Contents lists available at GrowingScience

International Journal of Industrial Engineering Computations

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A study on the nonlinear relationship between market, subsidy, and income of photovoltaic enterprises based on chaos theory

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C H R O N I C L E

Article history:
Received December 14 2023
Received in Revised Format January 30 2024
Accepted February 26 2024
Available online February 26 2024

Keywords:
Market dynamic adjustment ability
Government subsidy
Nonlinearity
Chaos

A B S T R A C T

With the annual promotion of the international "dual carbon" goals, countries attach great importance to the development and innovation of clean energy. The United States, Japan, and China have all created many policies for the research and market development of photovoltaic energy. This article incorporates market dynamic regulation capability into a two-dimensional system of government subsidy policies and photovoltaic revenue, constructs a three-dimensional dynamic nonlinear model based on market dynamic regulation capability, government subsidies, and enterprise revenue, and numerically simulates and analyzes the impact of parameter and initial value changes in the equation on enterprise revenue. The market dynamic regulation capability is obtained from Chaotic attractors and dynamic evolution graphs of the nonlinear evolution between government subsidies and corporate profits in different scenarios. Research has shown that: (1) Rapidly improving the dynamic regulation ability of the market cannot continuously increase the revenue of the photovoltaic industry; (2) The changes in market dynamics affect the dependence of enterprises on government subsidies; (3) The demand for government subsidies by enterprises gradually decreases with the increase of their own profits.

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1. Introduction

To serve the goal of achieving carbon peak and carbon neutrality, countries around the world have begun to attach importance to the development and research of clean energy and have provided many preferential policies for the market development and technological innovation of clean energy. However, the current photovoltaic energy industry is still affected by market and policy fluctuations, making it difficult to stabilize. How to achieve high returns and find innovative development paths in the photovoltaic industry has become an urgent issue. The dynamic regulation ability of the photovoltaic market and government subsidies have an important impact on corporate profits. Clarifying the dynamic relationship between them and corporate profits is of practical significance for the healthy development of photovoltaic enterprises.

For many years, experts and scholars have studied the impact of industry policies and other factors on the development of the photovoltaic industry. Tong et al. (2022) studied the dependence of sustainable development of China's photovoltaic industry on fiscal policies. Cai et al. (2022) studied the impact of government subsidies on technological progress in the photovoltaic industry. Luan and Lin (2022) studied the impact of government subsidies on the operational performance of China's photovoltaic industry. Zhang Tiantian et al. (2021) studied the determinants of China's photovoltaic industry. Wen et al. (2021) studied the effects of incentive policies on the photovoltaic industry and market in China, Germany, and Japan. Wei and Xin-Gang (2022) studied whether incentive policies can promote the diffusion of photovoltaic power generation in China. Chen et al. (2021) studied the incentive effect of government policies on research and development in the photovoltaic industry. Wang (2018) summarized the process of industrial development and government industrial policy reform and analyzed the impact of the new policy of photovoltaic power generation subsidies in 2018 on the photovoltaic industry and national energy

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ISSN 1923-2934 (Online) - ISSN 1923-2926 (Print)
2024 Growing Science Ltd.
doi: 10.5267/j.ijiec.2024.2.004

transformation. In addition, scholars also pay attention to research on the photovoltaic industry market. Xiang et al. (2022) studied the difficulties and solutions of financing for photovoltaic enterprises. Liu et al. (2021) studied the market prediction and employment effects of China's solar photovoltaic industry based on the GRA-BiLSTM model. Mints (2012) studied both EU and non-EU countries and demonstrated the positive impact of a series of photovoltaic technology innovation policies on industry performance, based on the continuous expansion of demand in the photovoltaic industry. Taylor (2008) analyzed the impact of photovoltaic market policies on photovoltaic research and development behavior under different market types by studying the photovoltaic industry in California, USA. Zheng and Kammen (2014) constructed a dual learning curve model by collecting data on the development of the photovoltaic industry in the United States, China, Germany, and Japan from 2000 to 2012. They believed that photovoltaic industry policies should be transformed, and the government should moderately balance the relationship between the market and technology research and development. Liao and Zhao (2014) used the GTAP model to empirically simulate the export effect of government subsidies in China's photovoltaic industry. Hu et al. (2022) studied the impact of policy orientation on the development of the photovoltaic industry.

Many experts and scholars have used different methods or models to verify the dynamic relationship between market capacity, policies, and returns in the photovoltaic industry. Xin-gang et al. (2021) conducted a dynamic analysis of the incentives for China's photovoltaic industry based on a system dynamics model. Shao Xuefeng et al. (2021) analyzed the performance of photovoltaic industry competition subsidies based on spatial econometric models. Yang and Wang (2019) used a multiple linear regression model to empirically test the effect of government subsidies on the photovoltaic industry. Qiu and Chen (2016) constructed an economic evaluation model to study the effectiveness of implementing distributed photovoltaic power generation subsidy policies. Based on the research of chaotic models on corporate returns, some scholars use nonlinear differentiation to analyze the corporate return model and study the mutual promotion and constraint relationship between dynamic capabilities, investment, and returns. Jiao and Ciu (2008) believe that dynamic capabilities can promote increased returns, and the development of dynamic capabilities over time is directly proportional to returns. Ge and Dong (2009) believe that in the early stages of enterprise development, when dynamic capabilities are relatively weak, increasing investment in unit dynamic capabilities can promote increased returns.

Previous studies by scholars have provided useful references for studying the nonlinear relationship between government subsidies and the profits of photovoltaic enterprises. In the past, scholars only studied the importance and impact of market factors or government policies on the development of the photovoltaic industry, without conducting detailed research on the dynamic adjustment ability of the market, government subsidy policies, and the dynamic relationship between photovoltaic enterprises. Therefore, based on relevant research, this article introduces market dynamic regulation ability into the two-dimensional system of government subsidy policies and photovoltaic revenue. Unlike previous studies, this article establishes a three-dimensional dynamic nonlinear model based on market dynamic regulation ability, government subsidies, and corporate profits; In addition, this article analyzes the mutual influence among the three by focusing on the chaotic effects formed between them. A nonlinear behavior equation was constructed to describe the relationship between market dynamic regulation ability, government subsidies, and profits. The stable equilibrium points and characteristic values were obtained, and the impact of parameter and initial value changes in the equation on the profits of photovoltaic enterprises was numerically simulated and analyzed.

2. Model Construction

The photovoltaic industry refers to a new industry that emerged with the invention and application of new technologies, as well as the generation and driving of new demands, and has a significant impact on a country's competitiveness or national security. In the current highly volatile external environment, China adheres to a market-oriented approach, fully utilizes the incentive functions of price and competition mechanisms, promotes technological innovation, and optimizes the allocation of government subsidy resources.

Since the photovoltaic energy industry is a key development industry in China's clean energy sector, scholars are increasingly deepening their research on the development of photovoltaic energy enterprises. This article considers the non-spontaneous influencing factors of photovoltaic enterprises in the market, such as the export prospects and situation of the photovoltaic industry, the global photovoltaic consumption market pattern, and the consumption willingness of Chinese consumers. As a developing photovoltaic enterprise, market interference has a significant impact. Therefore, a three-dimensional dynamic chaotic model of market dynamic regulation ability, government subsidies, and corporate profits is constructed (Zhanf et al., 2020; Sheng et al., 2018).

This article constructs a government subsidy and photovoltaic industry revenue system under market factor regulation constraints, and further analyzes the evolutionary impact of market factors on subsidy revenue. It is a key issue to solve the problem of maximizing photovoltaic revenue through appropriate government subsidies in the photovoltaic industry. Based on relevant literature on market factors, government subsidies, and the benefits of the photovoltaic industry, establish a dynamic evolution model of the photovoltaic industry market's dynamic regulatory capacity, government subsidies, and the benefits of the photovoltaic industry:

$$\frac{dx}{dt} = a_1 x(1-\frac{y}{M}) + a_2 y + a_3 z \tag{1a}$$

$$\frac{dy}{dt} = b_1 x(1-\frac{x}{N}) + b_2 y(1-\frac{y}{C}) + b_3 z(1-\frac{z}{E}) \tag{1b}$$

$$\frac{dz}{dt} = c_1 x(1-\frac{x}{N}) + c_2 y - c_3 z \tag{1c}$$

3D system:

$$\begin{cases} \frac{dx}{dt} = a_1 x(1-\frac{y}{M}) + a_2 y + a_3 z \\ \frac{dy}{dt} = b_1 x(1-\frac{x}{N}) + b_2 y(1-\frac{y}{C}) + b_3 z(1-\frac{z}{E}) \\ \frac{dz}{dt} = c_1 x(1-\frac{x}{N}) + c_2 y - c_3 z \end{cases} \tag{1}$$

Among them, $\frac{dx}{dt}$ represents the market dynamic adjustment ability that changes over time; $\frac{dy}{dt}$ is the government subsidy that varies over time; $\frac{dz}{dt}$ represents the revenue of the photovoltaic industry that varies over time. (1) In the formula, a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2, c_3, M, C, E, N is a normal number, and the meanings of each parameter are shown in Table 1.

Table 1
Parameter Meaning Table

parameter	meaning
a_1	Development coefficient of market dynamic regulation ability
a_2	The coefficient of the impact of government subsidies on market dynamic regulation ability
a_3	The coefficient of the impact of photovoltaic industry revenue on market dynamic regulation ability
b_1	The coefficient of the impact of market dynamic regulation ability on government subsidies
b_2	The elasticity coefficient of government investment development speed
b_3	The coefficient of the impact of the previous period's photovoltaic industry revenue on the next period's government subsidies
c_1	The coefficient of the impact of market dynamic regulation ability on the revenue of the photovoltaic industry
c_2	The coefficient of the impact of government subsidies on the revenue of the photovoltaic industry
c_3	The coefficient of the impact of subsidies and subsidies on returns, such as the ability to regulate market dynamics
M	The turning point of government subsidies in regulating market dynamics
C	The peak of government subsidies during an economic period
E	The peak revenue of the photovoltaic industry during an economic period
N	The turning point of the impact of market dynamic regulation ability on the revenue of the photovoltaic industry

Eq. (1a) indicates that the development of market dynamic regulation ability $x(t)$ over time is directly proportional to photovoltaic revenue $z(t)$. Before the government subsidy $y(t)$ reaches its peak M, the increase in government subsidy $y(t)$ will promote the development of market dynamic regulation ability $x(t)$. When government subsidy $y(t)$ reaches its peak, excessive government subsidies will have a restraining effect on market dynamic regulation ability. That is, for $a_1 x(1-\frac{y}{M})$, when $y < M$, $1-\frac{y}{M} > 0$, the development speed of market dynamic regulation ability will increase rapidly; When $y > M$, $1-\frac{y}{M} < 0$, the development speed of market dynamic regulation ability is slow.

Eq. (1b) indicates that the development of market dynamic regulation ability $x(t)$ will affect the dependence of photovoltaic enterprises on government subsidies $y(t)$. For $b_1 x(1-\frac{x}{N})$, when $x < N$, $1-\frac{x}{N} > 0$, it indicates that the demand for government subsidies increases before the peak of market dynamic regulation ability; When $x > N$, $1-\frac{x}{N} < 0$, it indicates that the market's dynamic regulation ability has decreased in demand for government subsidies after the peak arrives. For $b_2 y(1-\frac{y}{C})$, when $y<C$, $1-\frac{y}{C}>0$, it indicates that government subsidies developed rapidly before reaching their peak; When $y>C$, $1-\frac{y}{C}<0$, it indicates that the development speed of government subsidies gradually decreases after reaching its peak. Photovoltaic revenue $z(t)$ requires a large amount of government subsidies in its early development stage, but after reaching its peak, the demand decreases. That is, for $b_3 z(1-\frac{z}{E})$, when $z<E$, $1-\frac{z}{E}>0$, there is more government subsidies in the early stage of enterprise development; When $z>E$, $1-\frac{z}{E}<0$, when the photovoltaic revenue of the enterprise reaches a peak, the government subsidy will be appropriately reduced due to the increase in its revenue

Eq. (1c) indicates that the market's dynamic regulation ability $x(t)$ has an impact on photovoltaic returns $z(t)$. For $c_1 x(1-\frac{x}{N})$, When $x<N$, $1-\frac{x}{N}>0$, before the market's dynamic adjustment ability reaches the turning point, the increase in market dynamic adjustment ability has a positive impact on photovoltaic returns; When $x>N$, $1-\frac{x}{N}<0$, the increase in market dynamic regulation ability has a negative impact on photovoltaic returns after reaching the impact turning point. Government subsidies have a promoting effect on photovoltaic revenue. The marginal benefits of the photovoltaic industry gradually decrease as revenue increases.

2. Model Equilibrium Point and Stability Analysis

According to Hurwitz's Jacobian matrix, it can be concluded that:

$$J_0=\begin{bmatrix} a_1(1-\frac{y}{M}) & a_2 & a_3 \\ b_1(1-\frac{x}{N}) & b_2(1-\frac{y}{C}) & b_3(1-\frac{z}{E}) \\ c_1(1-\frac{x}{N}) & c_2 & -c_3 \end{bmatrix} \tag{2}$$

Assigning parameters to three-dimensional nonlinear differential equations can lead to different dynamic behaviors. For the determination of initial values of parameters during simulation, this article draws on the initial value determination methods of Zhang et al. (2020) and Sheng et al. (2018) when selecting initial values. However, the obtained initial values show negative subsidy benefit trajectories. Through multiple subtle fluctuations in the initial values, it is found that the third-order linear differential equation system presents a very good dynamic system when the following parameters are taken. Therefore, the fixed parameters are as follows:

$$\left.\begin{matrix} a_1=0.05 & a_2=0.0025 & a_3=0.01 & b_1=0.395 \\ b_2=0.085 & b_3=0.77 & c_1=0.04 & c_2=0.0083 \\ c_3=0.07 & M=0.85 & N=0.5 & C=2.02 \\ E=2.75 & & & \end{matrix}\right\} \tag{3}$$

According to Eq. (1), the three real equilibrium points and two virtual equilibrium points that can be calculated by inputting fixed parameters into the equation are approximately:

$$\left.\begin{matrix} s_1(0.2901, 2.8386, 2.6839) \\ s_2(0.5675, 0.9137, -0.0159) \\ s_3(-0.2430, -0.7161, 2.4175) \end{matrix}\right\} \tag{4}$$

The virtual equilibrium point is approximately:

$$\left.\begin{matrix} s_4(-0.1889+0.9980i, 0.7812+0.1188i, -0.8162+0.5659i) \\ s_5(-0.1889-0.9980i, 0.7812-0.1188i, -0.8162-0.5659i) \end{matrix}\right\} \tag{5}$$

The coefficient matrix of a linear approximation system is shown in Eq. (2). For the real equilibrium point $s_1(0.2901, 2.8386, 2.6839)$, its corresponding characteristic equation is:

$$f(\lambda)=\lambda^3+(-a_1(1-\frac{y}{M})+c_3-b_2(1-\frac{y}{C}))\lambda^2+(-a_1(1-\frac{y}{M})c_3-a_3c_1(1-\frac{x}{N})-b_3(1-\frac{z}{E})c_2+a_1(1-\frac{y}{M})b_2(1-\frac{y}{C})$$
$$-a_2b_1(1-\frac{x}{N})-b_2(1-\frac{y}{C}c_3)\lambda-(-a_1(1-\frac{y}{M})b_2(1-\frac{y}{C})c_3+a_2b_3(1-\frac{z}{E})c_1(1-\frac{x}{N})+a_3b_1(1-\frac{x}{N})c_2-a_3b_2(1-\frac{y}{C})c_1(1-\frac{x}{N})$$
$$-a_1(1-\frac{y}{M})b_3(1-\frac{z}{E})c_2+a_2b_1(1-\frac{x}{N})c_3)=0$$

By fixing the coefficients of the characteristic equation as shown in equation (3), the eigenvalues of the Jacobian matrix at the real equilibrium point $s_1(0.2901, 2.8386, 2.6839)$ can be calculated as:

$\lambda_1=-0.1219$； $\lambda_2=-0.0230$； $\lambda_3=-0.0765$

The eigenvalues of the matrix at the real equilibrium point s_1 are all negative, therefore, s_1 is a stable saddle point.

The eigenvalues of the Jacobian matrix at the real equilibrium point $s_2(0.5675, 0.9137, -0.0159)$ are:

$\lambda_1=0.0852$； $\lambda_2=-0.0015$； $\lambda_3=-0.1109$

At this point, not all matrix eigenvalues at the real equilibrium point s_2 are negative, therefore s_2 is an unstable saddle point.

The eigenvalues of the Jacobian matrix at the real equilibrium point $s_3(-0.2430, -0.7161, 2.4175)$ are:

$\lambda_1=0.1503$； $\lambda_2=0.0628$； $\lambda_3=-0.0759$

The eigenvalues of the matrix at the real equilibrium point s_3 are not all negative, therefore, s_3 is an unstable saddle point.

3. Analysis of Chaos Phenomenon

3.1 Analysis of two-dimensional model structure

The changes in parameter values between market dynamic regulation ability, government subsidies, and photovoltaic industry returns may exhibit complex chaotic phenomena. After data adjustment and analysis, this article has selected coefficient values that can better represent the trend of chaotic system changes to explain the chaotic evolution law between market dynamic regulation ability, government subsidies, and photovoltaic industry returns. Taking parameters as shown in Eq. (3) with initial values of (0.1, 0.9, 0.1), a chaotic attractor can be obtained, which is referred to as the subsidy benefit attractor in this paper, as shown in Fig. 1.

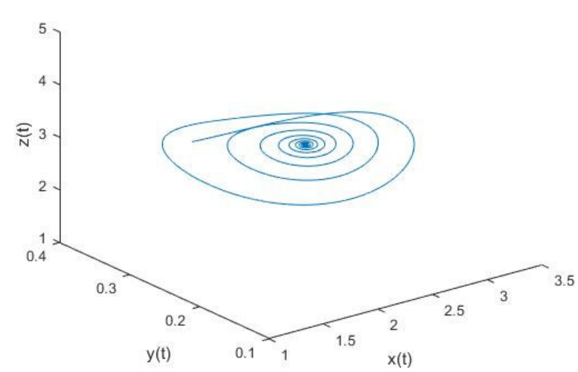


Fig. 1. Subsidy income attractor

From the graph, it can be seen that the system presents a pie shaped structure, indicating an disorderly and chaotic relationship between market dynamic regulation ability, government subsidies, and the revenue of the photovoltaic industry.

The projection of the system phase diagram in a two-dimensional plane can provide a clearer and more detailed explanation of the motion patterns of various factors between the systems, as shown in Figs. (2-4).

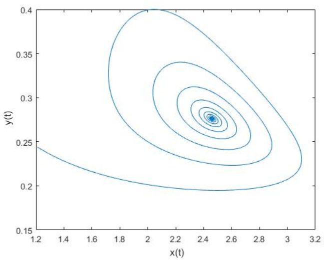


Fig. 2. Two dimensional phase diagram of the subsidy benefit attractor on the x-y plane

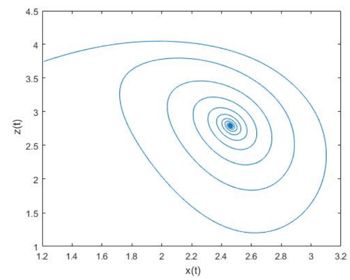


Fig. 3. Two dimensional phase diagram on the x-z plane

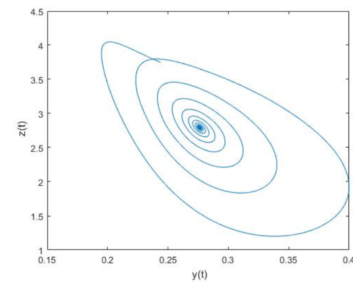


Fig. 4. Two dimensional phase diagram on the y-z plane

From Fig. 2, the attractor of subsidy benefits gradually enters a chaotic state over time. In the initial stage, the market's dynamic regulation ability is more dependent on government subsidies, but over time, the market's dynamic regulation ability gradually decreases its dependence on government subsidies. From Fig. 3 and Fig. 4, the dynamic regulation ability of the photovoltaic industry market initially promotes an increase in photovoltaic revenue. However, after a period of time, the relationship between variables gradually changes, not just a simple positive or negative relationship. The system gradually enters chaos, showing an irregular cycle phenomenon. The relationship between government subsidies and photovoltaic revenue also forms an irregular chaotic phenomenon over time.

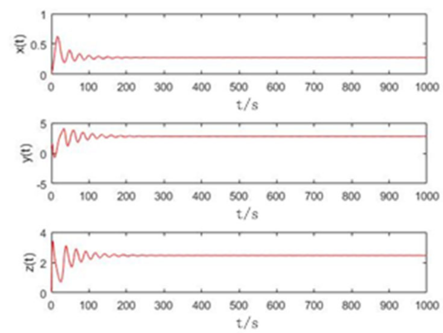


Fig. 5. System Time Series Diagram

Fig. 5 shows the time evolution sequence of market dynamic regulation ability, government subsidies, and photovoltaic industry returns. The time evolution sequence diagram of the system can provide a detailed description of the trend of each factor over time and reflect the frequency and amplitude of system operation. The vertical axis represents the stable values of market dynamic regulation ability, government subsidies, and photovoltaic industry returns, while the horizontal axis represents time (t/s). As shown in the graph, there will be strong fluctuations in market dynamic regulation ability and photovoltaic returns at the beginning of the period, but they gradually tend to stabilize over time. However, the oscillation phenomenon of government subsidies is not obvious at the beginning, and the amplitude of changes over time becomes smaller and eventually tends to stabilize.

3.2 Sensitivity dependency analysis

3.2.1 Analysis of parameter changes

Chaotic systems are sensitive to changes in internal parameters and initial values, which can cause significant changes in the chaotic system. Therefore, while keeping other values constant, analyze the impact of changing a certain parameter on the chaotic system and its magnitude. By fixing other parameters unchanged, the system trajectory undergoes a significant change, and its time series diagram also changes. As shown in Fig. 6 and Fig. 7, the system trajectory diagram shows a cyclic state. Figure 6 (a) shows the three-dimensional dynamic chaotic system at time $a_1 = 0.03$. Compared with the initial chaotic three-dimensional diagram of $a_1 = 0.05$, the three-dimensional chaotic dynamic chaotic diagram undergoes significant changes as the development coefficient of market dynamic adjustment ability decreases. Map it to a two-dimensional plane view to obtain Figures 6 (b), (c), and (d). For Fig. 6 (b), the development of market dynamic regulation ability affects the dependence of enterprises on government subsidies. Before the peak of market dynamic regulation ability, the dependence of photovoltaic enterprises on government subsidies gradually decreases. However, after reaching a peak, the dependence of photovoltaic enterprises on government subsidies gradually increases. For Fig. 6(c) and Fig. 6(d), the revenue of photovoltaic enterprises is influenced by market dynamic regulation ability and government subsidies. At the beginning of the development period, photovoltaic revenue slowly increases with the increase of market dynamic regulation ability. However, as the market dynamic regulation ability continues to increase, photovoltaic revenue does not increase but decreases. This is because enterprises need to invest a large amount of costs to cope with market changes, and excessive costs gradually reduce photovoltaic revenue; The changes in government subsidies have made photovoltaic revenue unstable, and companies require a large amount of government subsidies when their revenue is low. This demand gradually decreases as the company's photovoltaic revenue increases. From the time series Fig. 7, it can be seen that in this state, the market's dynamic regulation ability, government subsidies, and the profits of photovoltaic enterprises reach a stable development state relatively quickly.

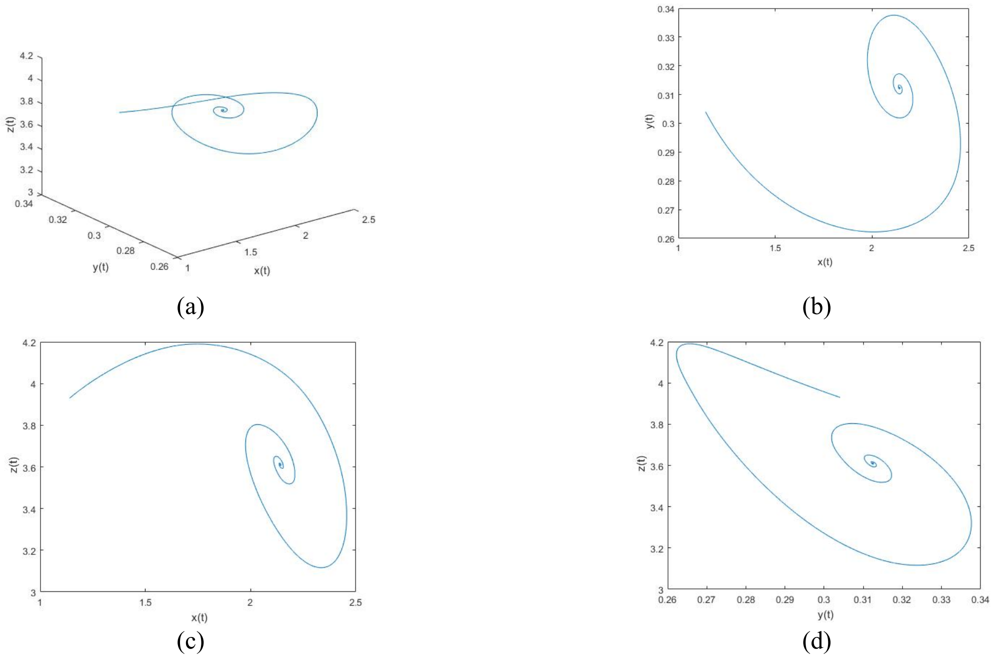


Fig. 6. System trajectory diagram when $a_1 = 0.03$

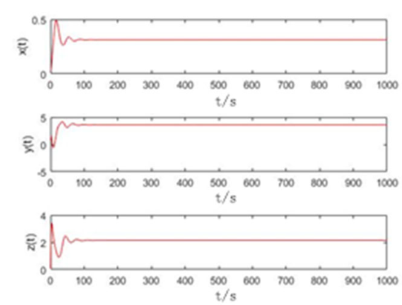


Fig. 7. System time series diagram when $a_1 = 0.03$

Fix other parameters unchanged, so that $a_2 = 0.009$, the system trajectory also undergoes a significant change. As shown in Fig. 8 and Fig. 9, at this point, it can be seen from Figure 8 (a) that as the coefficient $a_2 = 0.0025$ of the impact of government subsidies on market dynamic regulation capacity increases to $a_2 = 0.009$, it can be observed that the system trajectory graph shows an ear shaped line, which is different from the three-dimensional dynamic chaos graph under the initial state. And from this figure, obtain the two-dimensional mapping plane diagrams 8 (b), (c), and (d). From Fig. 8 (b), it can be observed that over time, the development of market dynamic regulation ability gradually reduces the dependence of enterprises on government subsidies; The growth of government subsidies in the later stage has led to a circuitous phenomenon in the market's dynamic regulation ability. For Fig. 8 (c), the initial market dynamic adjustment ability is directly proportional to the photovoltaic revenue of the enterprise, but after reaching its peak, the growth of market dynamic adjustment ability gradually reduces the photovoltaic revenue. For Fig. 8 (d), the revenue of photovoltaic enterprises is affected by government subsidies.

In the early stage of enterprise development, there are more government subsidies, but after the photovoltaic revenue of enterprises reaches a peak, the government subsidies will be appropriately reduced due to the increase in revenue. From the time series Fig. 9, in this state, the market's dynamic regulation ability, government subsidies, and the profits of photovoltaic enterprises reach a stable development state at an equally fast pace. At this point, the increase in the coefficient of the impact of government subsidies on market dynamic regulation ability shortens the time for the system to reach stability.

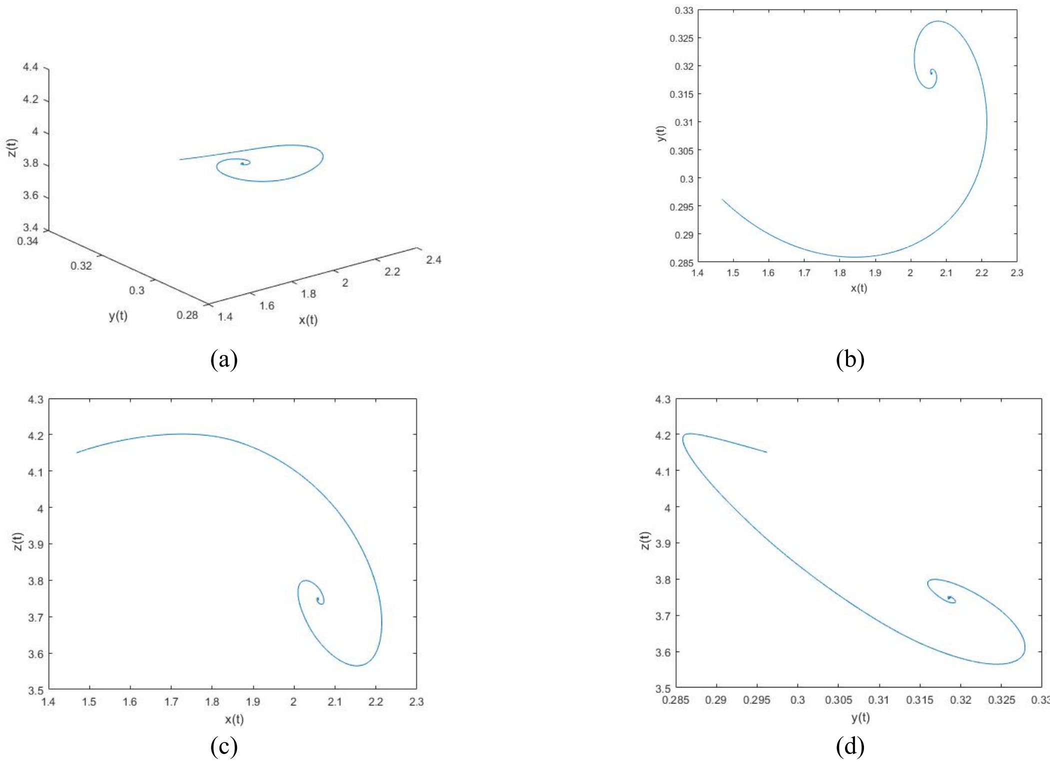


Fig. 8. System trajectory diagram when $a_2 = 0.009$

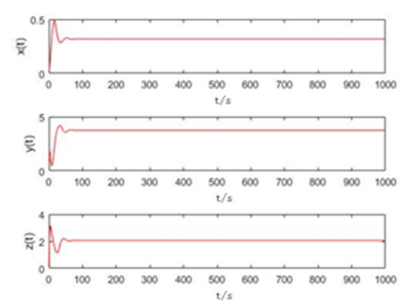
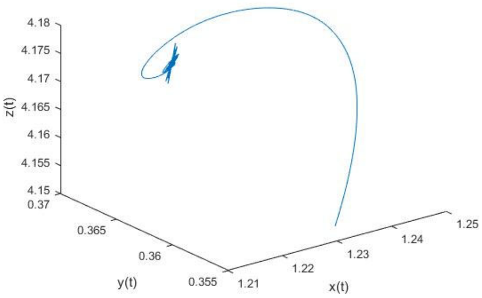
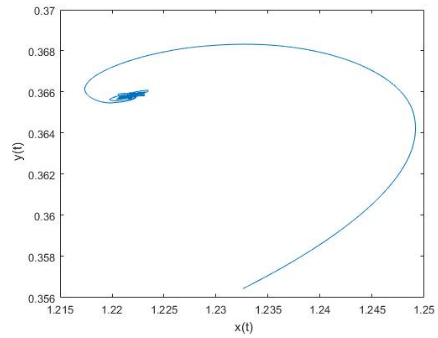


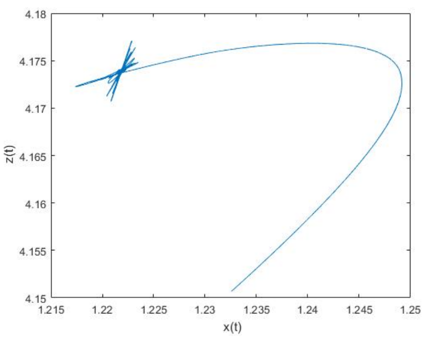
Fig. 9. System time series diagram when $a_2 = 0.009$

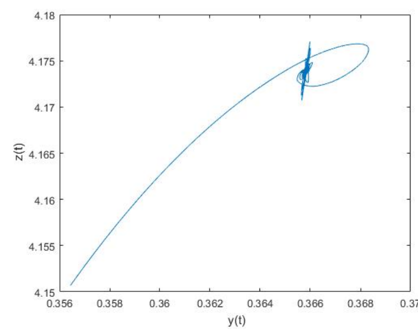
Keeping other parameters constant, the system trajectory of $a_3 = 0.05$ undergoes significant changes, and its time series diagram also changes, as shown in Fig. 10 and Fig. 11. From Fig. 10 (a), it can be seen that the increase in the coefficient a_3 of the impact of photovoltaic industry revenue on market dynamic regulation ability causes a significant change in the three-dimensional chaotic system diagram, which maps to a two-dimensional plane and has a more significant impact on the initial x (t)/z (t) chart. The improvement of market dynamic regulation ability has a greater effect on increasing photovoltaic industry revenue. A two-dimensional plane Fig. 9(b), Fig. 9(c), and Fig. 9(d) can be obtained from the chaotic diagram of a three-dimensional system. For Fig. 10(b), the increase in initial government subsidies can promote the improvement of market dynamic regulation ability, but after reaching a peak, the increase in government subsidies leads to a decrease in market dynamic regulation ability instead of an increase. For Fig. 10 (c) and Fig. 10 (d), the profits of photovoltaic enterprises at the beginning of the period are increased by the market's dynamic adjustment ability and the improvement of government subsidies, and the increase is more obvious than the initial value chart, but ultimately there is a roundabout phenomenon. From the time series Fig. 11, in this state, the market's dynamic regulation ability, government subsidies, and photovoltaic enterprise profits have reached a stable state in a relatively short period of time, and the vibration amplitude and frequency have decreased compared to the initial time series diagram. But the final stable income of the photovoltaic industry is slightly lower than the initial value.





(a) (b)





(c) (d)

Fig. 10. System trajectory diagram when $a_3 = 0.05$

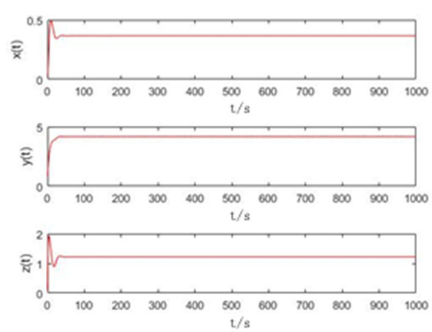


Fig. 11. System time series diagram when $a_3 = 0.05$

Similarly, when other parameters remain constant and coefficient b_1, b_2, b_3, c_1 、 c_2, c_3 is changed sequentially, both the system trajectory and time series graph show significant changes, indicating that the system is more sensitive to parameters.

3.2.2 Analysis of initial value changes

By fixing other parameters and changing the initial value of the three-dimensional nonlinear equation to (0.4, 0.7, 0.4), the system trajectory undergoes significant changes, as shown in Fig. 12 and Fig. 13. From Fig. 12 (a), it can be observed that after the initial value changes, the three-dimensional diagram of the chaotic system shows a significant change, and the non-linear relationship between market dynamic regulation ability, government subsidies, and photovoltaic industry returns changes. This is mapped to the two-dimensional plane Fig. 12 (b), Fig. (c), and Fig. (d) for further explanation. From Fig. 12 (b), when the initial market dynamic regulation ability weakens, the dependence on government subsidies gradually increases.

However, after the government subsidies reach a peak, continuing to increase government subsidies cannot effectively improve the market dynamic regulation ability. On the contrary, the system exhibits a roundabout phenomenon, and government subsidies have an impact on the market dynamic regulation ability, But at the same time, the ability of market dynamics to regulate also affects the degree of dependence of photovoltaic companies on government subsidies. From Fig. 12 (c) and Fig. 12 (d), after the initial value of the system changes, both the market's dynamic adjustment ability and the changes in government subsidies have an impact on the profits of photovoltaic enterprises. At the beginning, the change in market's dynamic adjustment ability is inversely proportional to the profits of photovoltaic enterprises, while the government's profits are directly proportional to the profits of photovoltaic enterprises. This indicates that when the initial dynamic adjustment ability is high, adjusting market dynamics again cannot effectively improve the marginal revenue of photovoltaic enterprises.

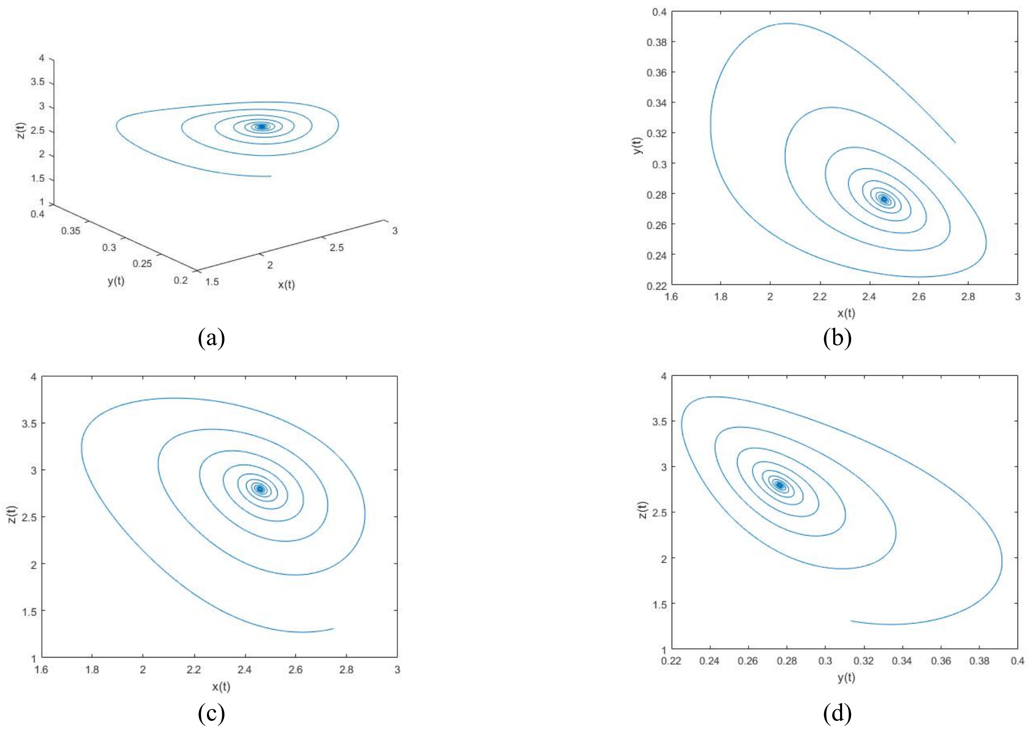


Fig. 12. System Trajectory after Changing Initial Values

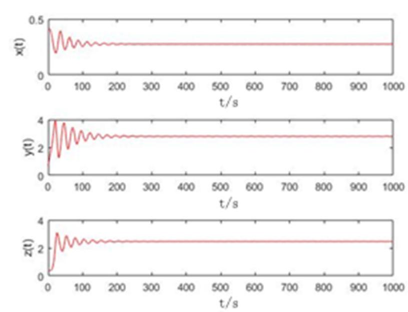


Fig. 13. Time series diagram of the system after changing the initial value

From the time series Fig. 13, after improving the market's dynamic regulation ability and reducing the initial value of government subsidies, the system will eventually reach stability, but the stable value will have slight differences. There are also chaotic attractors when the initial value changes, but it can be clearly observed that the system trajectory and time series graph have changed after the initial value changes, indicating that the system also has a certain sensitivity dependence on the initial value changes.

4. Conclusion and Countermeasures

4.1 Analysis of model conclusions

This article establishes a third-order nonlinear differential system model based on literature on market dynamic regulation ability, government subsidies, and corporate profits. The equilibrium point of the system is obtained and its stability is analyzed. The focus is on studying the sensitivity of chaotic systems to model parameters and initial values, and the following conclusions are drawn:

(1) Rapidly improving the dynamic regulation ability of the market cannot continuously increase the revenue of the photovoltaic industry. In the early stages of chaotic development, the improvement of market dynamic regulation ability is conducive to the increase of photovoltaic industry revenue. However, when the market dynamic regulation ability reaches a certain level, continuing to excessively improve market dynamic regulation ability is actually counterproductive, not conducive to the increase of photovoltaic industry revenue, and not conducive to the healthy development of the photovoltaic industry.

(2) The change in market dynamic regulation ability affects the dependence of enterprises on government subsidies. Before the market dynamic capacity reaches its peak, the dependence of enterprises on government subsidies first decreases and then increases. This is because in the early stages of chaos, the market dynamic regulation ability gradually increases, which has a positive boosting effect, and the dependence of enterprises on government subsidies is relatively low; But when the market regulation ability reaches its peak, enterprises need to pay a lot of costs to adapt to market changes, which gradually increases the financial pressure on enterprises. Therefore, the demand for government subsidies by enterprises gradually increases.

(3) The demand for government subsidies by enterprises gradually decreases with the increase of their own profits. When the profits of photovoltaic enterprises are low, they need a large amount of government subsidies to seek rapid development. However, when the profits of enterprises are high, their demand for government subsidies gradually decreases; However, blindly increasing subsidies by the government can also lead to fluctuations in the profits of photovoltaic enterprises, which is not conducive to the long-term stable development of photovoltaic enterprises. Due to the constraints of the development of technological innovation capabilities of enterprises, excessive government subsidies may not be able to be reasonably utilized.

4.2 Analysis of strategies for photovoltaic enterprises to increase profits

For the analysis of the chaotic relationship between the dynamic regulation ability of the photovoltaic industry market, government subsidies, and the revenue of photovoltaic enterprises, through three-dimensional nonlinear system modeling and numerical simulation, it is found that rapidly improving the dynamic regulation ability of the market cannot continuously increase the revenue of the photovoltaic industry; The changes in market dynamics affect the dependence of enterprises on government subsidies; The demand for government subsidies by enterprises gradually decreases with the increase of their own profits. In response to the relationship between the three, this article proposes strategies to improve the efficiency of the photovoltaic industry from the government and enterprise levels.

The government should attach importance to the healthy development of the photovoltaic industry and give it a certain degree of preferential treatment when formulating relevant industrial policies; At the same time, when formulating policies, attention should be paid to the diversification of policies, encouraging photovoltaic enterprises to actively apply for government related funding projects. At the same time, the government should comprehensively consider market dynamics and the development situation of enterprises to moderately invest in funding subsidies, and establish a supervision, review and acceptance mechanism for investment subsidies to promote the rational use of subsidies. The government should also pay attention to changes in the photovoltaic market while paying attention to the development of photovoltaic enterprises. When the market regulation ability is strong, the government can take a certain driving role to enhance the dynamic regulation ability of the market; When the market dynamic regulation ability is poor, the government can take corresponding measures to strengthen the vitality of the photovoltaic industry market and guide the development of the photovoltaic market; At the same time, when the market regulation ability is excessive, market changes are not conducive to the development of photovoltaic enterprises. At this time, the government should pay more attention to the market and take neutralization measures to ensure the stable operation of the market.

Enterprises should improve their market adaptability through long-term and subtle means. When responding to market changes, they not only need to change the market placement of their photovoltaic products, but also actively pay attention to market dynamics, cutting-edge and orientation, enhance their technological innovation dynamic capabilities, and efficiently enhance the impact of technological innovation dynamic capabilities on enterprise profits. But at the same time, it is also necessary to pay attention to the investment in other factors that constrain the development of the enterprise, and work together to add new impetus to the development of the enterprise. In the early stages of development, enterprises should actively pay attention to government policies that benefit enterprises, interact with the government, apply for funding projects that are conducive to enterprise development, and after obtaining government funding subsidies, they should also do a good job in the allocation of funds. Actively enhancing one's own technological innovation dynamic ability, researching and developing core technologies that drive enterprise development, and providing feedback to related industries, implicitly promoting the improvement of market dynamic adjustment ability. To adapt to market dynamics, enterprises should always pay attention to cutting-edge technologies in the industry, actively research and develop corresponding technologies without affecting company operations, enhance market competitiveness, enhance their own market adaptability, and actively respond to government policies to promote industry development. They cannot simply rely on government subsidies for survival.

Acknowledgement

Jiangsu Province University Philosophy and Social Science Project (2023SJYB1875); Jiangsu Province Education Science "14th Five Year Plan" Special Project (JS/2022/ZX0203-09410); Social Science Research Project of Huai'an City (2023SK45); Huaiyin Normal University Higher Education Project (2022GJYB08).

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