q_p-q_n)-C_p \\ +R_f+C_n+Ay+Py \end{pmatrix} & x(1-x)(A+P) \\ y(1-y)(-A-P) & (1-2y)\begin{pmatrix} -C_g-xA \\ +(1-x)P \end{pmatrix} \end{bmatrix}$$

The stability of each equilibrium point in the system is analyzed, as shown in Table III.

Proposition 3:

a. When $(p - c)\,(q_p - q_n) - C_p + R^f + C_n < 0$ and $P - C_g < 0$, $E_1(0, 0)$ is the stable equilibrium point, and the system's evolutionary strategy is that the energy sales company chooses a passive energy conservation promotion strategy, whereas the government adopts a lenient regulatory approach. In this case, the regulatory costs are high, and the penalty for passive promotion is relatively low. Hence, the government is unlikely to enforce strict regulation. On the company's side, the benefits from actively promoting energy conservation are not sufficient to cover the costs of promotion and increased operational costs. Therefore, the company prefers passive promotion and reduced costs, whereas the government opts for lenient regulation, thus making passive promotion the company's stable strategy.

b. When $(p - c)\,(q_p - q_n) - C_p + R^f + C_n + A + P < 0$ and $P - C_g < 0$, $E_2(0, 1)$ is the stable equilibrium point. In this case, the system's evolutionary strategy is that the energy sales company still chooses passive promotion, while the government adopts strict regulation. Although the cost of strict regulation is high, the penalty for passive promotion is sufficient to encourage strict government oversight. However, for the company, the cost and reduced profits from promoting energy conservation still outweigh the potential benefits, so the company sticks to passive promotion despite the government's stricter regulation.

c. When $(p - c)\,(q_p - q_n) - C_p + R^f + C_n > 0$, $E_3(1, 0)$ is the stable equilibrium point. Here, energy marketing firms prefer to actively promote energy efficiency when $(p - c)\,(q_p - q_n) - C_p + R^f + C_n > 0$, i.e., in the equilibrium of case 3 . In this case, the gain from corporate social responsibility is large enough to be greater than the sum of the difference between the cost of the different promotional strategies of the enterprise and the difference between the profit from the change in energy use of the whole society. Moreover, this case has nothing to do with the government's rewards and punishments A and P , i.e., changes in the government's rewards and punishments A and P may affect only the evolution process but not the outcome of the evolution.

IV. NUMERICAL SIMULATION ANALYSIS

To verify the effectiveness of the results, numerical simulations were conducted via MATLAB 2021b.

A. Simulation Results of the Game System under Different Conditions

Situation a: Assign a value to the parameter such that $(p-c)\,(q_p - q_n) - C_p + R^f + C_n < 0$, and when $P - C_g < 0$. For example, $p = 0.6$, $c = 0.3$, $q_p = 8$, $q_n = 10$, $C_p = 3$, $R^f = 0.5$, $C_n = 1$, $C_g = 0.5$, $A = 1$, $P = 0.2$. Obtain the dynamic evolution path of the system for case a.

$E_1(0, 0)$ is the evolutionary stability point of the system; regardless of the initial state of the two, they will eventually converge to the behavioral strategy of {energy sales enterprises' negative energy-saving publicity, the government strictly regulates the energy-saving publicity of energy sales enterprises }, which is consistent with the previous analysis.

TABLE III: Determinants and Traces of Equilibrium Points

Equilibrium Point	DeterminantdetJ	TracetrJ
$E_1(0,0)$	$(P - C_g)\ (p-c)(q_p-q_n) - C_p + R^f + C_n$	$(p-c)(q_p-q_n) - C_p + R^f + C_n + P - C_g$
$E_2(0,1)$	$(P-C_g)(p-c)(q_p-q_n) - C_p + R^f + C_n + A + P$	$(p-c)(q_p-q_n) - C_p + R^f + C_n + A - C_g$
$E_3(1,0)$	$(A+C_g)\ (p-c)(q_p-q_n) - C_p + R^f + C_n$	$1(p-c)(q_p-q_n) + C_p - R^f - C_n - A + C_g$
$E_4(1,1)$	$-(A+C_g)\ (p-c)(q_p-q_n) - C_p + R^f + C_n + A + P$	$1(p-c)(q_p-q_n) + C_p - R^f - C_n - P + C_g$
$E_5\ (x_0, y_0)$	$x_0y_0\ (1-x_0)(1-y_0)(A+P)^2$	0

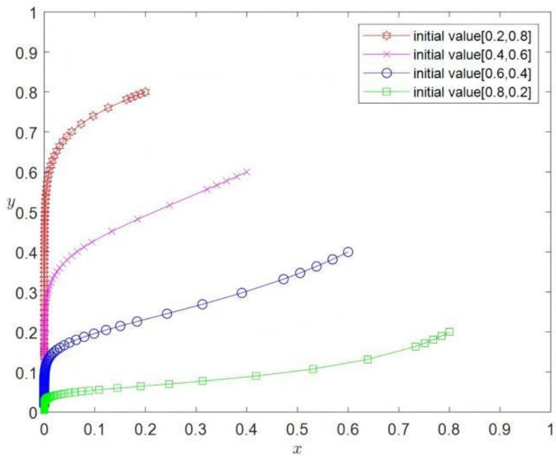


Fig. 2: Dynamic evolutionary path in case a

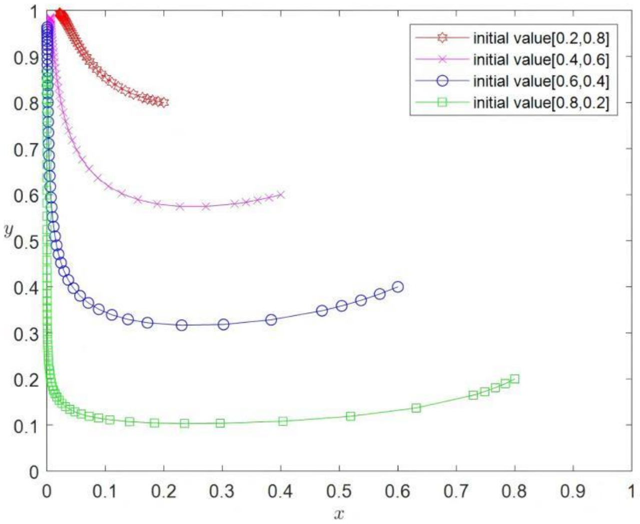


Fig. 3: Dynamic evolutionary path in case b

Case b : when values are assigned to parameters, and, for example, $(p-c)(q_p-q_n) - C_p + R^f + C_n + A + P < 0$, and when $P - C_g < 0$. For example, $p = 0.6$, $c = 0.3$, $q_p = 8$, $q_n = 10$, $C_p = 3$, $R^f = 0.5$, $C_n = 1$, $C_g = 0.5$, $A = 1$, $P = 1$. Obtain the dynamic evolution path of the system in case b.

$E_2(0,\ 1)$ is the evolutionary stability point of the system; regardless of the initial state of the two, they will eventually converge to the behavioral strategy of {energy sales enterprises negatively promote energy saving, and the government strictly regulates energy sales enterprises' energy-saving promotion }, which is consistent with the previous analysis.

(3) Case c : when values are assigned to parameters, and, for example, $(p-c)(q_p-q_n) - C_p + R^f + C_n > 0$, and when. For example, $p = 0.6$, $c = 0.3$, $q_p = 8$, $q_n = 10$, $C_p = 3$, $R^f = 5$, $C_n = 1$, $C_g = 0.5$, $A = 1$, $P = 1$. Obtain the dynamic evolution path of the system in case c.

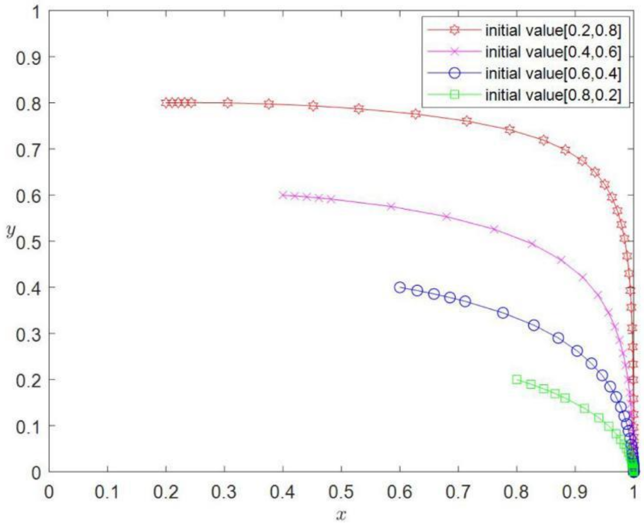


Fig. 4: Dynamic evolution path in case c

TABLE IV: Table of parameter values

	p	c	q_p	q_n	C_p	C_n	R^f	C_g	P	A
Group 1	0.6	0.3	8	10	3	1	5	0.5	1	1
Group 2	0.6	0.3	8	10	3	1	8	0.5	1	1
Group 3	0.6	0.3	8	10	3	1	5	0.5	1	10
Group 4	0.6	0.3	8	10	3	1	5	0.5	0	1
Group 5	0.6	0.3	8	10	3	1	5	0.5	3	1

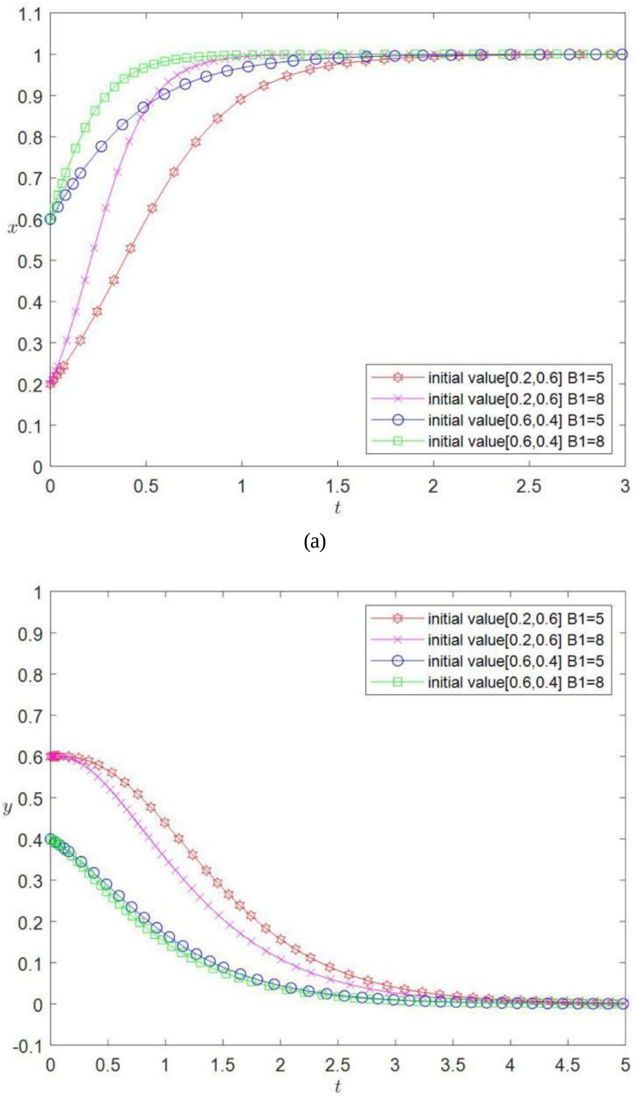
$E_3(1,\ 0)$ is the evolutionary stability point of the system; regardless of the initial state of the two, they will eventually converge to the {energy sales enterprises actively promote energy saving, and the government loosely regulates energy sales enterprises' energy-saving promotion } behavioral strategy, which is consistent with the previous analysis.

B. *Effect of parameter changes on the game outcome*

To further explore the effects of parameter values on the evolutionary path and trend of the system, we set Group 1 as the control group. The values of the parameters are shown in Table IV.

(1) The influence of the change in the earnings of corporate social responsibility on the evolution path. Take $x = 0.2$, $y = 0.6$, and $x = 0.6$, $y = 0.4$, respectively, as the initial state, increase R^f from 5 to 8 , i.e., compare Group 1 and Group 2, and obtain the simulation diagram of the evolution trend before and after the change in the earnings of corporate social responsibility.

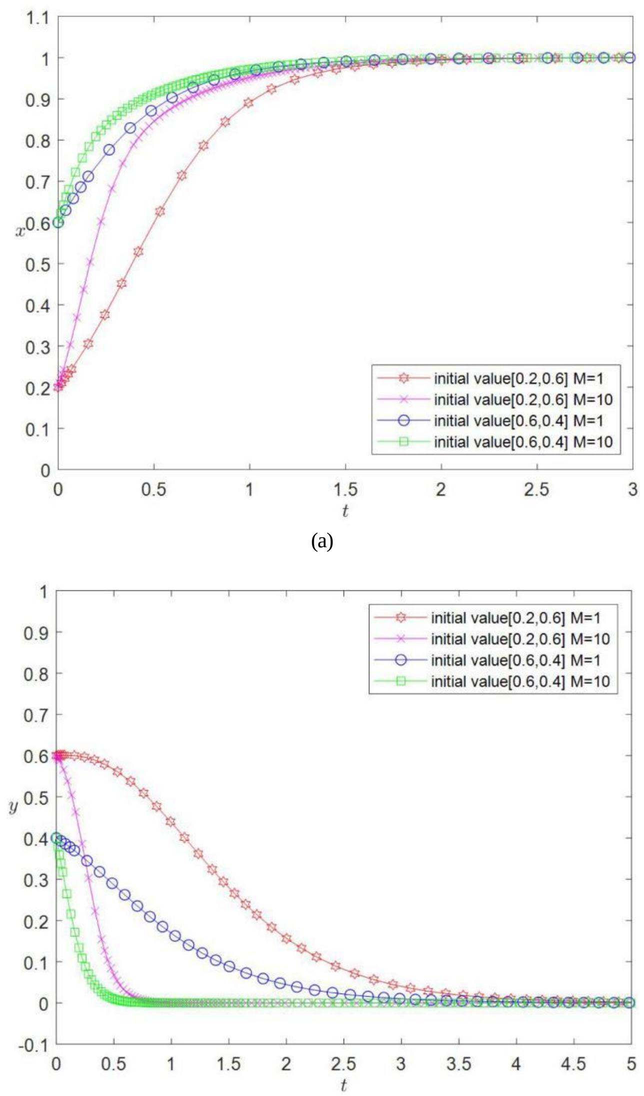
Figures 5a and 5b show that with the increase of R_f, the



(a)

(b)

Fig. 5: Simulation of the Evolutionary Trend Before and After Changes in Corporate Social Responsibility Benefits



(a)

(b)

Fig. 6: Evolutionary Trend Simulation Before and After Changes in Government Rewards

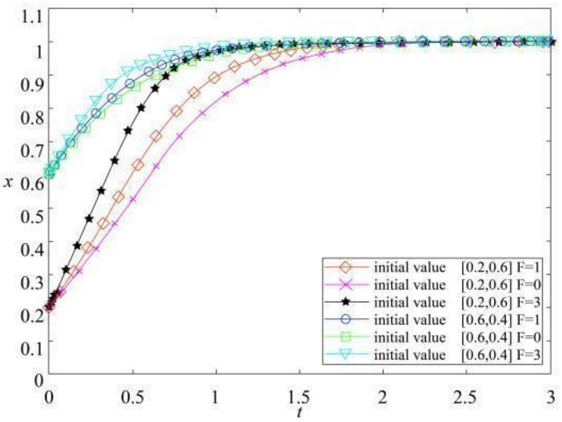
likelihood of energy sales companies actively promoting energy conservation knowledge increases. The speed at which the companies evolve toward a stable strategy accelerates, although the speed at which the government reaches a stable strategy does not significantly increase.

(2) The impact of changes in government rewards A on the evolution of energy sales companies' promotional strategies: To simulate this, set the initial values to $x = 0.2$, $y = 0.6$, and $x = 0.6$, $y = 0.4$. After the parameter A is changed from 110, the evolution trend before and after the change in government rewards A between Group 1 and Group 3 is compared. Figure 4 illustrates the evolution trajectory before and after the change.

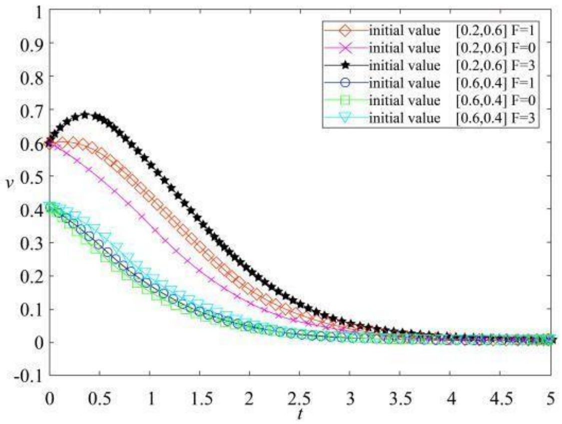
As shown in Figures 6a and 6b, with the increase in A, the rate at which energy sales companies evolve toward actively promoting energy-saving initiatives accelerates. Similarly, the government's evolution toward a more lenient regulatory strategy also speeds up significantly.

(3) The impact of changes in government penalty P on the evolutionary path of passive energy promotion: The impact of changes in the government-imposed penalty P for passive promotion by energy sales companies is analyzed by setting initial values of $x = 0.2$, $y = 0.6$ and $x = 0.6$, $y = 0.4$. The comparison between Group 4, Group 1, and Group 5, with respective values of $P = 0$, $P = 1$ and $P = 3$, demonstrates how changes in the penalty amount influence the evolutionary trend.

Figures 7a and 7b show that when the government only provides rewards for energy-saving promotion without imposing penalties (i.e., $P = 0$), the rate at which energy sales companies evolve toward active promotion is relatively slow. In particular, when the penalty P is high, the government's regulatory strategy curve shows that y will first increase and then gradually decrease, eventually converging to 0 . This indicates that while the government initially leans toward strict regulation to maximize revenue from penalties, over time, as the companies evolve toward active promotion, the need for strict regulation diminishes, and the government shifts toward a more lenient regulatory approach.



(a)



(b)

Fig. 7: Evolutionary Trend Simulation Before and After Changes in Government Penalties

V. CONCLUSION

This paper explores the energy-saving knowledge promotion strategies of energy sales companies under government regulation. The findings reveal that both corporate and governmental behaviors are influenced by several factors, including corporate social responsibility (CSR), energy prices, production costs, sales performance, promotional expenses, and government-imposed rewards or penalties. The level of CSR awareness within energy companies plays a crucial role in determining the final strategic outcome. Specifically, when the benefits of fulfilling social responsibility are significant, companies are more likely to evolve toward actively promoting energy-saving knowledge. However, if a company's CSR awareness is low, passive promotion becomes the dominant strategy, regardless of government regulatory actions. This is largely because companies with a limited CSR focus tend to prioritize cost management and sales performance, leading them to adopt less proactive approaches to energy promotion.

As CSR awareness increases, companies tend to shift from passive to active energy-saving promotion. Government incentives further accelerate this transition by increasing the likelihood that companies will adopt active promotional strategies. Simultaneously, governments often move toward more lenient regulation as the financial burden of providing rewards grows. On the other hand, when the government imposes higher penalties for passive promotion, companies face increased costs, motivating them to engage in more active promotion to avoid these penalties. Interestingly, when fines are substantial, the government may initially benefit from strict regulation through penalty revenues. However, as companies evolve toward active promotion, these revenues diminish, prompting the government to ultimately adopt a more lenient regulatory stance.

The conclusions of this study provide valuable insights for both corporate and governmental practices. For businesses, the results highlight the importance of adopting social responsibility as a core strategy. Companies should foster a green development mindset, integrating societal well-being into their operational objectives. This approach can transform corporate social responsibility from a mere compliance requirement into an intrinsic motivation for sustainable growth. By doing so, companies can not only achieve energy-saving goals but also play a leadership role in driving broader societal progress toward a green, low-carbon economy.

From the government's perspective, the findings emphasize the importance of balanced policies that combine incentives and penalties to influence corporate behavior. Governments should invest in ongoing educational initiatives that raise environmental awareness among businesses, encouraging them to internalize the understanding that environmental protection and economic growth are not mutually exclusive. Additionally, governments should continue to support energy-saving promotion by companies, adjusting the balance between incentives and penalties as necessary. By effectively leveraging both economic and administrative tools, governments can help resolve the tension between corporate energy-saving efforts and financial performance, fostering a more proactive approach to energy-saving initiatives.

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