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Evolutionary Game Analysis of Ecological Governance Strategies in the Yangtze River Delta Region, China

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Abstract: Under integrated ecological and green development in the Yangtze River Delta, the regional ecology is adversely affected by ineffective synergistic governance. Regional environmental governance is a collaborative process involving multiple stakeholders and mutual engagement, with each participant pursuing their interests and common goals simultaneously. This study employed stakeholder theory. A tripartite evolutionary game model of the public, enterprises, and local governments was constructed to analyze the behavioral strategies and influencing factors for the parties involved, and the impacts of key factors on the stability of the evolutionary game system were evaluated. The results indicate that ecological environmental governance in the Yangtze River Delta region is a complex and evolving system involving multiple stakeholders, within which system stability is influenced by stakeholders' behavioral strategies. The interests of each party are affected by the cost of public involvement in ecological environment governance and the benefits and subsidies that enterprises receive for active environmental governance. The costs and penalties paid by local governments for lax regulations impact their behavioral strategies. This study provides policy recommendations for ecological governance in the study region, including the government–enterprise co-construction of liquid regulatory funds, government–enterprise–public partnerships in low-cost regulatory models, and the sharing of high-quality regulatory outcomes.

Keywords: multiple stakeholders; evolutionary game; behavioral strategies; numerical simulation; ecological environment governance; collaborative framework

1. Introduction

In recent years, positive outcomes have been attained through integrated ecological and green development of the Yangtze River Delta region, inspired by Xi Jinping's "Thought on Socialism with Chinese Characteristics for a New Era". However, due to the region's excellent integrated growth and the acceleration of the new urbanization process, cross-border pollution has become an urgent bottleneck to further development in Shanghai, Jiangsu, Zhejiang, and Anhui (hereafter referred to as "three provinces and one city"). Against this background, in January 2021, the Office of the Leading Group for Integrated Development of the Yangtze River Delta released the "Plan for Joint Ecological Environment Protection in the Yangtze River Delta Region", which explicitly advocates for the promotion of collaborative environmental governance and strengthening of the foundation for green development. However, collaborative governance of the ecological environment entails the participation of multiple parties, and the divergent interests and conflicting behavioral orientations of these parties pose a predicament for collective action in the Yangtze River Delta region. Therefore, it is particularly necessary to explore the strategic choices of various stakeholders and their influencing factors in the environmental governance of the Yangtze River Delta region.

Considerable academic research has been conducted on regional ecological and environmental governance strategies. In particular, many studies have reported on the current state, features, and efficiency of environmental governance in the Yangtze River Delta

region [1–6]. Through both qualitative and quantitative approaches, researchers have proposed strategies for collaborative governance by multiple stakeholders. Among them, Mao et al. pointed out that the joint prevention and control of air pollution in the Yangtze River Delta region suffers from unresolved problems, such as a weak synergy of regional policies and low social participation [2]. Based on the case studies of Hangzhou and the Hefei metropolitan area, Suo et al. analyzed the core environmental pluralistic co-governance characteristics and reported that the government is the core body tasked with establishing a pluralistic synergistic environmental co-governance model [3]. Based on empirical data, other scholars have conducted systematic evaluations of the spatiotemporal characteristics of environmental pollution and assessed the effectiveness of regional environmental governance [4]. Further, they suggested that collaborative governance of the Yangtze River Delta requires the creation of a long-term dynamic mechanism that should include mechanisms to promote government responsibility and public participation [5,6]. Studies have focused on the significance of involving multiple actors. Most scholars have proposed macro-level countermeasures or collaborative governance led by local governments. However, different behavioral strategy choices among local governments have not yet been specifically explained at the micro level, and behavioral strategies and their interactions among multiple subjects, such as local governments, private enterprises, and the public, have not been studied in depth.

The most representative research on the multiparty joint governance of regional ecosystems is the synergistic governance model proposed by Ansell and Gash and Emerson et al. Ansell and Gash [7] developed the synergistic governance model comprising four components: starting conditions (S), catalytic leadership (F), institutional design (I), and synergistic process (C), with the synergistic process being the key element, while starting conditions, institutional design, and leadership provide supportive factors for synergistic governance. Emerson et al. [8] described a collaborative governance model comprised of three interacting components: "principled" participation, shared motivation, and the ability to act jointly. Based on this, scholars in China have developed various frameworks and models to analyze ecological and environmental governance [9–11]. These frameworks are based on the actual atmospheric or water environmental governance in the area. Among them, Wu et al. [9] proposed a "structure-process" analytical framework for collaborative air pollution management in the Yangtze River Delta region. They argued that a range of structural and process mechanisms can reduce transaction costs and cooperation risks and are beneficial for the functioning of the collaborative air pollution management model in this region. Other scholars have developed a "Dynamics-Structure-Process" analytical model and advocated for an inter-administrative environmental governance model named "Inter-Governmental Consultation" based on an analysis of governance costs and cooperation benefits [10]. Researchers have developed gravity models to demonstrate the spatial relationships of collaborative governance. These researchers have suggested a pathway to enhance collaborative governance of pollution and carbon reduction within China's three primary urban agglomerations in the Yangtze River Delta region [11]. Studies have been carried out to devise an analytical framework or model aimed at exploring the factors influencing ecological and environmental governance, as well as the mechanisms for nurturing synergistic approaches to ecological and environmental governance in the Yangtze River Delta region. However, previous research has not elucidated the fundamental determinants behind the adoption of behavioral strategies by multiple stakeholders and the implications of these determinants for environmental governance.

Evolutionary game theory is an approach that combines traditional game theory analysis with dynamic evolutionary process analysis, with an emphasis on "evolutionarily stable strategies" and "replication dynamics" [12–17]. By analyzing limited rationality and group behavior, evolutionary game theory reveals the interactions and behaviors of multiple stakeholders, which offers a novel approach of studying the behavioral strategies of multi-interest stakeholders and elucidating key underlying factors [18–45]. Academic research on the evolutionary game of regional ecological and environmental governance is divided into

three primary areas. The first is evolutionary games between government agents [18–24]. Scholars have analyzed the problem of ecological environmental governance from the perspective of evolutionary games between the central and local governments or between local governments [18–20]. Numerous Chinese scholars have focused on ecological and environmental governance in the Beijing–Tianjin–Hebei region, investigating the impact of collaborative air pollution management in the region and identifying influencing factors [21–23]. In these studies, game models to explore the relationships between the central and local governments or among local governments have been used [18–24]. In the Yangtze River Delta region, relatively few evolutionary game studies have been conducted on ecological and environmental governance. Bo et al. investigated the evolutionary game theory of haze governance behavior in this region by constructing a game model with local governments [24]. The second area concerns evolutionary games between the government and businesses [25,26]. Some scholars have studied how government policies affect enterprises' strategic choices by applying this government–enterprise game model. Song et al. found that formal environmental regulation can effectively promote enterprise innovation, and Izabela et al. verified the interactive effects of government and firm strategies [25,26]. The third area studies evolutionary games between multiple interested parties [27–46]. Some scholars systematically analyzed the strategy selection process of three primary parties by constructing a three-party evolutionary game model [27–31,43–45]. They explored the mutual influence mechanism of the behavioral strategies of all parties' interests under environmental regulations. In the Beijing–Tianjin–Hebei region, scholars have conducted numerous studies on ecological management based on evolutionary games [21–23]. However, there is a lack of evolutionary game studies on ecological and environmental governance in the Yangtze River Delta region [27,41,42]. Extant studies on ecological environment governance that have employed the evolutionary game approach have only examined the game played by central and local governments or between the governments of the three provinces and one city. These studies did not include other relevant stakeholders such as enterprises and the public in the evolutionary game analysis framework and thus it does not represent the actual situation of regional ecological and green integration development.

In summary, a research framework for ecological governance in the Yangtze River Delta Region is as shown in Figure 1: (1) This study incorporates enterprises and the public into a collaborative governance mechanism to explore the behavioral strategies of multiple stakeholders involved in ecological governance in the Yangtze River Delta region. (2) Based on the assumption of limited rationality, this study constructs a tripartite evolutionary game model of "public-enterprise-local government" to explore the strategic choices made by each stakeholder in ecological environment governance and their impacts on each other. This study was conducted to clarify the effects of crucial factors on ecological environment governance in the Yangtze River Delta region. (3) By simulating and analyzing the differential impacts of various factors and exploring their underlying mechanisms, this study enabled the construction of a synergistic governance model of "government-enterprise co-construction of liquidity regulatory funds, government-enterprise-public partnership in low-cost regulatory modes, and sharing of high-quality regulatory outcomes". These efforts may boost the interests of stakeholders involved in ecological and environmental governance while providing theoretical support and policy recommendations to promote sustainable development in the Yangtze River Delta.
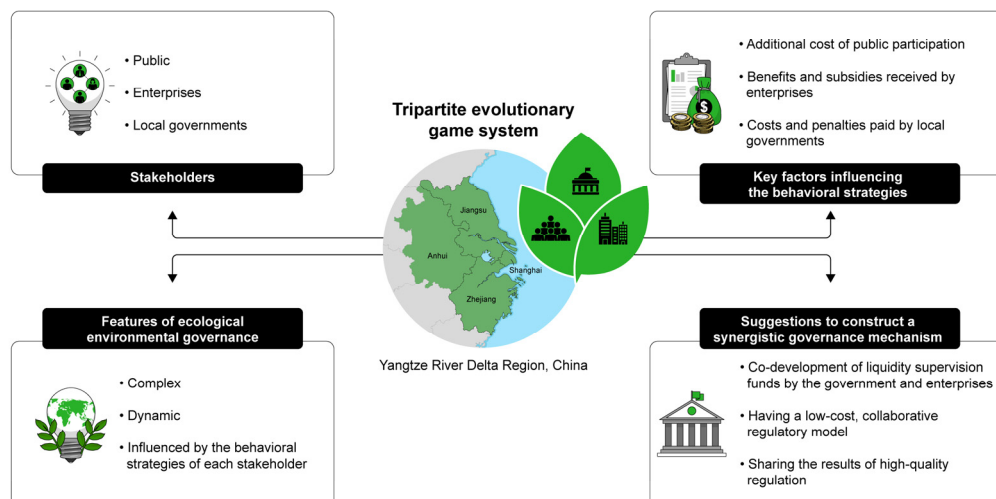
Figure 1. Research framework for ecological governance in the Yangtze River Delta region (prepared by the authors).

2. Materials and Methods

2.1. Study Area

In November 2018, at the First China International Import Expo (CIIE), Chinese President Xi Jinping announced his support for upgrading the integrated development of the Yangtze River Delta to a national strategy. The scope of the regional plan includes the entire area of Shanghai, Jiangsu, Zhejiang, and Anhui provinces (an area of 358,000 kilometers^2). The state of the ecological environment, which is the basis for human survival and development, determines a region's capacity for sustainable development. The Yangtze River Delta region, with its rich ecosystem types, deep ecological culture, and great ecological carrying capacity, is an important place for Xi Jinping's idea of ecological civilization to germinate. It is also a pioneer zone for building a beautiful China. At present, the integration of the Yangtze River Delta region is at a stage of higher quality development. The ecological environment has become an indispensable dimension for assessing the higher quality integrated development of the Yangtze River Delta.

Recently, the local governments of the three provinces and one city implemented the outline of the plan for the integrated development of the Yangtze River Delta region, clarified their respective roles and positions in the ecological environment, and made concerted efforts to build a beautiful and green Yangtze River Delta. Shanghai has sufficient economic, technological, and organizational advantages to play a leading role. Jiangsu Province serves as a model and has joined forces with Zhejiang Province and Shanghai to build a demonstration zone for integrated eco-green development. Zhejiang Province occupies an important position in the country in terms of water resources, including marine as well as other biological resources, and is the "Great Garden", as well as a practitioner of the concept of "two mountains". With good ecological resources and strong environmental protection, Anhui Province plays an important barrier protection role in Yangtze River Delta ecology. To better solve the ecological and environmental pollution problems, the three provinces and one city launched a set of governance practices. For example, Shanghai Municipality, Jiangsu Province, and Zhejiang Province jointly signed the first declaration on regional environmental cooperation in China in Hangzhou, which set out the need to strengthen cooperation across regional boundaries to solve environmental problems. Anhui Province has taken the lead in implementing the reform of the ecological forest management system and construction of the "atmospheric ecological compensation" model.

2.2. Stakeholders in Ecological and Environmental Governance in the Yangtze River Delta Region

Due to the public nature, complexity, and cross-border characteristics of regional ecological and environmental issues, regional ecological governance requires not only

strong input from the local governments of the three provinces and one city but also cooperation among various stakeholders. According to Freeman's stakeholder theory, which provides a theoretical framework for analyzing the behavior of ecological and environmental governance stakeholders in the Yangtze River Delta region, the ecological and environmental governance stakeholders' role in the Yangtze River Delta region has evolved from "passive influence" to "active participation" to "collaborative governance" [46,47]. Combining the degree of closeness of the relationship between stakeholders and ecological environmental governance, stakeholders are defined as the public, private enterprises, and local governments. The interests and interrelationships of the different game subjects were analyzed to identify logical relationships between the tripartite game subjects of ecological environmental governance in the Yangtze River Delta region, as shown in Figure 2.
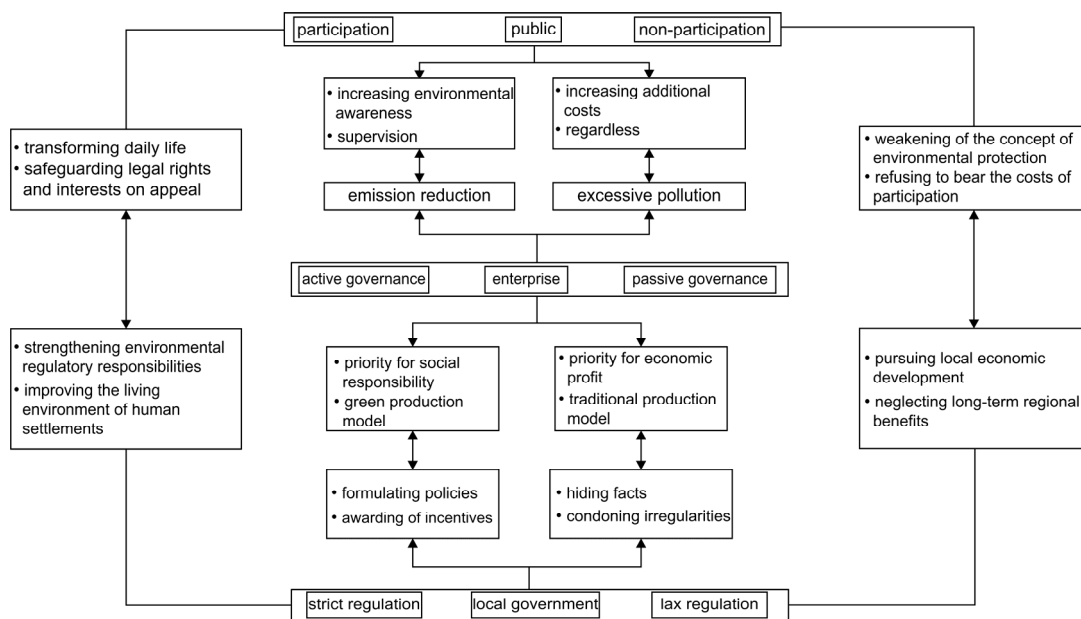

Figure 2. Logical relationship diagram of the three-party evolutionary game model (prepared by the authors).

In the regional governance of the ecological environment, the public, which is primarily affected by pollution in the region, experienced a noticeable delay in participating in the governance process [48]. The government–business model of governance alone cannot achieve the best strategy for environmental protection; the effectiveness of ecological and environmental governance is significantly influenced by the extent of public participation [49]. When the public takes the initiative to participate in eco-environmental governance, they actively respond to the government's call for environmental protection by changing their lifestyles through green travel and green consumption. When the living environment and physical and mental health are damaged by corporate production, the public can choose to report corporate emissions or appeal to defend their rights, and the local government may reward their behavior. Therefore, the public's behavior can push enterprises to change their production concepts from the bottom up and strengthen the government's adherence to regulatory responsibilities.

As enterprises are the main producers of ecological pollution, their behavioral strategies play a crucial role in ecological governance. In the context of the government's efforts to promote ecological governance, enterprises can earn subsidies from the local government and garner public recognition, while also establishing an admirable corporate image, if they prioritize social responsibility and opt for proactive governance. However, they must bear in mind that this requires them to incur a specific sum in green production costs. If a business seeks to maximize financial gains and is unwilling to pay elevated costs for transitioning to new production methods, even if this leads to a temporary boost in revenue,

it may face reprimands from local authorities and public scrutiny. Such consequences are not conducive to the sustainable growth and development of an enterprise.

Local governments in the three provinces and one city act as regulators of regional ecological and environmental governance. To create a green and beautiful Yangtze River Delta regional habitat, local authorities encourage innovation in eco-friendly practices by enterprises and offer policy incentives and subsidies to the public to promote environmental protection. At the same time, when the public chooses not to participate and enterprises choose to produce in violation of negative emission goals, local governments need to intervene in a timely manner and take administrative measures such as deadline rectification. As the quality of life improves and the image of the city is enhanced, the social credibility and influence of the local government will be significantly enhanced, but the higher costs incurred by strict regulations will also place financial pressure on that government. When local governments relax their requirements on the public and enterprises to seek local economic growth, they may conceal ecological and environmental pollution and condone illegal discharge by enterprises [50]. Consequently, local governments incur adverse societal impacts and the loss of public confidence.

2.3. Three-Party Evolutionary Game Model Construction

2.3.1. Model Assumptions

Based on the interests of each subject in the regional environmental governance, this study operated under the following assumptions combined with the actual situation of ecological and environmental governance.

Hypothesis 1. *There are three types of interests in the regional environmental governance system: public, enterprise, and local governments. All three have limited rationality.*

Hypothesis 2. *There are two types of behavioral strategy choices for all three parties. Among them, the strategic space for the public is (participation, nonparticipation), the strategic space for enterprises is (active governance and passive governance), and the strategic space for local governments is (strict regulation and lax regulation). The probability that the public chooses to participate is x ($0 < x < 1$), and the probability that they choose not to participate is $1 - x$. The probability that a firm chooses positive governance is y ($0 < y < 1$), and the probability that it chooses negative governance is $1 - y$. The probability that a local government chooses strict regulation is z ($0 < z < 1$), and the probability that it chooses lax regulation is $1 - z$.*

Hypothesis 3. *When the public chooses to participate, the public needs to invest a certain amount of time, transport, consumption, and other basic costs (C_1) to adapt to the green lifestyle, and, accordingly, the public obtains benefits such as environmental beautification, physical and mental pleasure, and so on (R_1). If enterprises pursue only economic benefits and neglect social responsibility, the public will experience losses such as pollution of their living environment and poor health conditions (S_3). However, under the government's policy of strict regulation, the public will actively report enterprises and file complaints to protect their rights, and enterprises will incur additional costs (F_1). If firms are socially responsible, the public gains through activities such as corporate compensation and local government incentives (S_2). Conversely, when the public chooses nonparticipation, it will not gain anything, but ecological degradation will result in losses of public physical and mental health (S_1).*

Hypothesis 4. *As far as the enterprises are concerned, when an enterprise chooses an active governance strategy, the enterprise responds to the government's call for green production and pays the costs of upgrading equipment, training personnel, and introducing innovative technologies such as transforming production methods (C_2). Compared to traditional production methods, firms lose a portion of their operating profits (S_4) to fulfill their social responsibilities; they also gain a portion of their operating profits and image enhancement, among other gains (R_2), and local governments subsidize these positive corporate governance behaviors. Conversely, when a firm chooses a negative*

governance strategy, it pays lower production method transformation costs (C_3) ($C_2 > C_3 > 0$) to obtain more operating profit (R_3) ($R_2 > R_3 > 0$). At this point, the public will report negative corporate governance behaviors, the local government will penalize negative corporate governance behaviors (F_2), and the firm will incur losses such as public compensation and negative public relations (S_5).

Hypothesis 5. *When the local government chooses a strict regulatory strategy, it is costly (C_4) to guide and incentivize the public and enterprises to carry out ecological and environmental management. Correspondingly, local governments obtain benefits (R_4) such as performance attainment, city image improvement, and social influence enhancement. Local governments that choose a lax regulatory strategy have a "free-rider" attitude and pay lower regulatory costs (C_5). At this point, if the enterprise actively manages the ecological environment, the local government obtains higher social benefits (A_1), and if the enterprise chooses to manage the ecological environment negatively, the local government is penalized because of the damage to the city's image (A_2). If the public participates in ecological environmental governance, the local government may be punished because of negative social opinion (B_1). If the public does not participate in ecological environmental governance, the local government will obtain fewer social benefits (B_2) than if they did participate.*

2.3.2. Benefits Matrix for Subjects in the Three-Party Evolutionary Game

According to the basic assumptions and parameter settings of the above model, a subject–benefit matrix of the tripartite evolutionary game was constructed as shown in Table 1.

Table 1. Benefits matrix for subjects of the three-party evolutionary game (prepared by the authors).

Combination of Strategies	Benefit Function		
	Public	**Enterprise**	**Local Government**
(participation, active governance, strict regulation)	$-C_1 + R_1 - F_1 - S_2$	$-C_2 + R_2 + T - S_4$	$-C_4 + R_4$
(participation, active governance, lax regulation)	$-C_1 + R_1 - S_2$	$-C_2 + R_2 - S_4$	$-C_5 + A_1 - B_1$
(participation, passive governance, strict regulation)	$-C_1 + R_1 - F_1 - S_3$	$-C_3 + R_3 - F_2 - S_5$	$-C_4 + R_4$
(participation, passive governance, lax regulation)	$-C_1 + R_1 - S_3$	$-C_3 + R_3 - S_5$	$-C_5 - A_1 - B_1$
(nonparticipation, active governance, strict regulation)	$-S_1$	$-C_2 + R_2 + T$	$-C_4 + R_4$
(nonparticipation, active governance, lax regulation)	$-S_1$	$-C_2 + R_2$	$-C_5 + A_1 + B_1$
(nonparticipation, passive governance, strict regulation)	$-S_1$	$-C_3 + R_3 - F_2$	$-C_4 + R_4$
(nonparticipation, passive governance, lax regulation)	$-S_1$	$-C_3 + R_3$	$-C_5 - A_2 + B_2$

Notes: C_1 represents the costs incurred when the public participates in governance; C_2 represents the costs of positive governance by enterprises; C_3 represents the costs of negative governance by enterprises; C_4 represents the costs of strict regulation by local government; C_5 represents the costs of lax regulation by local government; S_1 represents the losses when the public does not participate in governance; S_2 represents the losses to the public when enterprises are actively governed; S_3 represents the losses to the public when enterprises are negatively governed; S_4 represents the profits lost when enterprises are actively governed; S_5 represents the losses suffered when enterprises are negatively governed; R_1 represents the benefits received when the public participates in governance; R_2 represents the benefits of active governance by enterprises; R_3 represents the profits of negative governance by enterprises; R_4 represents the benefits of strict regulation by local governments; A_1 represents the social benefits that local governments receive when they are loosely regulated and when enterprises are positively governed; A_2 represents the penalties incurred by local governments when they are lax in regulation and are negatively governed by enterprises; B_1 represents the penalties incurred by local governments when they are laxly regulated and the public is participative in governance; B_2 represents the social benefits received by local governments when they are lax in regulation and the public is not participative in governance; F_1 represents the additional cost of public participation in governance when local governments strictly regulate; F_2 represents the penalties for negative enterprise governance when local governments strictly regulate; T represents the subsidy received by enterprises for active governance when local governments strictly regulate.

3. Results

3.1. Analysis of the Three-Party Evolutionary Game Model

3.1.1. Dynamic Equations of Replication of the Subject of the Three-Party Evolutionary Game

According to the payoff matrix of subjects in the three-party evolutionary game shown in Table 1, the expected payoffs for the public choosing the participation strategy U_{11}, the

expected payoffs of choosing the nonparticipation strategy U_{12}, and the average expected payoffs U_1 are

$$U_{11} = y*z*(-C_1+R_1-F_1-S_2) + y*(1-z)*(-C_1+R_1-S_2) + (1-y)*z*(-C_1+R_1-F_1-S_3) + (1-y)*(1-z)*(-C_1+R_1-S_3) \quad (1)$$

$$U_{12} = y*z*(-S_1) + y*(1-z)*(-S_1) + (1-y)*z*(-S_1) + (1-y)*(1-z)*(-S_1) \quad (2)$$

$$U_1 = xU_{11} + (1-x)U_{12} \quad (3)$$

At this point, the replication dynamic equation for public strategy choice is

$$F(x) = dx/dt = x(1-x)(U_{11}-U_{12}) = x*(x-1)*(C_1-R_1-S_1+S_3+F_1*z+S_2*y-S_3*y) \quad (4)$$

Similarly, the enterprise's expected return U_{21} from choosing a positive governance strategy, the expected return U_{22} from choosing a negative governance strategy, and the average expected return U_2 are

$$U_{21} = x*z*(-C_2+R_2+T-S_4) + x*(1-z)*(-C_2+R_2-S_4) + (1-x)*z*(-C_2+R_2+T) + (1-x)*(1-z)*(-C_2+R_2) \quad (5)$$

$$U_{22} = x*z*(-C_3+R_3-F_2-S_5) + x*(1-z)*(-C_3+R_3-S_5) + (1-x)*z*(-C_3+R_3-F_2) + (1-x)*(1-z)*(-C_3+R_3) \quad (6)$$

$$U_2 = yU_{21} + (1-y)U_{22} \quad (7)$$

At this point, the replication dynamic equation for the enterprises' strategy choice is

$$F(y) = dy/dt = y(1-y)(U_{21}-U_{22}) = -y*(y-1)*(C_3-C_2+R_2-R_3+F_2*z-S_4*x+S_5*x+T*z) \quad (8)$$

The government's expected return U_{31} from choosing a strict regulatory strategy, the expected return U_{32} from choosing a lax regulatory strategy, and the average return expectation U_3 are

$$U_{31} = x*y*(-C_4+R_4) + x*(1-y)*(-C_4+R_4) + (1-x)*y*(-C_4+R_4) + (1-x)*(1-y)*(-C_4+R_4) \quad (9)$$

$$U_{32} = x*y*(-C_5+A_1-B_1) + x*(1-y)*(-C_5-A_2-B_1) + (1-x)*y*(-C_5+A_1+B_2) + (1-x)*(1-y)*(-C_5-A_2+B_2) \quad (10)$$

$$U_3 = zU_{31} + (1-z)U_{32} \quad (11)$$

At this point, the replication dynamic equation for the government strategy choice is

$$F(z) = dz/dt = z(1-z)(U_{31}-U_{32}) = -z*(z-1)*(A_2-B_2-C_4+C_5+R_4-A_1*y+B_1*x-A_2*y+B_2*x) \quad (12)$$

3.1.2. Stability Analysis of the Equilibrium Point in the Three-Party Evolutionary Game

Based on the replicated dynamic equations for public, business, and government strategy choices, a Jacobi matrix of a three-party evolutionary game system was constructed as follows:

$$J = \begin{bmatrix} J_1 & J_2 & J_3 \\ J_4 & J_5 & J_6 \\ J_7 & J_8 & J_9 \end{bmatrix} = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix} = \begin{bmatrix} (2x-1)*(C_1-R_1-S_1+S_3+F_1*z+S_2*y-S_3*y) & x*(x-1)*(S_2-S_3) & x*(x-1)*(F_1) \\ -y*(y-1)*(-S_4+S_5) & -(2y-1)*\left(\begin{smallmatrix}C_3-C_2+R_2-R_3+F_2*z\\-S_4*x+S_5*x+T*z\end{smallmatrix}\right) & -y*(y-1)*(F_2+T) \\ -z*(z-1)*(B_1+B_2) & -z*(z-1)*(-A_1-A_2) & -(2z-1)*\left(\begin{smallmatrix}A_2-B_2-C_4+C_5\\+R_4-A_1*y+B_1*x\\-A_2*y+B_2*x\end{smallmatrix}\right) \end{bmatrix}$$

According to the equilibrium principle of replicating dynamic equations, the three-way evolutionary game between the public, firms, and government has an evolutionary stabilization strategy that serves as a pure Nash equilibrium strategy. This strategy includes

eight pure strategy equilibria: (0, 0, 0), (1, 0, 0), (0, 1, 0), (0, 0, 1), (1, 1, 0), (1, 0, 1), (1, 0, 1), (0, 1, 1), (0, 1, 1), and (1, 1, 1). These equilibria were obtained by setting $F(x) = 0$, $F(y) = 0$, and $F(z) = 0$. These eight pure strategy equilibria were substituted into the Jacobi matrix, and the eigenvalues of each equilibrium were determined. The equilibrium points of the three-party evolutionary game system and the eigenvalues of the Jacobi matrix are shown in Table 2.

Table 2. Equilibrium points of the tripartite evolutionary game system and eigenvalues of the Jacobi matrix (prepared by the authors).

Equilibrium Point	Characteristic Value		
	$\lambda1$	$\lambda2$	$\lambda3$
E_1 (0, 0, 0)	$R_1 - C_1 + S_1 - S_3$	$C_3 - C_2 + R_2 - R_3$	$A_2B_2 - C_4 + C_5 + R_4$
E_2 (1, 0, 0)	$R_1 - R_1 - S_1 + S_3$	$C_3 - C_2 + R_2 - R_3 - S_4 + S_5$	$A_2 + B_1 - C_4 + C_5 + R_4$
E_3 (0, 1, 0)	$R_1 - C_1 + S_1 - S_2$	$C_2 - C_3 - R_2 + R_3$	$C_5 - B_2 - C_4 - A_1 + R_4$
E_4 (0, 0, 1)	$R_1 - F_1 - C_1 + S_1 - S_3$	$C_3 - C_2 + F_2 + R_2 - R_3 + T$	$B_2 - A_2 + C_4 - C_5 - R_4$
E_5 (1, 1, 0)	$R_1 - R_1 - S_1 + S_2$	$C_2 - C_3 - R_2 + R_3 + S_4 - S_5$	$B_1 - A_1 - C_4 + C_5 + R_4$
E_6 (1, 0, 1)	$C_1 + F_1 - R_1 - S_1 + S_3$	$C_3 - C_2 + F_2 + R_2 - R_3 - S_4 + S_5 + T$	$C_4 - B_1 - A_2 - C_5 - R_4$
E_7 (0, 1, 1)	$R_1 - F_1 - C_1 + S_1 - S_2$	$C_2 - C_3 - F_2 - R_2 + R_3 - T$	$A_1 + B_2 + C_4 - C_5 - R_4$
E_8 (1, 1, 1)	$C_1 + F_1 - R_1 - S_1 + S_2$	$C_2 - C_3 - F_2 - R_2 + R_3 + S_4 - S_5 - T$	$A_1 - B_1 + C_4 - C_5 - R_4$

Notes: C_1 represents the costs incurred when the public participates in governance; C_2 represents the costs of positive governance by enterprises; C_3 represents the costs of negative governance by enterprises; C_4 represents the costs of strict regulation by local government; C_5 represents the costs of lax regulation by local government; S_1 represents the losses when the public does not participate in governance; S_2 represents the losses to the public when enterprises are actively governed; S_3 represents the losses to the public when enterprises are negatively governed; S_4 represents the profits lost when enterprises are actively governed; S_5 represents the losses suffered when enterprises are negatively governed; R_1 represents the benefits received when the public participates in governance; R_2 represents the benefits of active governance by enterprises; R_3 represents the profits of negative governance by enterprises; R_4 represents the benefits of strict regulation by local governments; A_1 represents the social benefits that local governments receive when they are loosely regulated and when enterprises are positively governed; A_2 represents the penalties incurred by local governments when they are lax in regulation and are negatively governed by enterprises; B_1 represents the penalties incurred by local governments when they are laxly regulated and the public is participative in governance; B_2 represents the social benefits received by local governments when they are lax in regulation and the public is not participative in governance; F_1 represents the additional cost of public participation in governance when local governments strictly regulate; F_2 represents the penalties for negative enterprise governance when local governments strictly regulate; T represents the subsidy received by enterprises for active governance when local governments strictly regulate.

According to the eigenvalue analysis of the Jacobi matrix, if all eigenvalues in the Jacobi matrix are less than zero, the equilibrium is the stable point of the evolutionary game system. On the basis of the eight equilibrium points indicated above, this study showed that there are six stable points: (1, 0, 0), (0, 1, 0), (0, 0, 1), (1, 0, 1), (0, 1, 1), and (1, 1, 1). This study explored the behavioral–strategic relationships between the subjects of the ecological and environmental governance evolution game in the Yangtze River Delta region under different stability scenarios based on the stability point.

Situation 1: E_2 (1, 0, 0) indicates (public participation, negative enterprise governance, and lax local government regulation). Awareness of public participation has increased, but public participation strategies have not led to changes in the strategic choices of other interest groups. Enterprises need to consider the loss of reputation due to public reporting. In the long-term evolutionary process, enterprises may initially choose a positive governance strategy, but when they find that the local government is lax in regulation, even if they are fined by the local government due to public reporting, enterprises may choose a negative governance strategy driven by profit maximization. Local governments need to consider penalties for public participation and reputational damage when choosing a lax regulatory strategy. However, benefits to local governments are still less than the costs of regulation in the case of public participation, and the relative net benefits are still less than zero in the case of strict regulation, which makes a lax regulatory strategy the optimal choice for local governments.

Situation 2: E_3 (0, 1, 0) indicates (public nonparticipation, active enterprise governance, and lax local government regulation). The public chose the nonparticipation strategy based on the active governance behavior of the enterprise and an awareness that the public would not gain anything even if they reported this behavior. The benefits gained by enterprises through green production and legal emissions outweigh the negative governance costs. The local government will increase the intensity of regulation considering the costs incurred by firms in active governance. However, finding that the relative net benefit is still less than zero when strict regulation is applied, the local government will choose to reduce the intensity of regulation, favoring a lax regulatory strategy.

Situation 3: E_4 (0, 0, 1) indicates (public nonparticipation, negative enterprise governance, and strict local government regulation). Local governments choose strict regulatory strategies when the relative net benefit of regulation is greater than zero. The benefit to the public from reporting negative enterprise governance behaviors increases, but the relative net benefit remains less than zero, and the public is biased toward a nonparticipation strategy. The subsidies and penalties received by enterprises will increase; however, the cost of active treatment may be high or the cost of illegal discharge may be low, for example, and enterprises will still choose a negative treatment strategy.

Situation 4: E_6 (1, 0, 1) indicates (public participation, passive enterprise governance, and strict local government regulations). In contrast to Situation 3, the public chooses to participate in ecological governance resulting in a relative net benefit greater than zero. With public reporting, firms need to consider losses such as public compensation and corporate image. Even after deducting losses from local government fines and public reporting, the relative net benefit when an enterprise governs negatively is still greater than zero and enterprises will still choose a negative governance strategy. Local governments need to consider the rewards for public reporting, as well as penalties associated with lax regulation, and will opt for a strict regulatory strategy if lax regulation results in significant losses.

Situation 5: E_7 (0, 1, 1) indicates (public nonparticipation, active enterprise governance, and strict local government regulation). The public choose not to participate in the strategy because positive corporate governance behavior does not negatively affect their living environment, and there is no gain from reporting it. Over the long term, enterprises may initially choose a negative governance strategy, but as local governments become more stringent in their regulations, enterprises will pay more fines while continuing to govern negatively and then receive more subsidies if they govern positively. Therefore, in the long term, enterprises gradually opt for an active governance strategy. A strict regulatory strategy is optimal for local governments considering both economic and social gains.

Situation 6: E_8 (1, 1, 1) indicates (public participation, active enterprise governance, and strict local government regulations). As the probability of enterprises choosing to govern actively and local governments choosing to regulate rigorously increases, the public's living environment improves and trust in enterprises and local governments deepens. By choosing an active governance strategy, enterprises can increase their production capacity through local government subsidies and technological upgrades, improve their image and visibility, and achieve high-quality development. Strict regulatory activities by local governments tend to normalize, regulatory systems tend to improve, regulatory costs are gradually reduced, and rewards and penalties for enterprises and the public gradually weaken. Ultimately, the regional environmental governance achieves a benign interactive situation of public participation, active enterprise governance, and strict supervision by local governments.

3.2. Simulation Analysis of the Three-Party Evolutionary Game

In the ecological and environmental governance of the Yangtze River Delta region, the strategic behavioral choices of the public, enterprises, and local governments are mutually influenced. To better visualize the progression of interactions in the tripartite game, and

to examine influential factors pertaining to stakeholders' behavioral strategies, MATLAB R2023a software was employed to conduct numerical simulations.

Combined with the actual situation of ecological environment governance in the Yangtze River Delta region and expert discussions, this study set the initial probability of the subject's willingness to 0.5 uniformly, and the relevant parameters were assigned as follows: $C_1 = 2$, $R_1 = 5$, $S_1 = 3$, $F_1 = 5$, $S_2 = 2$, $S_3 = 1$, $C_2 = 3$, $R_2 = 3$, $T = 2$, $C_3 = 2$, $R_3 = 2$, $F_2 = 4$, $S_4 = 1$, $S_5 = 1$, $C_4 = 1$, $R_4 = 4$, $C_5 = 4$, $A_1 = 3$, $A_2 = 1$, $B_1 = 4$, and $B_2 = 2$. The specific data do not represent the actual time or amount of money but indicate the relative size of each parameter, which helps to show the dynamic game evolution process more objectively and clearly.

3.2.1. Initial Setup for Simulation of Evolutionary Game Systems

The vertical axis represents the behavioral strategy probability p of the three parties' subjects of interest, the horizontal axis represents the evolution speed of the behavioral strategy probability of each subject of interest, and the entire three-party evolution game process is viewed as a change in time t. The initial state simulation results for the three-party evolutionary game system are shown in Figure 3, which verifies that under the conditions of $R_1 - F_1 - C_1 + S_1 - S_2 < 0$, $C_2 - C_3 - F_2 - R_2 + R_3 - T < 0$, $A_1 + B_2 + C_4 - C_5 - R_4 < 0$. In it, x tends to be 0, y tends to be 1, and z tends to be 1. Finally, the ecological environmental governance of the Yangtze River Delta Region has reached a stable state in which the public is not involved, enterprises are actively governed, and local governments are strictly supervised, i.e., the three-party evolutionary game system stabilizes at the equilibrium point (0, 1, 1).
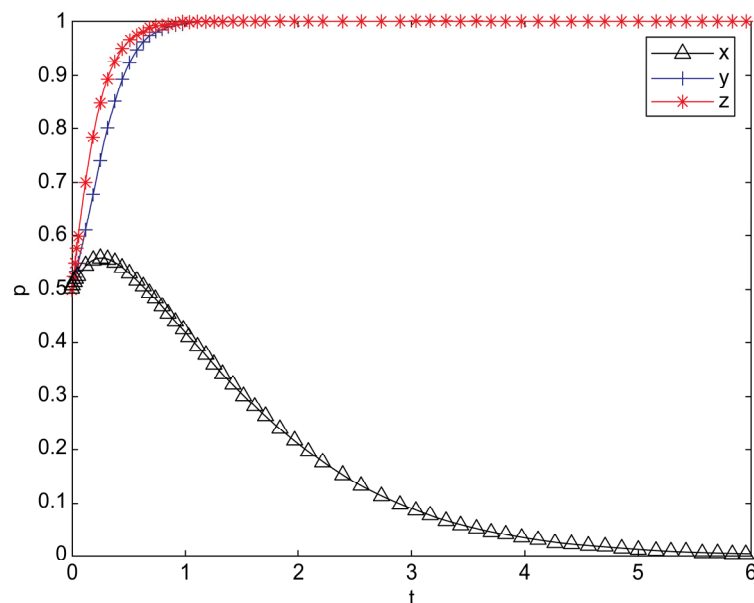

Figure 3. Simulation of the initial three-party evolutionary game strategy (prepared by the authors).

3.2.2. Effect of Public Parameters on the Stability of Evolutionary Game Systems

In the above evolutionary game system, the initial state of the evolutionary game is maintained at (0.5, 0.5, 0.5). The effect of the additional cost F_1 paid by the public to participate in ecological environment governance on the stability of the evolutionary game system was examined.

Figure 4 shows the simulation results when $F_1 = 3$ or 5 and the other parameters remain unchanged. Comparing these results with those shown in Figure 3, the context of strict regulation by the local government and the extra cost paid by the public to participate in ecological environmental governance not only affects trends in the public's strategy evolution but also affects trends in the strategy evolution of enterprises and local

government. When the additional cost of public participation in ecological environmental governance ($F_1 = 3$) is low, the public tends to participate in the strategy, enterprises actively manage, and the local government strictly regulates. When the extra costs paid by the public to participate in ecological governance ($F_1 = 5$) are high, compared to $F_1 = 3$, the change in the public's strategy from participation to nonparticipation is high, probably due to the extra costs paid by the public, which are higher than the benefits gained under the nonparticipation strategy. The public will actively participate in ecological governance in the early stages; however, after the trade-offs emerge, they will no longer participate in ecological governance.
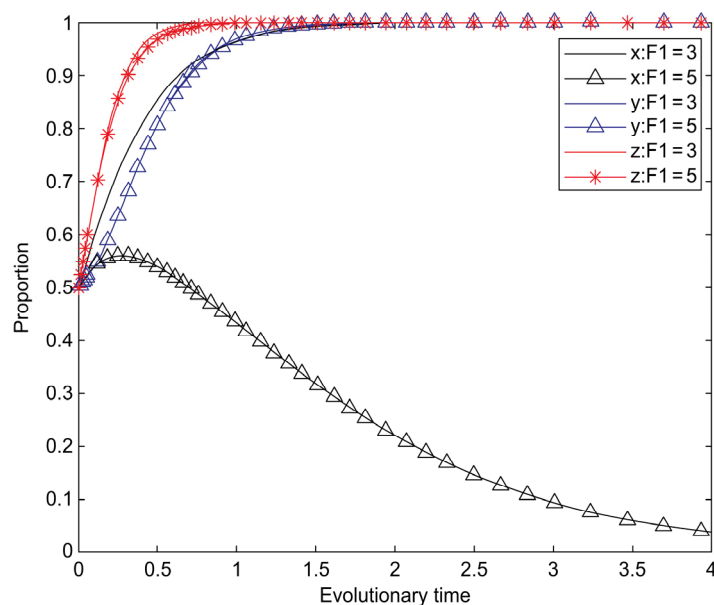

Figure 4. Effect of F_1 on the evolution of the system (prepared by the authors).

Local governments may experience a short-term delay in implementing a strict supervision strategy. This delay can be due to shift from a participation to a nonparticipation strategy by the public. The local government may perceive that the enterprises have achieved good results in ecological governance and therefore face less pressure from the public (i.e., opinions and complaints). Consequently, there would be a slight lag in supervising enterprises during the period. However, if the local government determines that the enterprise's ecological governance does not meet expectations, it will increase supervision and ultimately resort to strict measures. Although the enterprise operates under strict government supervision, the costs and benefits will remain unchanged. The enterprise would be committed to upholding environmental management standards with no significant alteration of its strategy from the initial state. Therefore, in the context of strict local government regulations, enterprises are compelled to implement active governance strategies regardless of whether the public opts to participate actively in the strategy. The above indicates that local governments play a crucial role in ecological governance.

3.2.3. Effect of Enterprise Parameters on the Stability of Evolutionary Game Systems

This section focuses on the impact of the benefit R_2 and local government subsidy T on the stability of the evolutionary game system when enterprises actively manage the ecological environment. For comparison, the initial state of the evolutionary game is maintained at (0.5, 0.5, 0.5).

Figure 5 shows the simulation results when $R_2 = 3$ or 5 and the other parameters remain unchanged. The level of benefits obtained from the enterprise's active governance strategy affects the enterprise's strategy evolution, as well as the strategy evolution of other stakeholders. As the benefits gained from enterprises' active governance strategies increase,

the probability of enterprises engaging in active governance increases significantly, thus stabilizing active governance as a strategy for longer periods. The enterprise selects a favorable governance strategy to improve its benefits, which stimulates its participation in ecological governance. Consequently, the enterprise increases its ecological governance efforts, upgrades and reforms its equipment, and expands its production scale to achieve a beneficial system. This ultimately leads to enterprise development becoming increasingly positive. The public's participation in ecological governance efforts can lead to improving the quality of the living environment. However, some may choose not to participate due to their confidence in the local government and corporate ecological governance. It is vital to maintain a harmonious coexistence between man and nature. The local government has not increased its investment in ecological governance during the period, which implies that it is the initial stage of governance strategies in which a favorable social environment for businesses and the public is provided. The simulation results demonstrate that the objective of ecological governance is to attain high-quality development for enterprises. Only when enterprises achieve the objectives of low pollution, high output, and high income can they realize a favorable status of synergistic development among local government, the public, and enterprises. This will lay a solid foundation for the achievement of the dual-carbon goal.
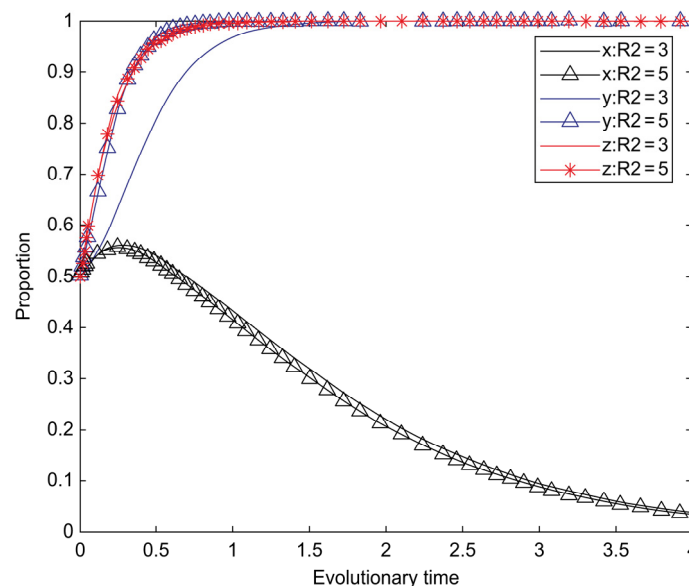

Figure 5. Effect of R_2 on system evolution (prepared by the authors).

Figure 6 shows the simulation results when T = 3 or 5 and the other parameters remain unchanged. In the context of strict local government regulations, changes in local government subsidies received through enterprises' active governance strategies have different impacts on the strategic evolution of stakeholders. When local governments increasingly provide subsidies to enterprises, those utilizing government subsidies can invest in ecological governance, equipment upgrading and transformation, and production expansion. Such activities can lead to a conscious increase in their own supervision and management, ensuring that enterprises actively adopt the strategy over the long term. Compared to the initial state, the local government's strategy has been slow in terms of progress. This is due to the increased costs of ecological governance imposed on enterprises. Consequently, enterprises have been investing more funds in ecological governance, leading to a short period of regulatory laxity. During this period, the public still actively participates in ecological governance. Therefore, the local government continues to increase its supervision of ecological governance, including over enterprises. Under strict regulation by local governments and active governance by enterprises, the public living environment tends to improve, which increases public trust in local governments and enterprises and encourages a nonparticipation strategy among the public. Some enterprises may divert

the government's ecological governance subsidies to other uses instead of using them for the intended purpose, which is tantamount to a waste of government resources. It is critical for the local government to monitor the use of such subsidies to ensure they are being used for ecological governance as intended. Therefore, local governments should focus on strengthening the supervision and assessment of enterprises. They should establish comprehensive mechanisms for subsidy fund supervision and ecological governance assessment and implement full-cycle supervision of fund use and ecological governance.
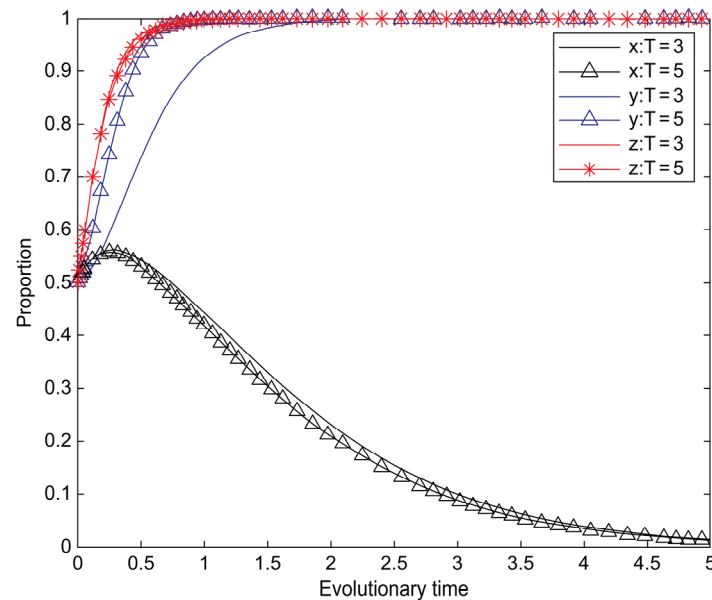

Figure 6. Effect of T on system evolution (prepared by the authors).

3.2.4. Effect of Local Government Parameters on the Stability of Evolutionary Game Systems

This section focuses on the impact of the cost C_5 paid by local governments and penalty B_1 imposed on local governments when the public chooses a participation strategy based on the stability of the evolutionary game system when local governments are loosely regulated. For comparison, the initial state of the evolutionary game was assumed to be (0.5, 0.5, 0.5).

Figure 7 shows the simulation results when $C_5 = 1$ or 5 and the other parameters remain unchanged. The local government's cost of lax regulation influences the evolution of strategies employed by the three parties of interest. In the early stage of system evolution, the public chooses to be involved in environmental governance, as the local government tends to favor a lax regulatory strategy and enterprises tend to favor a negative governance strategy so that the public's living environment cannot be safeguarded. However, in the late stage of system evolution, the public's living environment is continuously optimized under the dual governance of local governments and enterprises, the public's trust in local governments and enterprises is further enhanced, and the public then chooses not to participate in ecological and environmental governance. Local governments that initially implement lax regulatory strategies tend to choose negative governance strategies. However, when the local government implements a strict regulatory strategy, firms shift to an active governance strategy, and the stable time for firms to choose an active governance strategy increases as the local government's strict regulations increase. Local governments will favor strict regulatory strategies as their ecological and environmental governance costs continue to increase. The stabilization time for local governments choosing a strict regulatory strategy at $C_5 = 5$ was much greater than that for local governments choosing a strict regulatory strategy at $C_5 = 1$. The simulation results demonstrate that a good ecological environment is essential for high-quality development. It is vital to maintain a

balance between economic growth and environmental protection. Pursuing economic development without strict ecological governance may yield short-term economic benefits for local governments; however, it is not sustainable over the long term. However, ecological destruction can lead to a significant increase in the governance cost for local governments. Additionally, polluted areas are unable to produce economic benefits, which can result in the departure of enterprises and personnel, leading to even greater losses. Therefore, it is critical to consider the long-term consequences of environmental damage. The local government's strategy is crucial for ecological governance and significantly impacts the strategic decisions of the public and enterprises.
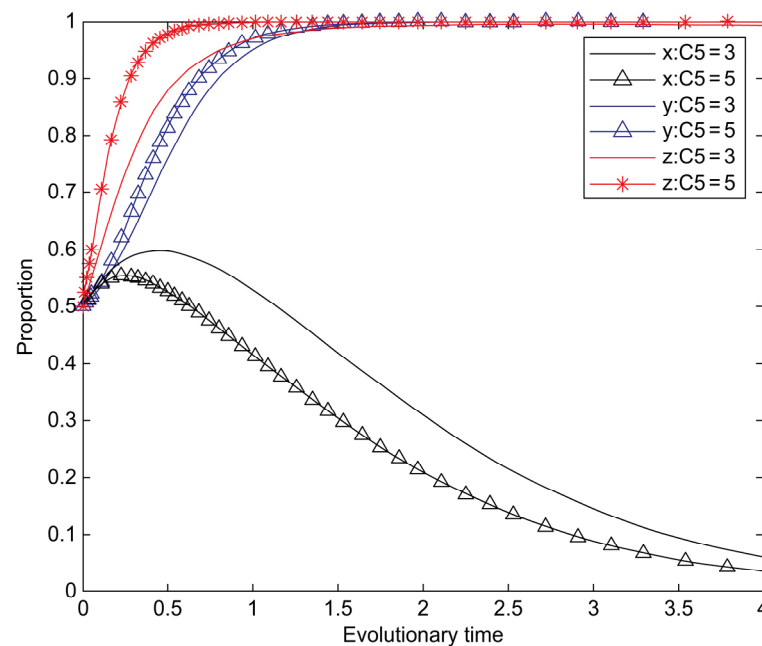

Figure 7. Effect of C_5 on system evolution (prepared by the authors).

Figure 8 shows the simulation results when $B_1 = 1$ or 6 and other parameters remain unchanged. Changes in penalties imposed on local governments affect the system's evolutionary trend, particularly when the public chooses a participation strategy in the context of lax local government regulations. Enterprises do not invest adequately in ecological governance under loose government supervision, resulting in the deterioration of the social and ecological environment. To foster a healthy living environment, the public must participate actively in ecological governance. However, this may have negative consequences for the local government, such as receiving complaints, letters, and public criticism, as well as facing increasing penalties from higher supervisory units. In such a context, local governments will implement stricter regulatory strategies for enterprises, resulting in a rapid increase in government regulation, as shown in Figure 8. Government policies can influence enterprises; however, enterprises could also adopt a more positive attitude toward participation in ecological governance. Notably, the public's focus on the social and ecological environment improves, leading to greater effectiveness in the governance of enterprises and local government. This increases regional satisfaction, and the public's choice of the nonparticipation strategy changes markedly. For the public, the living environment will be effectively improved, the intensity of public complaints and reports will be lower at $B_1 = 6$ than at $B_1 = 1$, and the public will eventually choose not to participate in ecological and environmental governance. The simulation results above demonstrate that lax regulation by local governments has a negative impact on ecological governance, resulting in unfavorable socioeconomic development. Therefore, it is crucial for local governments to maintain strict supervision of ecological governance, avoiding any

laxity and adhering strictly to ecological governance regulations to foster a green ecological environment and support socioeconomic development.
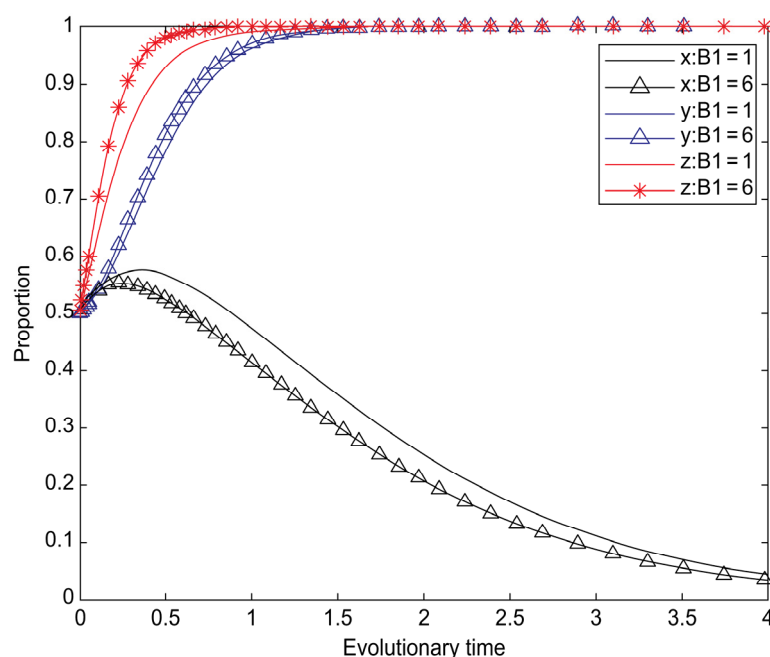

Figure 8. Effect of B_1 on system evolution (prepared by the authors).

4. Discussion

This paper presents a tripartite evolutionary game model of ecological governance in the Yangtze River Delta region. Behavioral strategies and underlying factors were analyzed and are discussed separately below.

(1) Regarding the evolutionary game of ecological governance in the Yangtze River Delta region, studies have been limited to the game between the central government and local governments or between the governments of the three provinces and one city [6,18–24]. Jiang et al. developed a central government–local government evolutionary game model to study the collaborative ecological spatial governance of lakes in the Yangtze River Delta across provincial boundaries [20]. Bo et al. analyzed and explored haze governance behavior in the Yangtze River Delta region [24]. Based on stakeholder theory and evolutionary game theory, this paper presents a tripartite evolutionary game model of public–enterprise–local government from the perspective of multiple stakeholders. The model analyzes the evolutionary game strategy of ecological governance in the Yangtze River Delta region and draws two new conclusions about ecological governance.

Firstly, ecological environment governance in the Yangtze River Delta region is a self-organized process of mutual games among multiple interest groups. This is consistent with the research conclusions of Jiang et al. and Bo et al. [20,24]. The present study further elucidated that the behavioral strategies of participating subjects cannot be analyzed in isolation in ecological governance, which is contrary to the concept of ecological governance. Because ecological governance is a systematic project, one-sided analysis of the game strategy between governments has certain limitations. The behavioral strategy of enterprises and the public also affects the choice of behavioral strategy of a local government. Therefore, in the practice of ecological governance in the Yangtze River Delta region, a closed-loop mechanism should be established for the whole chain and process; additionally, enterprises, the public, and local governments should take responsibility for the corresponding processes and nodes of ecological governance to establish a model area for the collaborative ecological governance in the Yangtze River Delta.

Secondly, local governments provide subsidies to encourage enterprises to engage in active governance, which has positive impacts on their governance strategy. Although

the public participates in ecological governance, local governments are penalized for negative public opinion, which encourages the government to adopt a strategy of strict regulation. Fu et al. used quantitative analysis to analyze the data of the main governance indicators of Hangzhou–Shaoxing–Ningbo and another three cities and concluded that there were differences in the regional ecological governance strategies [6]. However, they only analyzed the geographical differences in the governance results of Hangzhou–Shaoxing–Ningbo and another three cities and could not analyze the behavioral strategies of the participating subjects in depth. Therefore, the net increase in profitability for each stakeholder involved in the ecological governance of the Yangtze River Delta region must exceed the cost of implementation for the collaborative ecological governance mechanism to be sustainable and stable.

(2) The study's conclusions on behavioral strategies for ecological governance and their influencing factors in the Yangtze River Delta region align with the findings of Zhao et al. and Cao et al. regarding the variability in the selection of ecological governance strategies by multiple subjects [38,40]. However, the causes of this variability were analyzed from different perspectives, complementing and improving the understanding of the influencing factors. Zhao et al. highlighted variability in the enforcement of government environmental regulations [38]. They also noted that the costs and revenues of enterprises, as well as the costs and public psychology, are key factors influencing eco-governance. Cao et al. noted differences in enterprises' behaviors toward green technological innovation and listed several underlying factors, such as pollution tax and incentive compensation [40].

Researchers have typically examined the variations in ecological governance strategies and their influencing factors from various perspectives, including environmental regulation and green technological innovation [30–32,38–40]. In contrast, the present study focuses on the mechanisms of the whole ecological governance process in the Yangtze River Delta region and considers the public, enterprises, and local governments as game analysis subjects using model simulation. The simulation revealed that the key factors influencing behavioral strategies in the ecological governance of the Yangtze River Delta region are the additional costs paid by the public to participate in ecological governance, the benefits and subsidies received by enterprises when they actively govern the ecological environment, and the costs and penalties paid by local governments when they loosely regulate the ecological environment. Therefore, the establishment of a synergistic governance mechanism of "government–enterprise co-construction of liquid regulatory funds, government–enterprise–public partnerships in low-cost regulatory models, and the sharing of high-quality regulatory outcomes" is proposed as a strategy of motivating and encouraging relevant stakeholders to participate in ecological governance.

5. Conclusions

5.1. Findings

Further research on the behavioral strategies of multi-interested subjects and the mechanisms underlying influencing factors is needed to build a collaborative ecological and environmental governance model in the Yangtze River Delta region. This study applied stakeholder theory to include the public, enterprises, and local governments as interested parties in the collaborative environmental governance mechanism. Through evolutionary game modeling and simulation analysis, this study also explored the behavioral effects and influencing factors of different subjects in environmental governance; simulated the evolutionary trajectories of strategies employed by the three parties under scenarios with governance costs, governance subsidies, and regulatory costs; and analyzed the effectiveness of different policies and measures in promoting the high-quality operation of the collaborative governance of the Yangtze River Delta region. The results of this study enrich the body of theoretical research on the evolutionary game of ecological and environmental governance in the Yangtze River Delta region. The following main conclusions can be drawn from the results of this study:

(1)   The ecological governance of the Yangtze River Delta region is a dynamic evolutionary game system involving multiple stakeholders, and the behavioral strategies of each stakeholder will affect the stability of the system. As shown in Figure 2, during the initial phase of system development, local governments continue to strengthen their supervision to encourage enterprises to actively participate in ecological environmental management, and the public will actively participate in ecological environmental management through complaints and reports. The likelihood of enterprises activating their governance strategy increases rapidly at this point. In the final stage of system evolution, local governments and enterprises deliberately implement active governance and strict supervision strategies. Due to reduced publicity and investment in ecological environmental governance by local governments, enthusiasm for public participation decreases. Consequently, local governments transfer some of the regulatory costs to the public, along with incentives or subsidies for enterprises, to encourage public engagement in ecological environment governance. This leads to the stabilization of the three-party game system at the equilibrium point (0, 1, 1).

(2)   In the ecological governance of the Yangtze River Delta region, the behavioral strategies of each participant impact the stability of the system, meaning that the strategic choices of one party are influenced by and have a reciprocal effect on the other two parties. Based on the simulation results, under the background of strict regulation by local governments, enterprises are forced to implement active governance strategies regardless of whether the public chooses active participation strategies or not. Local governments pursue economic development without strict regulation of environmental governance, which can achieve certain economic benefits in the short term. However, if the environment is damaged, the environmental management costs paid by the local government increase dramatically, resulting in greater losses. Therefore, the strategic choices of local governments play important roles in the ecological governance of the Yangtze River Delta region and closely influence the strategic choices of the public and enterprises.

(3)   The costs and benefits of participating in ecological and environmental governance in the Yangtze River Delta region are the primary factors influencing the behavioral strategies of multiple stakeholders. Specifically, as the cost of public participation in ecological environmental governance increases, the public becomes more inclined towards nonparticipation, enterprises tend to support active governance, and local governments tend to favor strict regulations. The three-party evolutionary game system tends to be stable, and, for enterprises, the increased benefits and subsidies they receive when they actively manage the ecosystem can accelerate the tripartite evolutionary game system to a stable state. For local governments, the cost of lax regulations is a major factor influencing their strategic choices. Additionally, the size of the penalties imposed on local governments plays a crucial role in enterprise decisions.

(4)   The ecological governance of the Yangtze River Delta region is a systematic and open project. Adhering to the problem-oriented approach, universal linkage, comprehensive system, development, and change perspectives should be applied to analyze the subjects participating in collaborative ecological governance and their behavioral strategies to maximize the interests of all subjects. In addition, adhering to the system concept, the participating subjects should have clear subject responsibilities and obligations. Based on a people-first principle and considering that the ecological environment is linked the national economy and people's livelihoods, all participating subjects should adhere to the "green mountain is the golden silver mountain" concept, innovate, and work collaboratively to establish a demonstration zone for coordinated ecological governance in the Yangtze River Delta, which could facilitate high-quality economic and social development.

5.2. Recommendations

Based on the analysis of the three-party evolutionary game model and conclusions drawn from previous research, this study proposes the following actions.

(1) Government–enterprise co-development of liquidity supervision funds: The local governments of the three provinces and one city should collaboratively establish a capital supervision pool based on a certain proportion of revenue. Regulatory funds can provide subsidies to the relevant stakeholders when they actively participate in ecological and environmental governance and achieve success. In contrast, the subject of negative ecological environmental governance will be punished, the amount of the punishment will be paid to the regulatory pool, and all information on the flow of funds, rewards, and punishments will be open and transparent.

(2) A low-cost regulatory model in which the government, enterprises, and the public work synergistically. Using a big data information platform, the Yangtze River Delta region has implemented a one-click disclosure of ecological and environmental pollution sources. The local government carries out follow-up verification to determine the real source of pollution, penalizes the relevant interested parties, and establishes a sound mechanism for penalties and rectification, while the government, enterprises, and the private sector are monitored in real time by the tripartite body.

(3) The government, enterprises, and the public share the results of high-quality regulation. With regard to the additional benefits gained from regional ecological and environmental governance, the benefits will be shared by all of the people, enhancing the living conditions for residents, the operational environment for enterprises, and the regulatory circumstances for the government to encourage sustainable development of the ecological environment in the Yangtze River Delta region.

5.3. Limitations and Reflections

(1) Existing studies have only examined the ecological environment of the Yangtze River Delta region as a whole. Future investigations should focus on transboundary water and atmospheric pollution in this area for more specific information and analyses. Using the Yangtze River Delta region as a case study for water pollution governance, future research can be based on evolutionary game theory, with the aims of establishing a government–enterprise–public ecological governance evolutionary game model, exploring the behavioral strategies and the underlying factors for collaborative water pollution management in the Yangtze River Delta region and analysis of the pollution management effects of collaborative water pollution management mechanisms in the Yangtze River Delta region.

(2) The results of the simulation analysis of the tripartite evolutionary game model in this paper are based on the overview of the actual situation of ecological environmental governance in the Yangtze River Delta region, on the basis of which the relevant variables are derived in an ideal situation. Follow-up research can reinforce the cooperation among the public, enterprises, and the government and evaluate the cost of synergistic governance and synergistic governance effect of multi-interested parties to further explore the research questions put forth in this paper.

(3) This study focused on building a scientifically tested dynamic reward and punishment model. Local governments can increase regulatory efforts, penalties for negative corporate governance, and public incentives to report complaints. However, from the perspective of sustainable development, local governments must avoid providing excessive subsidies or incentives to enterprises or the public. Alternatively, they can employ methods such as policy encouragement and technical assistance to encourage eco-friendly practices among both businesses and the public.

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