Behavioral value functions for the plants are chosen for T-strategy and NT-strategy, respectively:

 (1)

 (2)

Average behavioral value function for the plants:

 (3)

The evolutionary stabilization strategies for the replicated dynamic equations are solved for the coal-fired power plant, the government, and the population, respectively:

Behavioral value functions for the government's choice of S-strategy and NS-strategy:

 (4)

 (5)

The average behavioral value function of the government:

 (6)

Behavioral Value Functions for Financial Institutions Choosing I-Strategies and NI-Strategies:

 (7)

 (8)

Average behavioral value function of financial institutions:

 (9)

The dynamic equation of the government's evolutionary replication is:

 (12)

Simplify as follows:

 (13)

Where B11 represents the value of government behavior when the plants engage in CCUS and financial institutions provide green products, B12 represents the value of government behavior when only the plants choose to engage in CCUS strategies, and B13 represents the value of government behavior when only financial institutions provide green products, and B14 represents the value of government behavior when the plants choose to not engage in CCUS strategies and financial institutions limit or refuse to provide green products to the plants. B14 represents the value of government behavior when a coal-fired power plant chooses not to pursue a CCUS retrofit strategy and financial institutions restrict or refuse to offer green products to the plants.

The dynamic equation for the evolutionary replication of financial institutions is:

 (14)

Simplify as follows:

 (15)

C11 represents the behavioral value of the financial institutions when the coal-fired power plant is undergoing CCUS, and the government is guiding it. C12 represents the value of financial institutions' behavior when only the plants implement the CCUS technology transformation strategy, C13 represents the value of financial institutions' behavior when only the government guides and C14 represents the value of financial institutions' behavior when the plants do not implement the CCUS technology transformation strategy, and the government does not guide.

The replicated dynamic equation G of the model can be obtained as follows:

 (16)

Then, based on the Jacobian matrix, local stability analysis can be conducted. The Jacobian matrix can be represented as follows:

 (17)

The PT-MA value function of each element in the Jacobi matrix can be expressed as: (18)

(19)

 (20)

(21)

 (22)

 (23)

 (24)

 (25)

 (26)

 (27)

 (28)

If the matrix satisfies the conditions det>0 and trJ<0, the equilibrium point is the ESS. In equation G let  Since x,y,z∈[0,1], then ten equilibrium points can be obtained. respectively:T1(0,0,0),T2(0,0,1),T3(0,1,0),T4(0,1,1),T5(1,0,0),T6(1,0,1),T7(1,1,0),T8(1,1,1),T9(),T10().From 0 ≤ x ≤ 1, 0 ≤ y ≤ 1, 0 ≤ z ≤ 1, T1 to T8 are the boundaries of the feasible domain. Since A14>A14-A12, B14>B14-B12, A13>A13-A11, B13>B13-B11, T9 and T10 are outside of the feasible domain and therefore meaningless.

Assume some constraints based on reality. For a coal-fired power plant:

 (29)

Restrictive condition and This can be expressed as the perceived cost of the dynamically incentivized behavior of "no CCUS retrofit" is greater than the perceived cost of the behavior of "CCUS retrofit." The restrictive condition can be represented as the perception that the cost of receiving dynamic penalties for "not implementing CCUS technology reform" is greater than the perception of the cost of receiving green product subsidies for "implementing CCUS technology reform." Whether the government and financial institutions adopt any form of regulatory cooperation or choose not to cooperate at all, these conditions are reasonable.

For governments.

 (30)

The restrictive condition can be expressed as the perceived cost of the behavior "without guidance" being greater than the perceived cost of the behavior "with guidance".can be understood that the government perceives a higher behavioral cost of losses when it chooses "not to provide guidance" compared to when it chooses "to provide guidance." In short, regardless of the financing and incentive cooperation methods adopted by the plants and financial institutions, these conditions are reasonable.

For financial institutions.

 (31)

The above constraints can represent the behavioral cost perception of "not providing green products" being higher than the behavioral cost perception of "providing green products." In other words, regardless of whether the the plants undergo CCUS technology transformation and whether the government provides guidance, these conditions are reasonable.

Given the outlined constraints, considering the increasing nature of both V(X) and Z(X), it becomes evident that all parameters - A11, A12, A13, A14, B11, B12, B13, B14, C11, C12, C13, C14 - assume positive values. Employing Lyapunov's first method: an equilibrium point is asymptotically stabilized when all eigenvalues of the Jacobian matrix possess negative real components. Conversely, should even a single eigenvalue of the Jacobian matrix exhibit a positive real component, the equilibrium point is rendered unstable. In instances where all eigenvalues of the Jacobian matrix display negative real components, barring the eigenvalues with real components of zero, the equilibrium point assumes a critical state. In such a case, the stability of the equilibrium point cannot be definitively determined by the signs of the eigenvalues. Therefore, when both detJ and trJ are greater than 0, it is an unstable point; when the positive and negative sign of trJ cannot be determined, it is a saddle point; and when both detJ and trJ are less than 0, it is an ESS. The next specific analysis of each equilibrium point's evolutionary stability and the stability conditions are shown in Table 7.

**Table 7**

The evolutionary stability and stability conditions of each equilibrium point

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| The equilibrium point | detJ | symbol | trJ | symbol | stability |
| T1(0,0,0) | A14B14C14 | **+** | A14+B14+C14 | **+** | unstable point |
| T2(0,0,1) | -A13B13C14 | **-** | A13+B13-C14 | Unsure | saddle point |
| T3(0,1,0) | -A12B14C13 | **-** | A12-B14+C13 | Unsure | saddle point |
| T4(0,1,1) | A11B13C13 | **+** | A11-B13-C13 | Unsure | saddle point |
| T5(1,0,0) | -A14B12C12 | **-** | -A14+B12+C12 | Unsure | saddle point |
| T6(1,0,1) | A13B11C12 | **+** | -A13+B11-C12 | Unsure | saddle point |
| T7(1,1,0) | A12B12C11 | **+** | -A12-B12+C11 | Unsure | saddle point |
| T8(1,1,1) | -A11B11C11 | **-** | -A11-B11-C11 | **-** | ESS |

From Table 6, it can be seen that there are seven evolutionary stabilization strategies in this evolutionary game, namely (the plants do not undergo CCUS technological transformation, the government does not provide guidance, and financial institutions provide green products), (the plants do not undergo CCUS technological transformation, the government provides guidance, and financial institutions restrict or refuse to provide green products to the plants), (the plants do not undergo CCUS technological transformation, the government provides guidance, and financial institutions provide green products), (the plants do not undergo CCUS technological transformation, the government provides guidance, and financial institutions to provide green products), (the plants undergo CCUS technological transformation, the government does not provide guidance, and financial institutions restrict or refuse to provide green products to the plants), (the plants undergo CCUS technological transformation, the government does not provide guidance, and financial institutions provide green products), (the plants undergo CCUS technological transformation, the government provides guidance, and financial institutions restrict or refuse to provide green products to the plants). (the plants undergo CCUS technological transformation, the government provides guidance, and financial institutions provide green products), corresponding to the seven equilibrium points T2, T3, T4, T5, T6, T7, and T8, respectively, where T8 is the ESS and T1 is the unstable point.

The plants, governments, and financial institutions are all bound by bounded rationality. Inaccurate judgments during the decision-making process arise from factors such as incomplete information, time constraints, and resource limitations, preventing the system from reaching an optimal state and lacking stable centrality. Various hindrances, such as high costs, low efficiency, elevated psychological expectations, and different risk preferences, lead to several issues.

The behavior costs of the plants, governments, and financial institutions are relatively high, resulting in correspondingly lower behavioral values. For the plants, management costs encompass operational expenses, labor costs, technology introduction expenses, etc. When financing the implementation of CCUS technology, they need to consider how to control these costs reasonably. The efficacy value of the plants involves aspects like selling carbon quotas. When conventional strategies fail to ensure profits, these plants may adopt measures to increase revenue.

For governments, administrative costs of regulation are high, while perceived compensation is relatively low, leading to an unequal balance between work quality and income. As a result, incentive mechanisms do not effectively motivate government personnel, making it challenging for the government to regulate the plants. Flexibility and innovation pose challenges for the government, as it is difficult to sustain comprehensive regulations.

Financial institutions require cooperation with the government to incentivize the plants to adopt CCUS technology. Consequently, financial institutions face a significant gap between choosing to provide green products or restrict and refuse financing to the plants. Although both options stem from the goal of promoting green sustainability, the decision involves considerable differences. Financial institutions may also be concerned about investing action costs without receiving adequate returns, making the government's guidance highly influential.

High psychological expectations are present among the plants, governments, and financial institutions, all seeking greater returns with minimal effort. When the value of these expectations (U0) is relatively large, it is not favorable for the plants to adopt the "introduce CCUS technology" strategy, and the government and financial institutions may also be affected in implementing regulatory procedures. Furthermore, effective communication between financial institutions and the plants to issue green products and promote CCUS technology becomes challenging without government leadership. Consequently, the plants are likelier to choose "not to adopt CCUS technology." For the government and financial institutions to achieve maximum benefits, active participation from both sides is crucial, making them more likely to opt for non-regulatory approaches.

*3.5．Model Analysis under the Dynamic Reward and Punishment Mechanism*

Similarly, the behavioral value functions of all players under different strategies can be obtained:

Behavioral value functions for the plants choosing T-strategy and NT-strategy: (32)

 (33)

Average behavioral value function for the plants:

 (34)

Behavioral value functions for the government's choice of S-strategy and NS-strategy:

 (35)

 (36)

The average behavioral value function of the government:

 (37)

Behavioral Value Functions for Financial Institutions Choosing I Strategies:

 (38)

Behavioral value function for financial institutions choosing NI strategies:

 (39)

Average behavioral value function of financial institutions:

 (40)

The evolutionary stabilization strategies for the replicated dynamic equations are solved for the coal-fired power plant, the government, and the population, respectively:

The evolutionary replication dynamic equation for the plants is as follows:

 (41)

The average behavioral value function of the government:

 (42)

Where A21 represents the value of government the plants' behavior when the government provides guidance, and financial institutions provide green products, A22 represents the value of the plants' behavior when only the government provides guidance, A23 represents the value of the plants' behavior when only financial institutions provide green products, and A24 represents the value of the plants' behavior when the government does not provide guidance and financial institutions restrict or refuse to provide green products to the plants.

The dynamic equation of the government's evolutionary replication is:

 (43)

The average behavioral value function of the government:

 (44)

Where B21 represents the value of government behavior when a coal-fired power plant engages in CCUS and a financial institution offers a green product, B22 represents the value of government behavior when only the coal-fired power plant chooses to engage in a CCUS strategy, and B23 represents the value of government behavior when only the financial institution offers a green product, and B24 represents the value of government behavior when the coal-fired power plant chooses not to engage in a CCUS strategy, and the financial institution restricts or refuses to offer a green product to the plant. B24 represents the value of government behavior when a coal-fired power plant chooses not to pursue the CCUS technology retrofit strategy and financial institutions restrict or refuse to provide green products to the coal-fired power plant. Only the asymptotic stability of T1 ~ T8 is discussed below.

The evolutionary replication dynamic equation for financial institutions is:

 (45)

It can be simplified as:

 (46)

C21 represents the behavioral value of the financial institutions when the coal-fired power plant is undergoing CCUS, and the government is guiding it. C22 denotes the behavioral significance of financial institutions when only the coal-fired power plant has a CCUS technology transformation strategy, C23 denotes the behavioral value of financial institutions when only the government guides, and C24 means the behavioral significance of financial institutions when the coal-fired power plant does not have a CCUS technology transformation strategy and the government does not guide.

The replicated dynamic equation G of the model can be obtained as follows: (47)

Local stability analysis based on Jacobi matrix. The Jacobi matrix can be expressed as follows:

 (48)

The PT-MA value function of each element in the Jacobian matrix is expressed like formula 18-28. Similarly, in equation G2, let, there are 8 meaningful equilibrium points. They are：T1(0,0,0),T2(0,0,1),T3(0,1,0),T4(0,1,1),T5(1,0,0),T6(1,0,1),T7(1,1,0),T8(1,1,1)。

In analyzing the dynamic and static punishment mechanisms in the evolutionary game, it is found that they have similar characteristics and effects. The dynamic reward and punishment mechanisms and the static punishment mechanisms create similar constraints and incentives between the plants, governments, and, financial institutions. The Dynamic Reward and Punishment Mechanism model, which is the core of this thesis, aims to explore the strategic evolution process of the interactions among the government, the plants, and financial institutions during the financing of the plants' environmental protection and sustainable development projects.

This paper uses simulation to conduct experiments to verify the effectiveness and practicality of the dynamic reward and punishment mechanism model.