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"Zero-sum game" or "win-win cooperation": an analysis of the evolution effect of competition neutrality based on the participation of four parties

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To effectively grasp the interactive evolution mechanism of relevant entities in the process of competitive neutrality and reveal the impact of the implementation effect of the principle of competitive neutrality on the evolution path of the game system is the key to guiding the development of the government, industry associations and enterprises with reasonable policies. The equilibrium point of the game is analyzed by the four-party evolutionary game model, and the influence of the change of relevant parameters on the evolution result of the game system is further simulated by numerical simulation. The results show that the central government supervision plays an important role in guiding the strategy selection of different game players. By raising the penalty standards for non-neutral competitive behavior of market players and increasing the non-neutral penalty for local governments, the system can evolve faster to the ideal state of "loose supervision by the central government, neutral implementation by local governments, strong supervision by industry associations, and active cooperation by enterprises." Therefore, to improve the execution effect of competitive neutrality, the central government shall formulate a reasonable regulatory system, and to maximize inspire the enthusiasm of local government, industry associations and enterprises, to promote stability in the sustainable development of the market.

KEYWORDS

competitive neutrality, four-party game, numerical simulation, evolutionary game, simulation analysis

1 Introduction

The Report of the 20th National Congress of the Communist Party of China stressed that China should promote high-level opening-up and steadily expand the opening-up of rules, regulations, management and standards. Competitive neutrality as a regulation principle, policy orientation, order state or related institutional arrangement. Adhering to the principle of competitive neutrality is an important way to protect the equality of property rights and legitimate interests of various forms of ownership. However, in recent years, the participation of industry associations has gradually increased. For example: In 2021, the Health Bureau of a certain county in Hunan reached an agreement with Sinopharm Holding Company to issue mandatory targets for drug procurement by

county public medical institutions, severely restricting fair competition in the drug market. Afterwards, the Medical Association specially organized personnel to actively publicize the Anti-Monopoly Law, the Implementation Rules of the Fair Competition Review System and other legal and policy provisions to the public to maintain a fair market environment. The relevant subjects of my country's competitive neutrality principle are expanding from the traditional three parties to four parties. This article establishes a four-party competitive neutral dynamic game model of the central government-local government-industry associations-enterprises to explore the interactive relationship between the various subjects in the system, which is of great significance for promoting the coordination of the interests of all parties and improving the implementation effect of the principle of competitive neutrality.

In recent years, domestic and foreign scholars have conducted a large number of in-depth studies on the connotation and logical construction of competitive neutrality, which mainly involve four aspects: First, the universal practical research on competitive neutrality, which mainly explores the general rules of a country's practice of competitive neutrality [1–4]. and practices [5–7]. The second is research on the application of competitive neutrality in specific countries, such as developing countries [8], Australia [9], India [10], China [1, 7, 11], etc. The third is research on the application of competitive neutrality in specific industries and fields, such as banking and securities industries [12], telecommunications networks [13–15], and public-private cooperation fields [16–18], domestic scholars have paid a lot of attention to the application of competitive neutrality in the reform of state-owned enterprises ([19]; Smith et.al., 2023). The fourth is the research on the application of competitive neutrality in international economic and trade rules, which mainly introduces the competitive neutrality rules in relevant economic and trade agreements and studies how China responds [20–22]. In addition, domestic and foreign scholars have conducted a large number of in-depth studies on the implementation process of the principle of competitive neutrality based on game theory (Wang and Liu [23–25]). First, regarding the game between the government and enterprises [26], established a complete information dynamic model of local governments and tobacco enterprises to study the impact on the development of the local tobacco industry under the conditions of local government's protective taxation [27]. Constructed a "dual capability" game model of the competitiveness of large enterprises and found that government regulation and rent-seeking exist in society, and enterprises will allocate certain resources to obtain government support. Shi [28] constructed a two-level supply chain for game analysis and found that the government cannot effectively supervise the final product and downstream enterprises. The second is about the game between the central and local governments. Wang et al. [29] believe that the positive and negative external effects generated by competition between neighboring local governments are more sensitive, and both the central government and local governments are highly sensitive to the intensity of punishment. The third is about the game between local government, central government and enterprises [30]. found that by adjusting relevant parameters, enterprises can escape from a bad state and evolve into a good state. Wang and Liu [23] found that increasing the severity of penalties imposed by the central government on local governments can increase the enthusiasm of enterprises.

By reviewing previous research findings, it can be observed that many scholars have conducted in-depth studies on the interactive relationships among the participants involved in the implementation of the competition neutrality principle, as well as the influencing factors. The research focus has predominantly centered on the two-party or three-party game between the central and local governments, industry associations, and enterprises. However, the reality of competition neutrality involves a complex system of interactions among multiple entities. Solely investigating the two-party or three-party game relationships may lead to incomplete research results. In light of this, placing the central government, local government, industry associations, and enterprises simultaneously within a unified framework can compensate for the shortcomings of previous research and comprehensively analyze the dynamic evolution process of different participants' strategic choices during the implementation of competition neutrality.

This paper constructs a four-party evolutionary game model of central government-local government-industry association and enterprise under the evolution effect of competitive neutrality, analyzes the evolutionary stable strategies under different circumstances, and uses numerical simulation to simulate the influence of the change of each parameter on the game system, so as to provide theoretical basis and policy reference for our country to improve the implementation effect of the competitive neutrality principle.

2 Construction of the four-party evolutionary game model: central government—local government—industry association—enterprise

2.1 Problem description and basic model assumptions

Under the background of China's high-level opening up, the introduction of the competition neutrality principle by the government will exert a positive coercive effect, facilitating the better achievement of economic development goals. The central government, by formulating competition neutrality policies, mandates subordinate governments to implement measures to improve the local business environment. Due to the limited regulatory capacity of the central government, it is possible for local governments to vigorously support state-owned enterprises and restrain other ownership enterprises to seek private interests, leading to the potential loss of a fair competitive market environment.

Driven by the goal of maximizing profits, enterprises may choose to passively cooperate with the implementation of policies. Simultaneously, industry associations, as a service platform to communicate the relationship between government and enterprises, will spontaneously supervise local governments' non-neutral treatment of all enterprises, thus influencing the utility

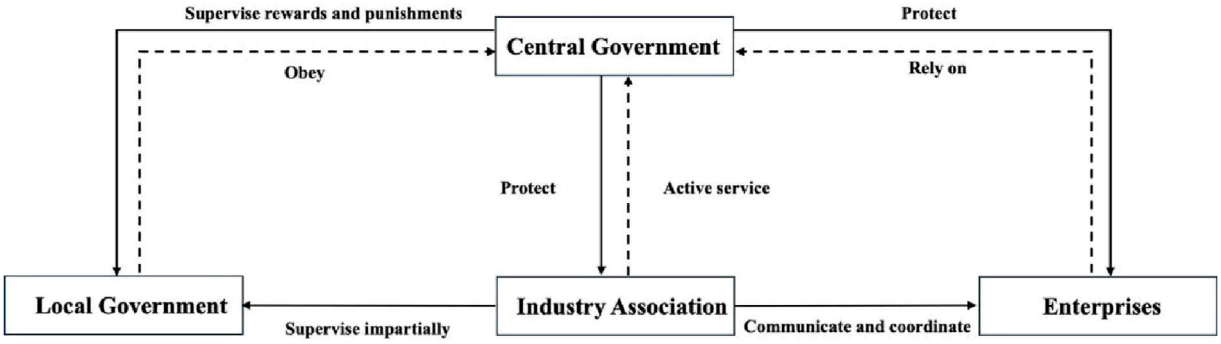

FIGURE 1
Logic relationships of multi-participant competition neutrality effect game model.

levels of both central and local governments and the profits of all enterprises. To address this issue, this study constructs a four-party game model of competition neutrality effects with government participation, and the logical relationship among the game participations is depicted in Figure 1.

To construct a game model to build a game model among stakeholders based on the principle of competition neutrality, the central government, local governments, industry associations and enterprises interact and influence each other, the following basic assumptions are proposed following the aforementioned context.

Assumption 1: Selecting the central government, local government, industry associations, and enterprises as the game players. The probability of strong supervision by the central government is x, and the probability of weak supervision is 1-x; The probability of local government treating enterprises neutrally is y, and the probability of non-neutral treatment is 1-y; The probability of industry association actively supervising the behavior of government and enterprises is z, and the probability of passively supervising the behavior of government and enterprises is 1-z; The probability of enterprises actively cooperating with the government is m, and the probability of passively cooperating with the government is 1-m; x, y, z, m$\in$[0,1]. Expanding to the entire societal group, each probability can be interpreted as the proportion of the entire group of game participants selecting a certain strategy. All four entities are risk-neutral, to maximize their interests.

Assumption 2: Local governments choose to adopt the principle of competition neutrality, and fair treatment of all enterprises will bring them benefits Q. Adopting neutrality towards all enterprises requires more personnel and time, resulting in execution costs of C_1, while adopting non-neutrality towards all enterprises results in execution costs of C_2; Since the supervision of industry associations is closely related to government-enterprise relations when local governments issue relevant policy documents, the industry associations actively communicate to bring benefits, which are denoted as T. The cost of active supervision is C_3, and the cost of passive supervision is C_4. The supervisory effectiveness of industry associations indirectly affects the decision-making behavior of enterprises. Some enterprises, upon seeing industry association supervision, are willing to spend more effort to actively cooperate, incurring additional costs of C_5; After the central government issues policy guidance documents, the cost of strict supervision is C_6, while the cost of lenient supervision is C_7.

Assumption 3: The local government actively adhering to the competition neutrality principle convey a signal of fair treatment to all enterprises, making enterprises willing to cooperate and winning the trust for the central government. The positive effects brought to enterprises and the central government are B_1 and B_2 respectively. The local government treat all enterprises in a non-neutral way and falsely cooperate with the policies of the central government, which brings negative effects to enterprises and the central government, denoted as N_1 and N_2 respectively.

Assumption 4: If the central government supervises local governments before they treat all enterprises in a non-neutral way, stops all unfair behaviors in time, and punishes local governments and relevant trade associations, assuming that the penalties imposed by the central government on local governments and trade associations are F_1 and F_2 respectively, it can effectively avoid the non-neutral treatment of local governments and reduce social losses.

Assumption 5: When the non-neutral treatment behavior of local governments is publicly exposed throughout society if all enterprises continue to actively cooperate with the implementation of higher-level requirements, then the reputational loss incurred by the local governments due to questioning is denoted as R_1, and the reputational loss incurred by industry associations due to the inability to communicate and provide services promptly is denoted as R_2. If all enterprises choose to passively cooperate, resisting non-neutral behavior through means such as strikes, the reputational loss incurred by the local governments is denoted as R_3, and the reputational loss incurred by industry associations is denoted as R_4.

According to the above assumptions, the payoff matrix for the four-game players can be obtained as shown in Table 1.

TABLE 1 Payoff matrix of four-party game stages between central government, local government, industry association, and enterprises.

Strategy selection				Central government			
				Strict regulation x		Lax regulation 1-x	
				Local government		Local government	
				Neutral treatment y	Non-neutral treatment 1-year	Neutral treatment y	Non-neutral treatment 1-year
Enterprises	positive cooperation m	Industry Association	Active supervision z	B_2- C_6	-N_2-C_7	B_2- C_7	-N_2-C_7
				Q-C_1	-C_2	Q-C_1	-C_2
				T-C_3	-C_3	T-C_3	-C_3
				B_1- C_5	-N_1-C_5	B_1- C_5	-N_1-C_5
			Passive supervision 1-z	B_2- C_6	-N_2 + F_1 + F_2-C_6	B_2- C_7	-N_2-C_7
				Q-C_1	-C_2-F_1	Q-C_1	-C_2-R_1
				T-C_4	-C_4-F_2	T-C_4	-C_4-R_2
				B_1- C_5	-N_1-C_5	B_1- C_5	-N_1-C_5
	Negative cooperation 1-m	Industry Association	Active supervision z	B_2- C_6	-N_2-C_7	B_2- C_7	-N_2-C_7
				Q-C_1	-C_2	Q-C_1	-C_2
				T-C_3	-C_3	T-C_3	-C_3
				B_1	-N_1	B_1	-N_1
			Passive supervision 1-z	B_2- C_6	-N_2 + F_1 + F_2-C_6	B_2- C_7	-N_2-C_7
				Q-C_1	-C_2-F_1	Q-C_1	-C_2 -R_3
				T-C_4	-C_4-F_2	T-C_4	-C_4-R_4
				B_1	-N_1	B_1	-N_1

2.2 Replication dynamic equation construction

2.2.1 Replication of dynamic equations for the central government

The expected payoff of the central government is denoted as EX, where EX_1 represents the expected payoffs when the central government enforces strict supervision, and EX_2 represents the expected payoffs when the central government adopts lenient supervision.

$$\begin{aligned}EX_1 &= yzm(B_2 - C_6) + yz(1-m)(B_2 - C_6)\\ &\quad + y(1-z)m(B_2 - C_6) + y(1-z)(1-m)(B_2 - C_6)\\ &\quad + (1-y)zm(-N_2 - C_7) + (1-y)z(1-m)(-N_2 - C_7)\\ &\quad + (1-y)(1-z)m(-N_2 + F_1 + F_2 - C_6)\\ &\quad + (1-y)(1-z)(1-m)(-N_2 + F_1 + F_2 - C_6)\\ &= (C_7 - C_6 + F_1 + F_2)yz + (B_2 - F_1 - F_2 + N_2)y\\ &\quad + (C_6 - C_7 - F_1 - F_2)z\end{aligned}$$

$$\begin{aligned}EX_2 &= yzm(B_2 - C_7) + yz(1-m)(B_2 - C_7)\\ &\quad + y(1-z)m(B_2 - C_7) + y(1-z)(1-m)(B_2 - C_7)\\ &\quad + (1-y)zm(-N_2 - C_7) + (1-y)z(1-m)(-N_2 - C_7)\\ &\quad + (1-y)(1-z)m(-N_2 - C_7)\\ &\quad + (1-y)(1-z)(1-m)(-N_2 - C_7)\\ &= (B_2 + N_2)y - C_7 - N_2\end{aligned}$$

According to the above equations, the replication dynamic equation $F(x)$ of the central government is as follows:

$$\begin{aligned}F(x) &= \frac{dx}{dt} = x(EX_1 - EX) = x(1-x)(EX_1 - EX_2)\\ &= x(x-1)\left[(C_7 - C_6 + F_1 + F_2)yz + (F_1 + F_2)y\right.\\ &\quad \left. + (C_7 - C_6 + F_1 + F_2)z - (C_7 - C_6 + F_1 + F_2)\right]\end{aligned}$$

$$\begin{aligned}F'(x) &= (2x-1)\left[(C_7 - C_6 + F_1 + F_2)yz + (F_1 + F_2)y\right.\\ &\quad \left. + (C_7 - C_6 + F_1 + F_2)z - (C_7 - C_6 + F_1 + F_2)\right]\end{aligned}$$

According to the stability theorem of differential equations, the conditions that the central government must satisfy to choose strict regulation to achieve stability is:

$$F(x) = 0 \text{ and } F'(x) < 0$$

When $y = y_0 = \frac{(C_7 - C_6 + F_1 + F_2)(1-z)}{(C_7 - C_6 + F_1 + F_2)z + F_1 + F_2}$, $F'(x) = 0$, the stability strategy cannot be determined; When $0 < y < y_0 = \frac{(C_7 - C_6 + F_1 + F_2)(1-z)}{(C_7 - C_6 + F_1 + F_2)z + F_1 + F_2}$, to ensure $F'(x) < 0$, we should choose strict supervision strategy, otherwise we should choose loose supervision strategy.

2.2.2 Replication of dynamic equations for the local government

The expected payoff of the local government is denoted as EY, where EY_1 represents the expected payoffs when the local government adopts competition neutrality, and EY_2 represents the expected payoffs when the local government passively adopts non-competition neutrality.

$$\begin{aligned} EY_1 = {} & xzm(Q - C_1) + xz(1-m)(Q - C_1) + x(1-z)m(Q - C_1) \\ & + x(1-z)(1-m)(Q - C_1) + (1-x)zm(Q - C_1) \\ & + (1-x)z(1-m)(Q - C_1) + (1-x)(1-z)m(Q - C_1) \\ & + (1-x)(1-z)(1-m)(Q - C_1) \end{aligned}$$

$$\begin{aligned} EY_2 = {} & xzm(-C_2) + xz(1-m)(-C_2) + x(1-z)m(-C_2 - F_1) \\ & + x(1-z)(1-m)(-C_2 - F_1) + (1-x)zm(-C_2) \\ & + (1-x)z(1-m)(-C_2) + (1-x)(1-z)m(-C_2 - R_1) \\ & + (1-x)(1-z)(1-m)(-C_2 - R_3) \end{aligned}$$

$$\begin{aligned} EY = {} & yEY_1 + (1-y)EY_2 \\ = {} & (R_1 - R_3)xyzm - (F_1 - R_3)xyz - (R_1 - R_3)xym \\ & - (R_1 - R_3)xzm - (R_1 - R_3)yzm + (F_1 - R_3)xy \\ & + (F_1 - R_3)xz + (R_1 - R_3)xm - R_3yz + (R_1 - R_3)ym \\ & + (R_1 - R_3)zm - (F_1 - R_3)x + (C_2 - C_1 + R_3 + U)y + R_3z \\ & - (R_1 - R_3)m - C_2 - R_3 \end{aligned}$$

According to the above equations, the replication dynamic equation $F(y)$ of the local government is as follows:

$$\begin{aligned} F(y) = \frac{dy}{dt} &= y(EY_1 - EY) = y(1-y)(EY_1 - EY_2) \\ &= -y(y-1)\begin{bmatrix} (R_1 - R_3)xzm - (F_1 - R_3)xz - (R_1 - R_3)xm - (R_1 - R_3)zm \\ +(F_1 - R_3)x - R_3z + (R_1 - R_3)m + C_2 - C_1 + R_3 + Q \end{bmatrix} \\ F'(y) &= (1-2y)\begin{bmatrix} (R_1 - R_3)xzm - (F_1 - R_3)xz - (R_1 - R_3)xm - (R_1 - R_3)zm \\ +(F_1 - R_3)x - R_3z + (R_1 - R_3)m + C_2 - C_1 + R_3 + Q \end{bmatrix} \end{aligned}$$

According to the stability theorem of differential equations, the conditions that the local government must satisfy to choose strict regulation to achieve stability is:

$$F(y) = 0 \text{ and } F'(y) < 0$$

When $m = m_0 = \frac{(F_1 - R_3)x(z-1) + R_3(z-1) + C_1 - C_2 - Q}{(R_1 - R_3)(1-x)(1-z)}$, $F'(y) = 0$, the stability strategy cannot be determined; When $0 < m < m_0 = \frac{R_2(1-y) + C_4 - C_3}{(F_2 - R_2)(y-1)}$, to ensure $F'(y) < 0$, we should choose competitive neutral strategy, otherwise we should choose non-competitive neutral strategy.

2.2.3 Replication of dynamic equations for the industry association

The expected payoff of the industry association is denoted as EZ, where EZ_1 represents the expected payoffs when the industry association actively supervises, and EZ_2 represents the expected payoffs when the industry association passively supervises.

$$\begin{aligned} EZ_1 = {} & xym(T - C_3) + xy(1-m)(T - C_3) + x(1-y)m(-C_3) \\ & + x(1-y)(1-m)(-C_3) + (1-x)ym(T - C_3) \\ & + (1-x)y(1-m)(T - C_3) + (1-x)(1-y)m(-C_3) \\ & + (1-x)(1-y)(1-m)(-C_3) \end{aligned}$$

$$\begin{aligned} EZ_2 = {} & xym(T - C_4) + xy(1-m)(T - C_4) \\ & + x(1-y)m(-C_4 - F_2) + x(1-y)(1-m)(-C_4 - F_2) \\ & + (1-x)ym(T - C_4) + (1-x)y(1-m)(T - C_4) \\ & + (1-x)(1-y)m(-C_4 - R_2) \\ & + (1-x)(1-y)(1-m)(-C_4 - R_4) \end{aligned}$$

$$\begin{aligned} EZ = {} & zEZ_1 + (1-z)EZ_2 \\ = {} & -(F_2 - R_2)xyz + (F_2 - R_2)xy + (F_2 - R_2)xz - R_2yz \\ & -(F_2 - R_2)x + (R_2 + T)y + (C_4 + R_2 - C_3)z - C_4 - R_2 \end{aligned}$$

According to the above equations, the replication dynamic equation $F(z)$ of the industry associations is as follows:

$$\begin{aligned} F(z) = \frac{dz}{dt} &= z(EZ_1 - EZ) = z(1-z)(EZ_1 - EZ_2) \\ &= z(z-1)\left[(F_2 - R_2)xy - (F_2 - R_2)x + R_2y + C_3 - C_4 - R_2\right] \\ F'(z) &= (2z-1)\left[(F_2 - R_2)xy - (F_2 - R_2)x + R_2y + C_3 - C_4 - R_2\right] \end{aligned}$$

According to the stability theorem of differential equations, the conditions that the industry associations must satisfy to choose strict regulation to achieve stability is:

$$F(z) = 0 \text{ and } F'(z) < 0$$

When $x = x_0 = \frac{R_2(1-y) + C_4 - C_3}{(F_2 - R_2)(y-1)}$, $F'(z) = 0$, the stability strategy cannot be determined; When $0 < x < x_0 = \frac{R_2(1-y) + C_4 - C_3}{(F_2 - R_2)(y-1)}$, to ensure $F'(z) < 0$, we should choose active supervision strategy, otherwise we should choose the negative supervision strategy.

2.2.4 Replication of dynamic equations for the enterprises

The expected payoff of the enterprise is denoted as EM, where EM_1 represents the expected payoffs when the enterprises cooperate actively, and EM_2 represents the expected payoffs when the enterprises cooperate passively.

$$\begin{aligned} EM_1 = {} & xyz(B_1 - C_5) + xy(1-z)(B_1 - C_5) \\ & + x(1-y)z(-N_1 - C_5) + x(1-y)(1-z)(-N_1 - C_5) \\ & + (1-x)yz(B_1 - C_5) + (1-x)y(1-z)(B_1 - C_5) \\ & + (1-x)(1-y)z(-N_1 - C_5) \\ & + (1-x)(1-y)(1-z)(-N_1 - C_5) \end{aligned}$$

TABLE 2 Asymptotic stability analysis of equilibrium points in the replicator dynamic system under strict regulation by the central government.

Equilibrium point	λ_1	λ_2	λ_3	λ_4	Sign of eigenvalues	Stability
(1, 0, 0, 0)	$-C_5$	$C_4 - C_3 + F_2$	C_6-C_7-F_1-F_2	$C_2 - C_1 + F_1 + Q$	-, U, -, -	U
(1, 0, 0, 1)	C_5	$C_4 - C_3 + F_2$	C_6-C_7-F_1-F_2	$C_2 - C_1 + F_1 + Q$	+, U, -, -	×
(1, 0, 1, 0)	0	$-C_5$	C_2-C_1+U	C_3-C_4-F_2	0, -, U, U	×
(1, 0, 1, 1)	0	C_5	C_2-C_1+U	C_3-C_4-F_2	0, +, U, U	×
(1, 1, 0, 0)	C_4-C_3	C_6-C_7	$-C_5$	C_1-C_2-F_1-Q	-, +, -, -	×
(1, 1, 0, 1)	C_5	C_4-C_3	C_6-C_7	C_1-C_2-F_1-Q	+, -, +, U	×
(1, 1, 1, 0)	C_3-C_4	C_6-C_7	$-C_5$	C_1-C_2-Q	+, +, -, U	×
(1, 1, 1, 1)	C_5	C_3-C_4	C_6-C_7	C_1-C_2-Q	+, +, +, U	×

Note: In the "Sign of Eigenvalues" column, "U" represents the uncertain sign, and in the "Stability" column, "U" represents the undetermined stability of the local equilibrium point. "–" indicates the negative value, "+" indicates the positive value, and "×" indicates instability of the local equilibrium point.

TABLE 3 Asymptotic stability analysis of equilibrium points in the replicator dynamic system under lenient regulation by the central government.

Equilibrium point	λ_1	λ_2	λ_3	λ_4	Sign of eigenvalues	Stability
(0, 0, 0, 0)	$-C_5$	$C_4 - C_3 + R_2$	$C_7 - C_6 + F_1 + F_2$	$C_2 - C_1 + R_3 + Q$	-, U, U, U	U
(0, 0, 0, 1)	C_5	$C_4 - C_3 + R_2$	$C_7 - C_6 + F_1 + F_2$	$C_2 - C_1 + R_1 + Q$	+, U, U, U	×
(0, 0, 1, 0)	0	$-C_5$	$C_2 - C_1 + Q$	$C_3 - C_4 - R_2$	0, -, U, U	×
(0, 0, 1, 1)	0	C_5	C_2-$C_1 + Q$	C_3-C_4-R_2	0, +, U, U	×
(0, 1, 0, 0)	C_4-C_3	C_7-C_6	$-C_5$	C_1-C_2-R_3-Q	-, -, -, -	U
(0, 1, 0, 1)	C_5	C_4-C_3	C_7- C_6	C_1-C_2-R_1-Q	+, -, -, U	×
(0, 1, 1, 0)	C_3-C_4	C_7-C_6	$-C_5$	C_1-C_2-Q	+, -, -, U	×
(0, 1, 1, 1)	$-C_5$	C_4-C_3	C_7-C_6	C_1-C_2-Q	-, -, -, U	U

TABLE 4 Parameter setting.

Variables	Q	C_1	C_2	T	C_3	C_4	C_5	C_6	C_7	B_1
Initial value	8	27	2	13	10	1	10	11	1	20
Variables	B_2	N_1	N_2	F_1	F_2	R_1	R_2	R_3	R_4	
Initial value	30	12	20	5	3	10	8	15	25	

$$EM_2 = xyz(B_1) + xy(1-z)(B_1) + x(1-y)z(-N_1) + x(1-y)(1-z)(-N_1) + (1-x)yz(B_1) + (1-x)y(1-z)(B_1) + (1-x)(1-y)z(-N_1) + (1-x)(1-y)(1-z)(-N_1)$$

$$EM = mEM_1 + (1-m)EM_2 = (B_1 + N_1)y - C_5 m - N_1$$

$$F(m) = \frac{dm}{dt} = m(EM_1 - EM) = m(1-m)(EM_1 - EM_2) = m(m-1)C_5$$

$$F'(m) = (2m-1)C_5$$

When $0 < m < \frac{1}{2}$, $F'(m) < 0$, then choose the active cooperation strategy.

3 Analysis of the stable strategy of the four-party evolutionary game

3.1 Analysis of the equilibrium points

$$\text{Let} \begin{cases} F(x) = \frac{dx}{dt} = 0 \\ F(y) = \frac{dy}{dt} 0 \\ F(z) = \frac{dz}{dt} = 0 \\ F(m) = \frac{dm}{dt} 0 \end{cases}$$

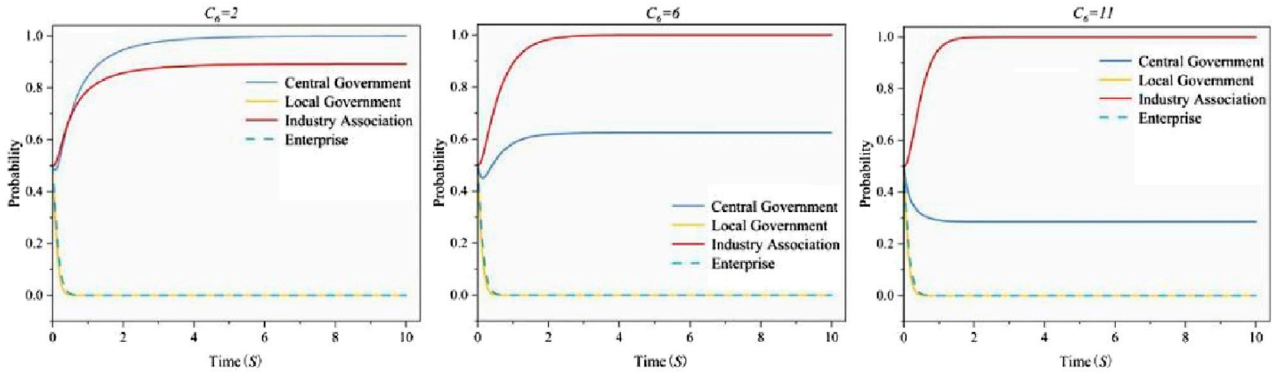

FIGURE 2
The impact of central government regulatory costs on the evolutionary strategies of each party.

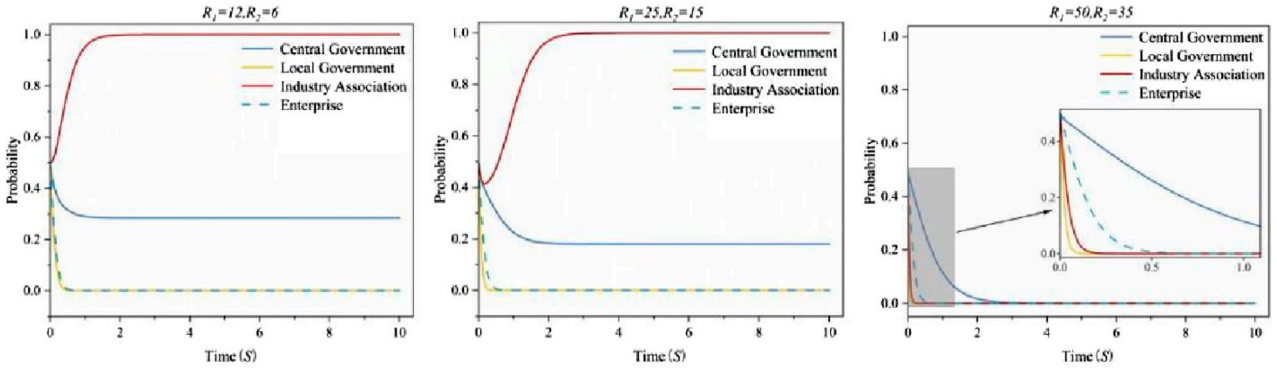

FIGURE 3
The impact of local government's non-neutral competition policy on the evolutionary strategies of each party.

We can get that the equation has 2^4 or 16 equilibrium solutions of pure strategies, which are (0, 0, 0, 0)(0, 0, 0, 1)(0, 0, 1, 0)(0, 0, 1, 1)(0, 1, 0, 0)(0, 1, 0, 1)(0, 1, 1, 0)(0, 1, 1, 1)(1, 0, 0, 0)(1, 0, 0, 1)(1, 0, 1, 0)(1, 0, 1, 1)(1, 1, 0, 0)(1, 1, 0, 1)(1, 1, 1, 0)and (1, 1, 1, 1), along with one mixed strategy point (x*, y*, z*, m*). Pointed out that the stable solutions in multi-population evolutionary games are strict Nash equilibria, and strict Nash equilibria must be pure strategies. Therefore, this study will analyze the stability of the pure strategy equilibrium points.

Based on the replicator dynamic equations of each game player, the Jacobian matrix J of the replicator dynamic system is obtained.

$$J = \begin{vmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} & \frac{\partial F(x)}{\partial m} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} & \frac{\partial F(y)}{\partial m} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} & \frac{\partial F(z)}{\partial m} \\ \frac{\partial F(m)}{\partial x} & \frac{\partial F(m)}{\partial y} & \frac{\partial F(m)}{\partial z} & \frac{\partial F(m)}{\partial m} \end{vmatrix}$$

3.2 Stability analysis of strategy combinations under strict regulation by the central government

When the central government adopts strict regulation, it satisfies the condition: $(C_7 - C_6 + F_1 + F_2)yz + (F_1 + F_2)y + (C_7 - C_6 + F_1 + F_2)z - (C_7 - C_6 + F_1 + F_2) < 0$.The asymptotic analysis of the equilibrium points for the replicator dynamic system is presented in Table 2.

As can be seen from the above table, there is a (1,0,0,0) pure strategic stability point, which means that the central government has strong supervision, local governments implement the principle of non-neutral competition, industry associations adopt loose supervision and enterprises maintain a negative cooperative attitude.

From the equilibrium point (1,1,0,0), it can be seen that when the central government chooses strict regulation as the stability strategy, the local government's stability strategy is to adopt the principle of competitive neutrality to treat all enterprises, the industry association adopts the strategy of passive supervision,

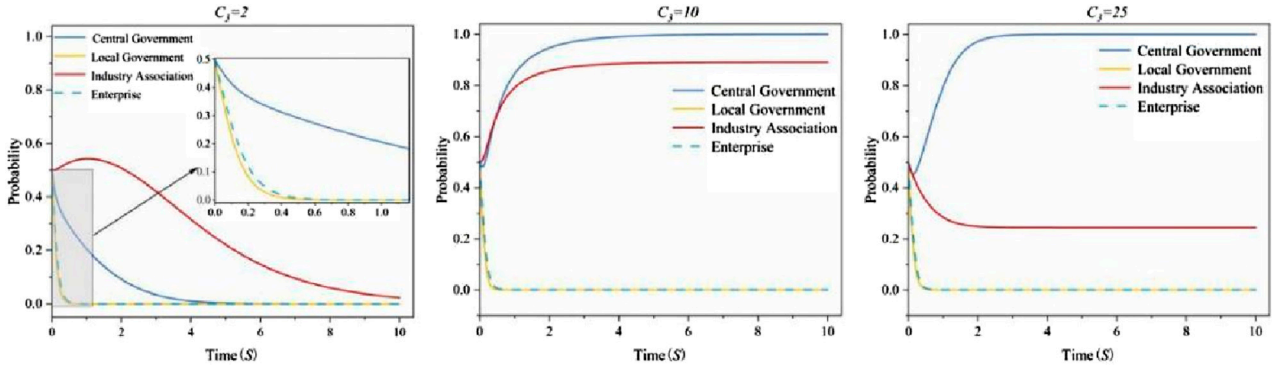

FIGURE 4
The impact of industry association supervision costs on the evolutionary strategies of each party.

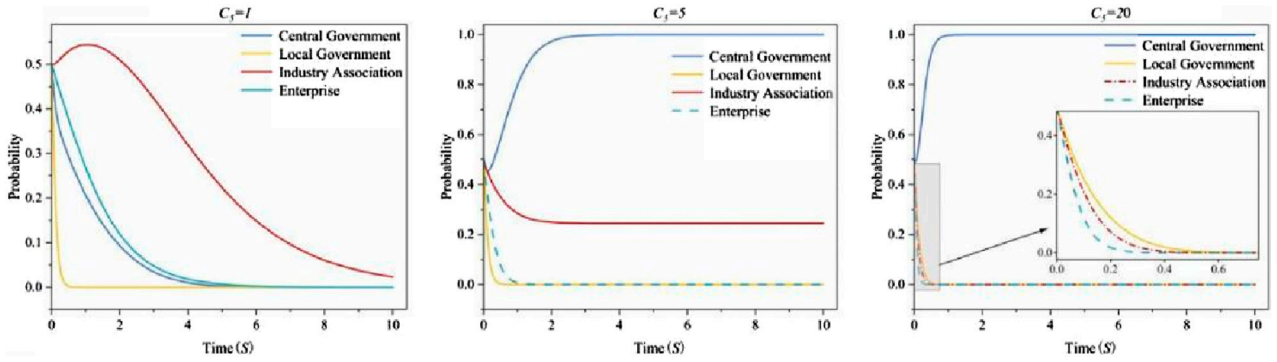

FIGURE 5
The impact of enterprise cooperation costs on the evolutionary strategies of each party.

and the enterprises adopt a negative attitude to cooperate with the implementation of the policy. However, the choice of local governments is unstable. At this point, the central government can carry out appropriate loose regulation, give local governments and industry associations appropriate flexibility, encourage enterprises to actively participate, create a good atmosphere of competition and cooperation, and promote local governments to actively implement the principle of competition neutrality positively.

3.3 Stability analysis of strategy combinations under lenient regulation by the central government

When the central government adopts lenient regulation, it satisfies the condition: $(C_7 - C_6 + F_1 + F_2)yz + (F_1 + F_2)y + (C_7 - C_6 + F_1 + F_2)z - (C_7 - C_6 + F_1 + F_2) < 0$ The asymptotic analysis of the equilibrium points for the replicator dynamic system is presented in Table 3.

There exist two pure strategy stable points: (0,0,0,0) and (0,1,0,0). Among them, (0,1,0,0) indicates that the local government actively responds to the call of the central government and encourage equal competition among all enterprises in its jurisdiction. Industry associations and enterprises lag behind government departments in their understanding of policies, so they adopt a cautious and conservative attitude to cooperation. According to the stability theorem of differential equations, if the local government adopts the principle of competitive neutrality as a stable state, the conditions must be satisfied: $F(y) = 0$ and $F'(y) < 0$, in other words, fulfilling $m < \frac{R_2(1-y)+C_4-C_3}{(F_2-R_2)(y-1)}$.

(0,0,0,0) indicates that in the context of loose regulation by the central government, local governments, industry associations, and enterprises maintain a reserved attitude towards neutral competitive principles and are unwilling to actively cooperate in implementation. To avoid such situations, we should give full play to the communication and cooperation functions of government personnel and industry associations, along with effective publicity efforts, to build a positive image for the government and relevant parties, thereby avoiding the situation where (0,0,0,0) becomes a stable equilibrium point.

In the new era of the simultaneous development of diverse economic systems, overly lenient supervision by the central government is not conducive to the formation of an orderly and fair economic environment. To prevent local governments from adopting non-neutral competitive

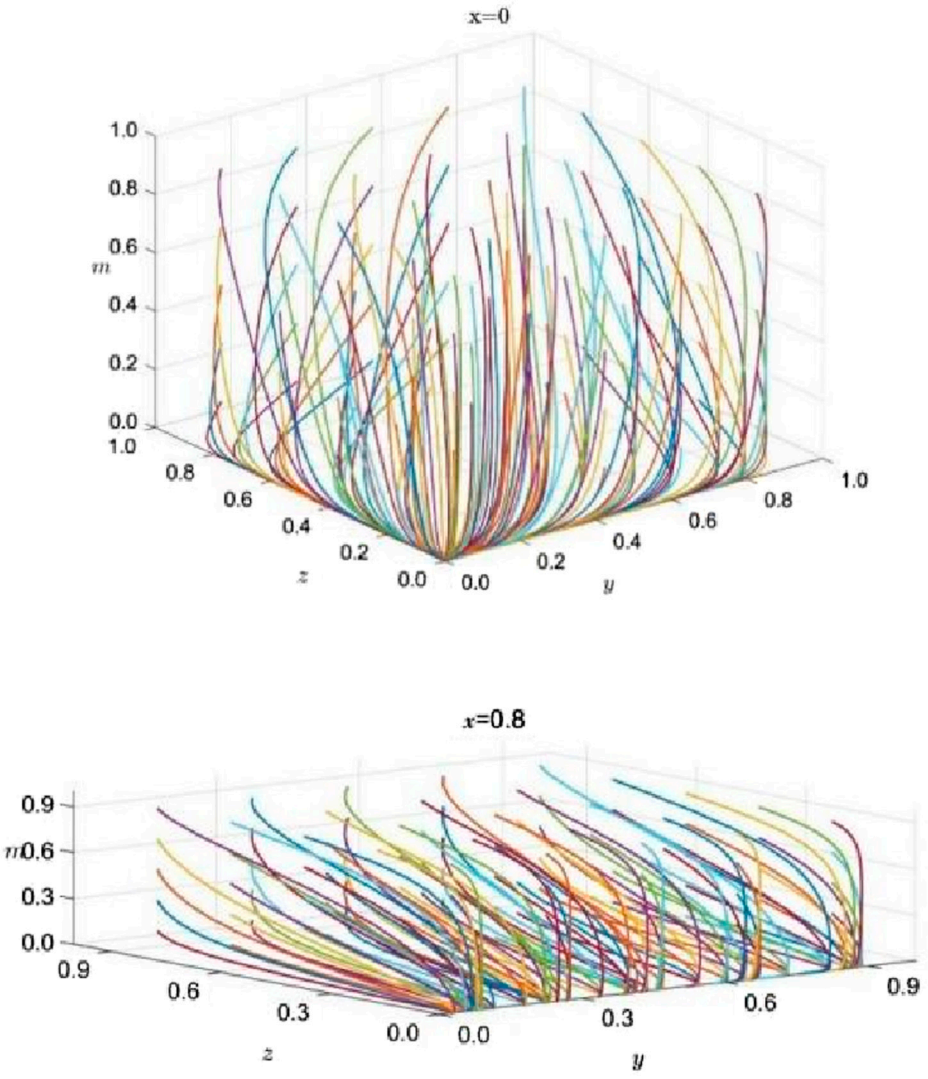

FIGURE 6
The impact of central government regulatory probability on the evolutionary strategies of each party.

principles, which means unfair treatment of all enterprises, the central government departments can take measures of both rewards and penalties. This approach can encourage local government regulatory departments and relevant personnel from industry associations, who possess professional qualities and good integrity, to actively supervise and cooperate. It also assists various types of enterprises in understanding policies, thus making it a stable strategy.

4 Simulation analysis of the evolutionary game

Based on the above analysis, to more visually observe the evolutionary paths of multi-party game players under different constraints and regulatory strategies and the impact on the evolution results, this paper uses MATLAB2018 to simulate the evolution trajectory of each game player and uses ode instruction to solve the replication dynamic equation.

4.1 Initial system simulation settings

Initially, it is assumed that the probabilities of the central government, local government, industry association, and enterprises choosing the strategies of strict regulation, neutral treatment, active supervision, and active cooperation are [0.5, 0.5, 0.5, 0.5] respectively. The horizontal axis represents time (t), and the vertical axis represents the probabilities (p) of the central government (x), local government (y), industry association (z), and enterprises (m) choosing their respective strategies. The initial parameter settings are shown in Table 4.

4.2 Impact of parameter changes on the system

4.2.1 Impact of central government regulatory costs

Setting C6 = {2, 6, 12}, the evolutionary process and outcomes of the four-party game players are illustrated in Figure 2.

As shown in Figure 2, the level of central government regulatory costs not only affects the evolutionary trend of the central government's strategies but also influences the evolutionary trends of the other three parties. When the regulatory costs of the central government increase, the probability of proactive supervision by industry associations gradually rises and tends to stabilize. Therefore, by raising the regulatory costs of the central government, it can not only stimulate the supervision efficiency of industry associations but also provide service communication to local governments and all enterprises.

4.2.2 Impact of local Government's neutral competition policy

Setting R_1 = {12, 25, 50}, R_2 = {6, 15, 35}, the evolutionary process and outcomes of the four-party game players are illustrated in Figure 3.

From Figure 3, it is evident that when non-neutral competitive behavior by local governments becomes public and results in a gradual increase in reputational losses for the central government and industry associations, the probability of active cooperation by enterprises will continuously decrease to zero, ultimately transitioning to passive cooperation and stabilizing. This indicates that enterprises can adjust their response to non-neutral treatment of various businesses by local governments based on the influence of the central government and industry associations in society. It is essential to maintain rationality, actively address various unfair situations, and create maximum social value.

4.2.3 Impact of industry association regulatory costs

Setting C_3 = {2, 10, 25}, the evolutionary process and outcomes of the four-party game players are illustrated in Figure 4.

From Figure 4, it can be observed that the level of supervision costs for industry associations has an impact on the intensity of central government regulation, the implementation of neutral policies by local governments, and the degree of cooperation by enterprises. When the supervision cost C_3 = 2, the probabilities of the central government, local government, and enterprises gradually decrease to zero, with local governments and enterprises exhibiting a faster-declining trend. However, when the supervision costs C_3 = 10 or C_3 = 25, the probability of local governments adopting a neutral competition principle is significantly increased, benefiting both the central government and enterprises.

4.2.4 The impact of enterprises cooperating with neutral competition principles

Setting C_5 = {2, 10, 25}, the evolutionary process and outcomes of the four-party game players are illustrated in Figure 5.

From Figure 5, it is evident that after observing industry association supervision, enterprises are willing to devote more effort to active cooperation. The level of additional cost C_5 will affect the evolutionary trends of the central government, local government, and industry association. When the additional cost C_5 = 1, the probabilities of the other three parties are all decreasing and finally approaching 0. When the additional cost C_5 = 10, the probability of active supervision by industry associations gradually decreases to 0.2 and then remains stable. However, when the additional cost C_5 = 25, the probability of the central government increases and eventually stabilizes at 1.

4.2.5 Impact of central government regulatory probability

Setting x = {0,0.8}, the evolutionary process and outcomes of the four-party game players are illustrated in Figure 6.

Setting the probability of the central government's participation in regulation x as x = 0 and x = 0.8 respectively, we explore the evolutionary paths of different strategies of local government, industry associations, and enterprises in three-dimensional space under the states of regulation and non-regulation by the central government, and conduct simulation analysis. The simulation results are shown in Figure 6.

From Figure 6, when x = 0, indicating that the central government does not regulate whether the local government effectively implements neutral competitive principles, various situations exist regarding the stable strategies of the local government under the influence of factors such as reputation loss. The industry associations are more inclined to maintain the existing government-enterprise relationship through passive supervision. When x = 0.8, indicating that the central government implements strict supervision and inspection mechanisms on the local government, although there is no stable strategy in the replicating dynamic equation system, if the central government regulatory department maintains a certain degree of regulatory probability, the probability of active supervision by the industry association will significantly increase and stabilize at active supervision. In this case, enterprises can maintain trust in both the local and central governments.

5 Conclusion and recommendations

5.1 Main conclusions

By establishing a four-way evolutionary game model of central government, local government, industry association, and enterprise, this paper analyzes the analyze the stable strategies under different situations and uses simulation analysis to examine the evolutionary paths of the impact of parameter changes on the system. The following conclusions can be drawn from the analysis:

(1) Among the 16 pure strategy equilibrium points in the four-party evolutionary game system, there are a total of 4 conditionally stable points, while the remaining 12 equilibrium points are unstable under any conditions. These four conditionally stable points represent the possible strategic equilibrium of various stakeholders under the principle of competition neutrality. When the relative net income of a certain strategy in the strategy set is positive, related participants will be more inclined to choose this strategy.

(2) Through numerical simulation analysis, it is found that increasing the punishment intensity of the central government towards the local government's passive implementation of competition-neutral principles and enhancing the supervision of industry associations can not only boost the local government's enthusiasm for implementing competition neutral principles but also increase the probability of industry associations actively supervising non-neutral competition behaviors of local governments and enterprises. Raising the punishment standards for non-neutral competition behaviors of market entities and increasing the penalties for non-neutral actions by local governments will have an impact on the strategic choices of local governments, industry associations, and enterprises, which would make the system evolve more rapidly toward the ideal state of "loose supervision by the central government, the neutral implementation by local governments, strong supervision by industry associations and active cooperation by enterprises." However, excessively lenient central government regulation will hinder the game system from reaching a stable state, making it an ineffective governance model in the long run. Finally, recommendations for constructing the principle of competitive neutrality are proposed from the perspectives of central government, local government, industry associations, and enterprises.

5.2 Policy recommendations

Based on the research conclusions above, the following policy recommendations can be proposed:

For the central government, establishing a unified legal system and policies, strengthening supervision and law enforcement, and ensuring information transparency and openness are effective ways to punish unfair monopolies and unfair competition. By establishing a competition-neutral supervision mechanism, the central government can effectively reduce the inaction of local governments and the speculative behavior of industry associations. While implementing the relevant legal responsibilities of local governments, it actively promotes the combination of cloud computing, big data and artificial intelligence, reduces regulatory costs, and takes appropriate measures to solve social problems in a timely manner.

For local governments, they must actively implement central policies and create a level playing field. We will strictly implement the central government's policies and regulations on competitive neutrality and avoid local protectionism and policy bias. We will treat all enterprises the same in terms of attracting investment and government procurement, and avoid favoring local enterprises or state-owned enterprises in support policies. At the same time, the approval process is simplified, business costs are reduced, and the overall level of the local business environment is improved.

For industry associations, it is necessary to maintain a neutral attitude, rationally view the commitments of local governments and enterprises, and play the role of middlemen. Encourage industry associations to actively learn the essentials of the principle of competitive neutrality and publicize popular science to enterprises and the public, formulate and promote industry self-discipline norms, and ensure that member enterprises comply with the principle of competitive neutrality. By coordinating the cooperation among members to jointly deal with the challenges of the industry, advocate fair competition, prevent monopoly and unfair competition in the industry, and ensure the sustainable and healthy development of the entire industry.

For enterprises, they need to abide by the law, abide by the national anti-monopoly law, anti-unfair competition law and other laws and regulations, establish and improve internal compliance mechanisms to ensure that they follow the principle of competitive neutrality in their daily operations. Actively feedback the problems encountered in competitive neutrality to the government and industry associations, undertake corporate social responsibility, actively participate in public welfare and social services, and establish a good corporate image.

In summary, by promoting fair competition among enterprises, the central government aims to improve the economic environment of the entire country to support sustainable development; by decentralizing power to local governments, improving the reward and punishment mechanism, and rewarding entities that actively create a fair competitive environment, Increase punishment for entities whose powers and responsibilities are not clear and allow unfair monopoly and unfair competition to occur, strictly examine the relationship between government and business, and urge local government departments to actively rectify; severely punish industry associations that passively supervise for the sake of profit, and punish speculative industry associations Supervise through fines, notifications and criticisms, severely crack down on non-neutral competition, and be responsible to society.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

YZ: Conceptualization, Writing–original draft, Writing–review and editing, Data curation, Investigation, Methodology, Software, Supervision. MW: Conceptualization, Formal Analysis, Funding acquisition, Investigation, Project administration, Supervision, Validation, Writing–review and editing. JL: Data curation, Formal Analysis, Methodology, Project administration, Software, Validation, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Publisher's note

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