



# Research on the Internal and External Monitoring Mechanism of the Electricity Market in the Spot Market: From the Perspective of the Evolutionary Game Theory

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The internal and external monitoring mechanism is a beneficial monitoring mode which is in line with the current national condition, the situation of the power grid, and the construction progress of the power spot market. However, the independence of third-party monitoring agencies cannot be completely guaranteed because of the incomplete management system of China's electricity market at present. Therefore, the market is prone to power rent-seeking in which third-party monitoring agencies conspire with the market internal monitoring organization. Based on the evolutionary game theory, this study constructed a coordination game model between third-party monitoring agencies and the market internal monitoring organization, as well as an asymmetric coordination game model between the interest group composed of internal and external monitoring agencies and government regulatory authorities. By analyzing the evolutionarily stable strategy of each game participant, the study identified the underlying factors that affect the strategic choices made by internal and external monitoring agencies and government regulatory authorities and then put forward some reasonable suggestions for reducing the probability of third-party monitoring agencies colluding with internal monitoring organizations so that the efficiency of internal and external monitoring mechanisms can be improved.

**Keywords:** electricity market, internal and external monitoring mechanisms, third-party monitoring agency, government supervision, internal monitoring organizations

## 1 INTRODUCTION

With the continuous development of China's electric power system reform and the establishment of the electricity spot market, power market supervision has drawn more and more attention (Streimikienė et al., 2016; Strielkowski et al., 2017; Kumar and France, 2022). The electricity market is often extremely complicated in design because of the economic and social demand on its supply–demand balance and a reliable electric power system. In addition, the electricity load has a small demand elasticity, which means it cannot respond to the market's real-time price immediately, so this enables power generators to have an opportunity to adjust load and manipulate prices (Song and Cui, 2016; Maekawa and Shimada, 2019). Due to these characteristics, in the process of China's electric power market reform, there are not only behaviors that disrupt the fair and effective market competition but also speculative behaviors that take the advantage of electricity market rules' loopholes, which greatly affect the operation

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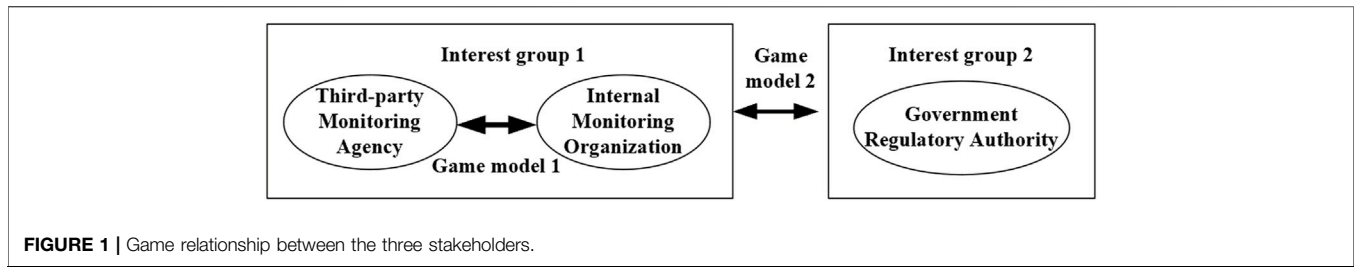


FIGURE 1 | Game relationship between the three stakeholders.

TABLE 1 | Payoff matrix between the third-party monitoring agency and the internal monitoring organization.

		Internal monitoring organization	
		Conspiracy (x)	Non-conspiracy (1 - x)
Third-party monitoring agency	Conspiracy (x)	$(P \cdot (-F' - S') + (1 - P) \cdot F, P \cdot (-F' - S') + (1 - P) \cdot F)$	$(P' \cdot (-T' - S) + (1 - P') \cdot T, 0)$
	Non-conspiracy (1 - x)	$(0, P' \cdot (-T' - S) + (1 - P') \cdot T)$	$(0, 0)$

Note: The income of third-party monitoring agencies and internal monitoring organization are shown in parentheses.

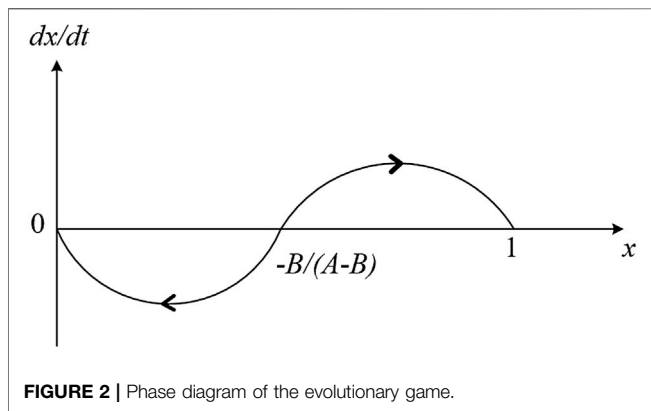


FIGURE 2 | Phase diagram of the evolutionary game.

efficiency of the electricity market. So establishing a powerful market monitoring mechanism is an efficient way to solve these problems. Through monitoring, simulation, and analysis, the monitoring agencies propose the constructive advice for the power dispatching and trading center, the behavior of all market participants, market rules, and scheduling procedures' defects so as to ensure the smooth and orderly operation of the electricity market (Dzikevičius and Šaranda, 2016; Jin et al., 2021). The most fundamental vitality of the electricity market comes from the market itself, which is embodied in efficiency. Therefore, building a comprehensive electric power monitoring mechanism can minimize the impact of market external factors on

efficiency so that the long-term vitality of the power market can be guaranteed.

The objective of market monitoring includes not only the violations in the ordinary sense but also the behaviors that conform to market rules but violate the original intention of market design. Moreover, monitoring agencies have obligations to discover rules and loopholes and propose corresponding solutions timely before the market participants find and abuse them for personal gain. For example, the monitoring agency should be able to effectively identify the abuse of market power and market manipulation that hinder market efficiency, playing a role in correcting market failures. In the meantime, they can provide evaluation and beneficial suggestions for market performance and judge whether the market rules have created incentives for market participants, thereby enabling the electric power market to operate efficiently. The market monitoring agencies supervise all market participants; therefore, a high-quality monitoring result is the source and guarantee of market participants' confidence in the market. This requires that the monitoring agencies must release genuine and transparent monitoring results. For example, the monitoring agency should have no interest relationship with the monitoring results and should regularly release their market evaluation reports to the public. Consequently, the monitoring agencies play an indispensable role in the electricity power market reform and construction.

So who should be responsible for monitoring the market? At present, the international power monitoring mode can be roughly

TABLE 2 | Payment matrix between interest group 1 and interest group 2.

		Interest group 2	
		Supervision (z)	Non-supervision (1 - z)
Interest group 1	Violation (y)	$(Q \cdot (-N) + (1 - Q) \cdot M, Q \cdot M - C)$	$(Q' \cdot (-N) + (1 - Q') \cdot M, Q' \cdot M)$
	Non-violation (1 - y)	$(0, M - C)$	$(0, M)$

**TABLE 3** | Analysis of the local equilibrium.

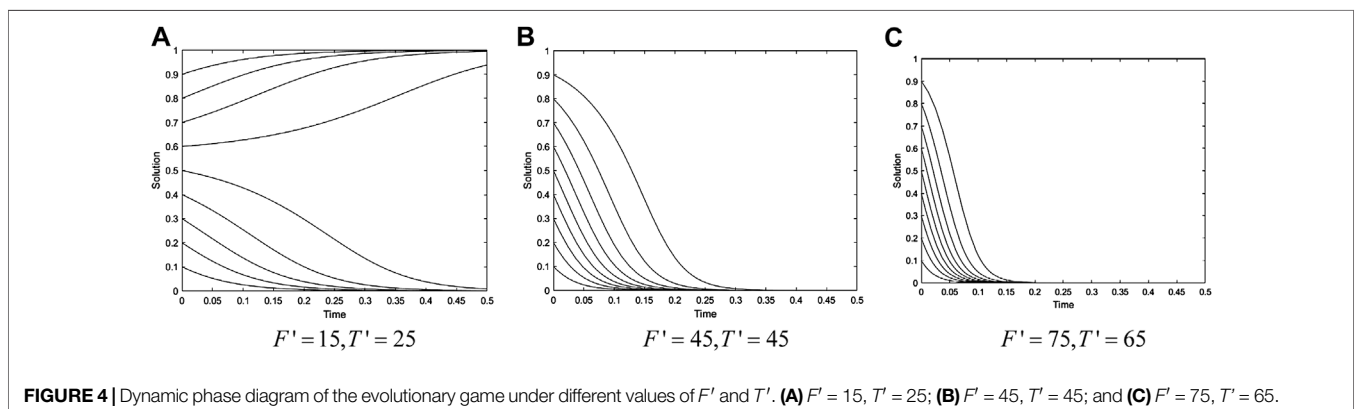
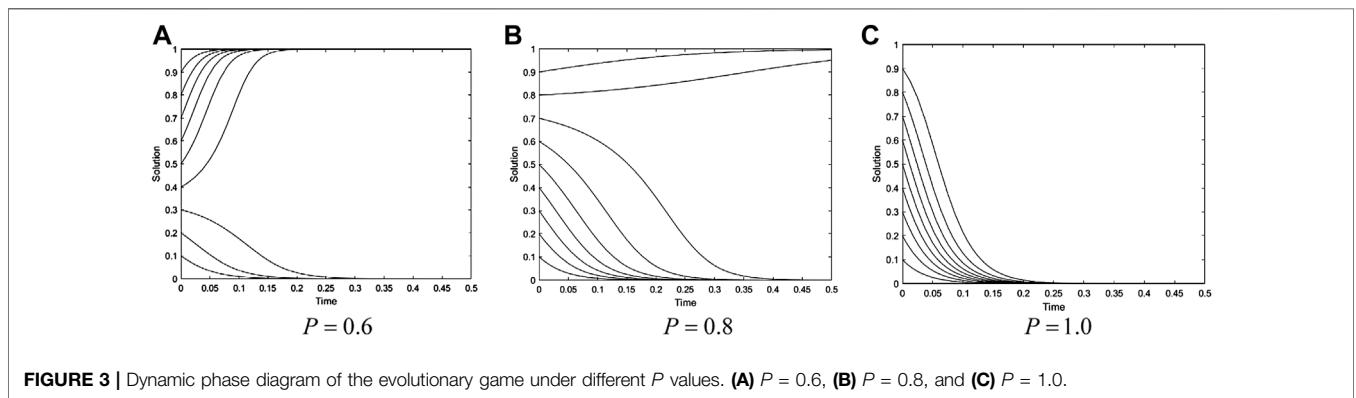
Local equilibrium	Tr J	Det J
$E_1(0, 0)$	$X'' - C$	$-X'' \cdot C$
$E_2(0, 1)$	$X' + C$	$X' \cdot C$
$E_3(1, 0)$	$-X'' + (Y' - Y'' - C)$	$-X'' \cdot (Y' - Y'' - C)$
$E_4(1, 1)$	$-X' - (Y' - Y'' - C)$	$-X' \cdot (Y' - Y'' - C)$

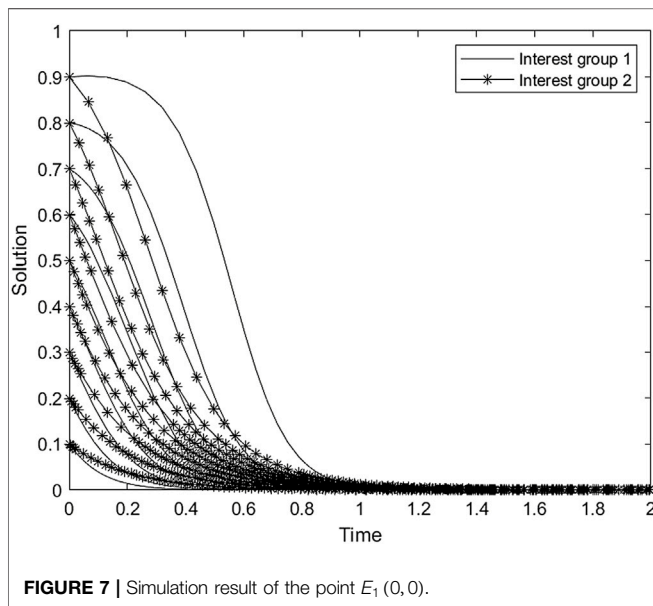
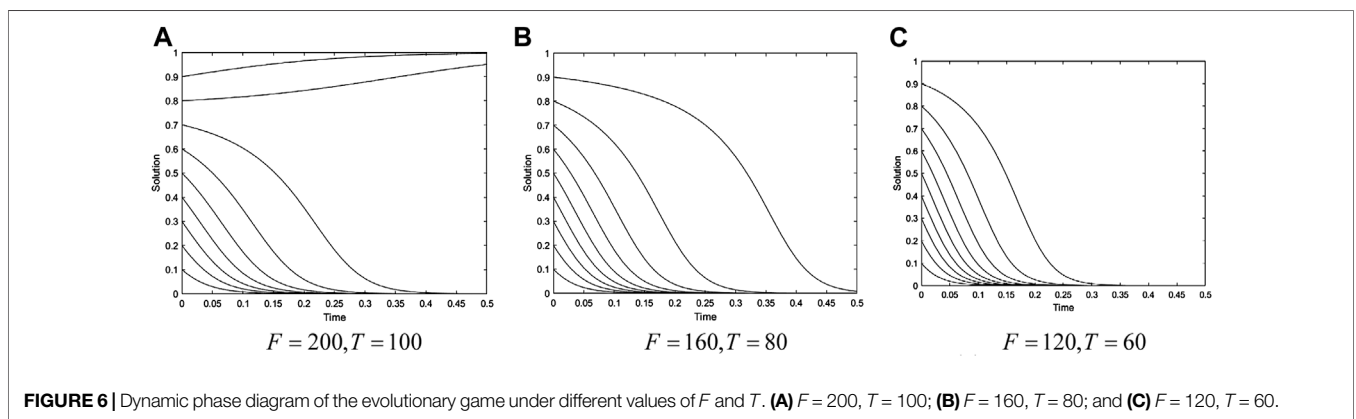
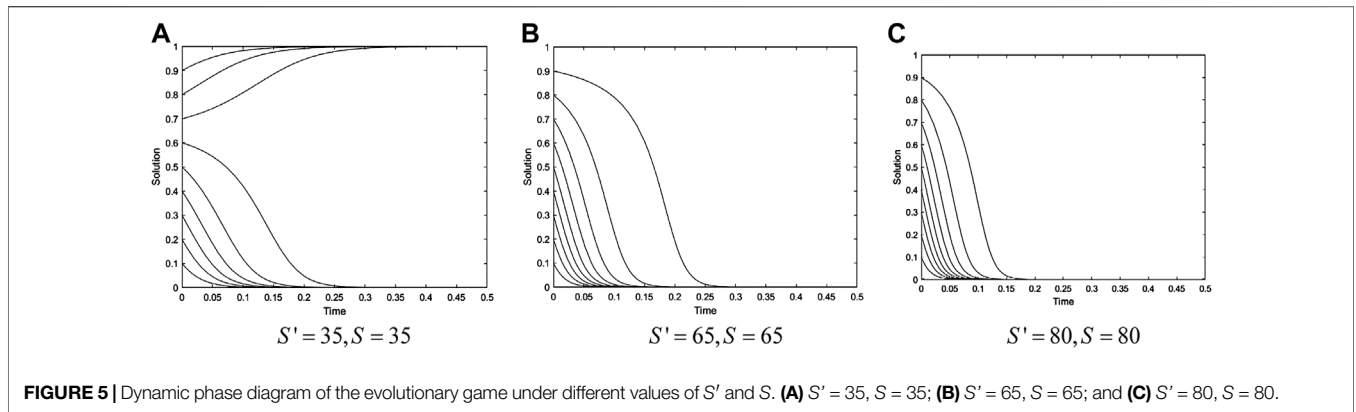
Note:  $X'' = Q' \cdot (-N) + (1 - Q') \cdot M$ ;  $X' = Q \cdot (-N) + (1 - Q) \cdot M$ ;  $Y'' = Q' \cdot M$ ;  $Y' = Q \cdot M$

divided into three categories: government monitoring, internal monitoring, and independent third-party monitoring. However, neither the government nor the power trading and dispatching agencies are eligible to supervise due to their role and function. Government authorities, on the one hand, cannot attract professional monitoring talents with an economics background because of the wages and staffing issues. On the other hand, the government’s work on employment, environmental protection, and taxation may not coincide with or even contradict the goals required by the electricity market. So the government’s impartiality in market monitoring will be doubted. As the rule makers and operators of power dispatching, trading and dispatching agencies may intentionally or unintentionally uphold existing regulations and are sensitive to criticisms and accusations, which may lead to the failure of internal market

monitoring. An independent third party has three characteristics: the budget of the monitoring department is independent, the monitoring personnel is independent, and the monitoring agency has independent decision-making power. Market monitoring is carried out by independent “third parties” in mature markets such as Europe and the United States, such as PJM and FERC. Therefore, as the electric power reform deepens, market participants’ calls for third-party monitoring are strengthening.

The independent third-party monitoring is new to China’s electricity market design. At present, China continuously introduces third-party monitoring agencies. The basic rules for intermediate and long-term electricity transactions jointly issued by the National Development and Reform Commission and the National Energy Administration in 2020 encourage regions which met standards to introduce third-party monitoring. Guangdong province has taken the lead in introducing third-party market business audit institutions, and the electric power spot market rules in Zhejiang province have also determined to introduce third-party monitoring agencies. After the introduction of third-party detection, what is the behavioral decision of each subject under the dual detection mechanism? How to improve the efficiency of electricity market monitoring? How to prevent conspiracy between third-party monitoring agencies and internal stakeholders? These questions need to be settled properly, and enough attention should be paid to the design



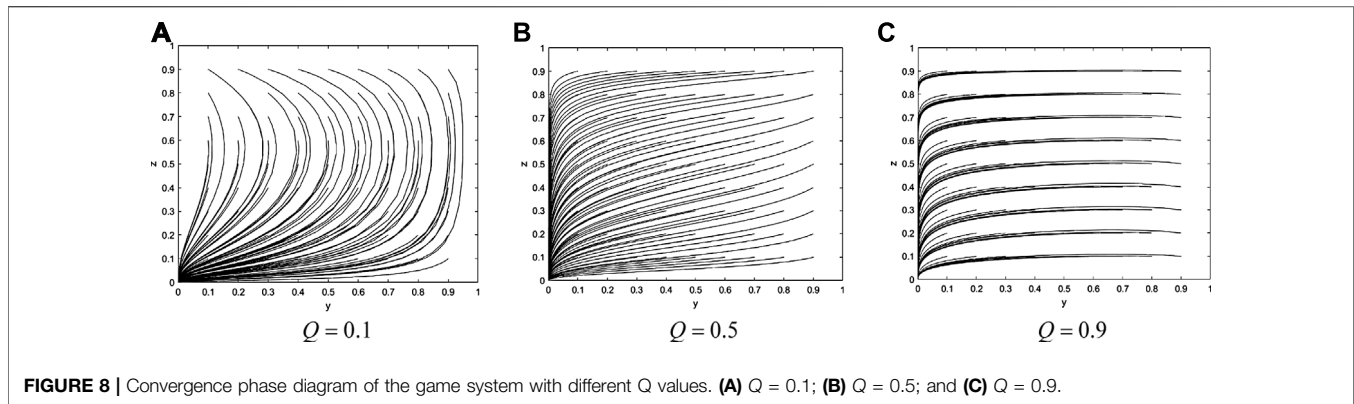


and construction of the power spot market so that the legitimate rights and interests of market participants can be protected, and a good market order can be maintained.

Based on the earlier discussion, this study takes the internal and external monitoring mechanism of the electricity market in the spot market as the research object and takes advantage of the evolutionary game model to investigate the behavior selection of government regulatory authorities, third-party monitoring agencies, and electric power market internal monitoring organizations under the circumstance of information asymmetry and limited rationality, in order to identify the problems and obstacles that exist in the actual operation of the internal and external monitoring mechanism in the power spot market so as to provide conducive suggestions for the government to effectively introduce and establish a truly independent third-party monitoring. The remainder of this study is structured as follows. **Section 2** presents a review of the related literature works, followed by the model hypothesis, model building, and analysis in **Section 3**. Conclusion and policy suggestions are presented in **Section 4**.

## 2 LITERATURE REVIEW

Electricity market monitoring plays a key role under the conditions of free electricity market. (Chen et al., 2018; Xu et al., 2021). The core purpose of electric power monitoring is



to ensure the efficient, fair, open, and impartial operation of the electric power market, meanwhile maximizing market efficiency and social benefits without damaging the power reliability and stability (Pinczynski and Kasperowicz, 2016; Du et al., 2021; Halkos and Nomikos, 2021). Power market operation monitoring can master the situation of the power market in real time by closely tracking the adjustment or addition of trading varieties, trading rules, trading parameters, and changes in related policies, thus identifying potential problems and risks in advance and then providing the reference for establishing the market simulation mechanism.

Therefore, the issues in the monitoring of the electricity market and prevention of incorrect electric usage behavior have attracted worldwide attention in the research field of the competitive electricity market (Lisin et al., 2016; Cheng and Yao, 2021), which has been fully embedded in sustainable energy development strategies. Many scholars have carried out research studies on the construction of the market monitoring index system and the measurement and monitoring of market power in the electric power market. In the research field of the measurement index of the electric market, (Lin et al., (2002) based on the market structure design, the concentration ratio (CR) has been proposed. Gan and Bourcier (2002a) and Gan and Bourcier (2002b) put forward the must-run ratio (MRR) index based on market supply and demand. Ding et al. (2003) put forward market price controllable (MPC). The Lerner index (LI) is presented by Zhao et al. (2003) based on the market efficiency design. In addition, Patton (2003) brings forward the Residual Supply Index (RSI), and Bataille et al. (2019) proposed the “Return on Withholding Capacity Index” (RWC) as a complementary index to the RSI. Amanibeni (2021) proposes a comprehensive approach for market power detection based on a centrality concept in social network analysis (SNA), and the obtained results show that SNA can be used as an effective tool for monitoring the market power in future smart grids with a plenty of players and complexity. These indexes, respectively, provided ideas and methods for the measurement and evaluation of the sellers’ market power in the electricity market from different perspectives, reflecting the size and changing rules of the market power and providing a lot of valuable information for the electricity market monitoring. After an overview of various indicators, Yu et al. (2022)

analyzed and summed up the United States, Nordic, and Singapore electricity market monitoring indicator system design. Finally, the theoretical characteristics of each index and its advantages and disadvantages in the application are summarized, which has an enlightening effect on the countermeasures of multiple transaction entities in China’s electricity market.

In discussing the research on the establishment of monitoring institutions in the electricity market, Patton (2003) provided a brief overview of the positioning of electricity market monitoring agencies and recommended specific solutions to monitor the market power and market operation. Rahimi and Sheffrin (2003) summarized an effective market design and the key elements required to implement the market monitoring system, and then pointed out that the effectiveness of the electricity market is ensured by monitoring market inefficiencies, the possibility of market power abuse, and market power issues. By studying the monitoring experience of the electric power market in Britain, California, New Zealand, Spain, and other countries, Wolak (2005) expounded on the procedures of market monitoring and the independence of market monitoring procedures. Garcia and Reitzes (2007) elaborated on the reasons for the emergence of market power in the electricity market and the necessity of setting up an independent market monitoring agency for the electricity market. They also described some commonly used methods for monitoring the electricity market and weakening market power and finally drew conclusions about the approaches in practice and the reasons behind policy differences. Zhao et al. (2008) built a monitoring system for helping the regulator make decisions on the market policy and predicting the future market scenarios, which consists of a price forecast mechanism and market simulator. With the system theory of electricity market monitoring as its basis and by using principal component analysis, the study conducts empirical analysis on the operation of the electric power market in California from 2000 to 2007, which proved the practicality and importance of the electricity market monitoring and early warning function. Gao et al. (2008), Michaels (2008) took RTO and market monitoring institutions (MMI) as examples to study the important role which market monitoring agencies play in power market monitoring, such as supervising the electricity market competition to ensure that the

electricity transaction will not be manipulated by the market power of the generator. Yang et al. (2021) investigated the development status of the power spot market in Gansu from the perspectives of power structure and transaction mode and also expounded the necessity and path for establishing the market monitoring mechanism.

From the previous literature, it can be discovered that most of the existing literature works focus on the monitoring of the power market from the perspective of monitoring methods and the evaluation of monitoring results, and little attention is paid to who should take the monitoring role, which means that the monitoring mechanism is not known. Currently, there are three main monitoring modes, namely, the government supervision, internal monitoring, and independent third-party monitoring. In Australia, New Zealand, and Europe, the government takes the role of monitoring, while PJM in the United States belongs to third-party monitoring. Due to their functions and complex interest relationships, the government and internal monitoring organizations cannot be well qualified for power market monitoring. However, it is very difficult to ensure the complete independence of China's electric power market monitoring if the European and American monitoring models are replicated. Therefore, introducing third-party monitoring agencies to form an internal and external monitoring mechanism which suits China's national conditions has become an important step for China's electric power market reform and design. This was also the aim of this study. Under the theoretical framework of evolutionary game, this study constructed two models: one is the coordinated and balanced game model between third-party monitoring agencies and internal monitoring organization, and the other is the asymmetry evolutionary game model between interest groups, which consist of third-party monitoring agencies and internal monitoring organization, and government regulatory agencies, aiming to investigate how to guarantee the independence of third-party monitoring and the reliability and effectiveness of monitoring results to the maximum content under the internal and external monitoring mechanism.

### 3 MODEL CONSTRUCTION

As a crucial economic analysis tool, game theory has been widely used in various fields to explain some social phenomena (Su et al., 2018a; Su et al., 2018b; Ma and Sun, 2018; Xie et al., 2018). Based on the bounded rationality and incomplete information of the participants, evolutionary game theory breaks through the condition of complete rationality of traditional games, which has greatly developed game theory, making it more applicable (Smith, 1976). The operation efficiency of the dual-monitoring mechanism in the electricity market is the result of the continuous study of the respective interests of the system composed of government regulatory authorities, internal monitoring organizations, and third-party monitoring agencies and then adjusting its strategy accordingly, which is consistent with the evolutionary game theory. Therefore, by adopting the

evolutionary game theory as the analysis tool and researching the evolution of participants' strategies, this article finds out the underlying factors that propel government regulatory authorities, third-party monitoring agencies, and internal monitoring organizations to falsify supervision results and affect their strategic choices under evolutionary stability and equilibrium and then put forward some suggestions so that the monitoring efficiency of the power spot market can be improved.

### 3.1 Model Hypothesis and Building

The dual-monitoring mechanism of the electricity market refers to internal market monitoring organizations and third-party monitoring agencies complementing each other. Monitoring agencies are in a favorable position compared with the electricity market participants as a result of information asymmetry. Market internal monitoring organizations have potential interest relationships with power generators, while nowadays the independence of third-party monitoring agencies cannot be guaranteed, so the public must resort to government authorities to supervise in order to defend their own interests. Internal market monitoring organizations and third-party monitoring agencies are all for the purpose of making profits, while government supervision is mandatory and aims to ensure the effective operation of the market. Therefore, according to the purpose and status of each monitoring subject, we defined the market internal monitoring organization and third-party monitoring agencies as interest group 1 and government regulatory authorities as interest group 2, to investigate the game equilibrium results between the two interest groups. At the same time, there is also a game within the interest group 1, and the result of the game will directly exert influence on the government's regulatory strategy. In particular, this section will construct two evolutionary game models for market internal monitoring organizations, third-party monitoring agencies, and government regulatory agencies: (1) the equilibrium game model between the third-party monitoring agencies and the internal market monitoring agencies within the interest group 1; (2) the asymmetric evolutionary game model between interest group 1 and interest group 2. The game relationships between the three stakeholders are shown in Figure 1.

### 3.2 Game Between Third-Party Monitoring Agencies and Internal Market Monitoring Organizations

#### 3.2.1 Basic Assumptions and Model Analysis

Under the internal and external monitoring mechanism, market monitoring is mainly conducted by the internal monitoring organizations of the electricity market trading and dispatching agencies and independent third-party monitoring agencies. On the one hand, because the monitoring reports and recommendations are made by third-party monitoring agencies and internal monitoring organizations, other power market participants have no access to know their authenticity due to information asymmetry. Therefore, third-party agencies

and internal monitoring organizations are susceptible to power rent-seeking. On the other hand, it is not easy for third-party monitoring agencies to become truly independent. Even in the North American power market where the third-party monitoring model has been more mature, there are many contradictions and obstacles for independent third-party monitoring agencies, such as the tangible or intangible intervention from the monitored market participants' management level, or third-party monitoring agencies' budgets being actually controlled by some monitored participants. Moreover, China's current electricity management system cannot provide a sound independent environment for third-party monitoring agencies, so it is hard for third-party monitoring agencies to publish unconstrained reports. In order to prevent power rent-seeking, supervision from government authorities plays an indispensable role in the internal and external monitoring mode. However, the supervision from government authorities has limitations, so third-party monitoring agencies and market internal monitoring organizations may conspire with each other to jointly conceal the true monitoring information or selectively publish reports that are beneficial to power generators. In addition, one of them may resort to power rent-seeking, too. Based on the aforementioned analysis, the hypotheses are proposed as follows:

**Hypothesis 1:** the strategy set of the third-party monitoring agencies and the internal market monitoring organizations is {conspiracy, non-conspiracy}.  $x(t)$  represents the probability of third-party monitoring agencies and the internal market monitoring organizations choosing a strategy of conspiracy, where  $t$  refers to the time,  $x(t) \in [0, 1]$ .

**Hypothesis 2:** the probability of the conspiracy being exposed by the government regulatory department is  $P$ , while the probability of not being exposed is  $1 - P$ . When only one party chooses power rent-seeking, the probability of being investigated by the government regulatory authorities is  $P'$ , and the probability of successfully avoiding supervision is  $1 - P'$ . Normally, conspiracy is easier to get away with the supervision of government regulatory authorities, so this article assumes  $P' \geq P$ , which means the possibility of one-party power rent-seeking being exposed is greater.

**Hypothesis 3:** when the conspiracy is discovered and punished by government regulators, both parties will be fined  $-F'$  ( $F' \geq 0$ ). In the meantime, they will suffer losses  $S'$  ( $S' \geq 0$ ) due to their bad reputation and the decline of credibility among the public. If it is not found, both parties will be benefitted  $F$  ( $F \geq 0$ ). When one of them resorts to power rent-seeking and is discovered by the government regulatory authorities, it will be fined  $-T'$  ( $T' \geq 0$ ), and at the same time suffer losses  $S$  ( $S \geq 0$ ) due to the worsening of their social reputation and credibility. Otherwise, the monitoring agency gets a positive return  $T$  ( $T \geq 0$ ).

We assumed a medium risk for third-party monitoring agencies and the internal market monitoring organizations, and the payoff matrix is shown in **Table 1**.

### 3.2.2 Game Equilibrium Analysis

Under government supervision, there is information asymmetry between government departments, third-party monitoring agencies, and market internal monitoring organizations that will make the game participant judge the strategies of other game participants based on historical experience, and they will continuously learn and adjust their own strategy in trials. Consequently, the dynamic adjustment of third-party monitoring agencies and internal market monitoring organizations' strategies can be reflected by the replication dynamic process in the evolutionary game. Based on the payoff matrix in **Table 1**, this study computed the replicator dynamics equations of third-party monitoring agencies and internal market monitoring organizations and conducted analysis of the stability of their strategies, respectively.

$U_x^1$  stands for the expected return when a third-party monitoring agency chooses to conspire, and  $U_{1-x}^1$  indicates the expected return when it chooses not to conspire and the average expected return is  $\bar{U}_1$ ; the equations are as follows:

$$U_x^1 = x \cdot [P \cdot (-F' - S') + (1 - P) \cdot F] + (1 - x) \cdot [P' \cdot (-T' - S) + (1 - P') \cdot T], \tag{1}$$

$$U_{1-x}^1 = 0, \tag{2}$$

$$\bar{U}_1 = xU_x^1 + (1 - x)U_{1-x}^1. \tag{3}$$

Likewise,  $U_x^2$  denotes the expected return when a market internal monitoring agency chooses to conspire,  $U_{1-x}^2$  is the expected return when it chooses not, and  $\bar{U}_2$  represents the average expected return; the equations are, respectively, as follows:

$$U_x^2 = x \cdot [P \cdot (-F' - S') + (1 - P) \cdot F] + (1 - x) \cdot [P' \cdot (-T' - S) + (1 - P') \cdot T], \tag{4}$$

$$U_{1-x}^2 = 0, \tag{5}$$

$$\bar{U}_2 = xU_x^2 + (1 - x)U_{1-x}^2. \tag{6}$$

Since the game is a symmetrical game, the replicator dynamics equations of third-party monitoring agencies and market internal monitoring organizations selecting conspiracy strategy are the same, which are shown in **Eq. 7**.

$$G(x) = \frac{dx}{dt} = x(U_x - \bar{U}) = x(1 - x) \cdot \{x \cdot [P \cdot (-F' - S') + (1 - P) \cdot F] + (1 - x) \cdot [P' \cdot (-T' - S) + (1 - P') \cdot T]\}. \tag{7}$$

Three equilibrium solutions are derived from  $G(x) = 0$ , which are  $x_1 = 0$ ,  $x_2 = 1$  and  $x_3 = -[P' \cdot (-T' - S) + (1 - P') \cdot T] / [P \cdot (-F' - S') + (1 - P) \cdot F - P' \cdot (-T' - S) - (1 - P') \cdot T]$ .

It should be denoted that  $A = P \cdot (-F' - S') + (1 - P) \cdot F$  and  $B = P' \cdot (-T' - S) + (1 - P') \cdot T$ , which, respectively, indicate the

expected utility of colluding by two parties and colluding by one party alone. When  $P' > T'/(T' + T + S)$ ,  $B < 0$ . When  $P' < T'/(T' + T + S)$ ,  $B > 0$ . In order to investigate the violations of third-party monitoring agencies and internal monitoring organizations, this study only focused on  $B < 0$ . Similarly, when  $P > F/(F' + F + S')$ , we have  $A < 0$ . When  $P < F/(F' + F + S')$ ,  $A > 0$  is obtained. If the government supervision authorities do not fully fulfill their responsibility of supervising, the conspiracy between third-party monitoring agencies and the market internal monitoring organizations is unlikely to be found. If they are exposed soon after the conspiracy, they will not suffer serious economic penalties and that means  $F'$  is small. In this case, we have  $A > 0$ . When  $A > 0$  and  $B < 0$ , we have  $G(0)' < 0$ ,  $G(1)' < 0$ , and  $G(x_3)' > 0$ . It can be obtained from the stability theorem of the differential equation that  $x_1 = 0$  and  $x_2 = 1$  are the two stable equilibria of the game model, and the dynamic phase diagram of the game model is shown in **Figure 2**.

As shown in **Figure 2**, (conspiracy, conspiracy) and (non-conspiracy, non-conspiracy) may be the stable equilibrium strategy solution of the evolutionary game system. The final convergence point of the long-term evolution of the system will finally converge depending on the value of parameters  $(P, P', F', F, T', T, S', S)$  and the setting of the initial state of the game. In particular, if the initial value of  $x$  falls in the interval  $(0, -B/(A - B))$ , the evolution model will finally stabilize at  $x_1$ . If the initial value of  $x$  falls in the interval  $(-B/(A - B), 1)$ , the evolution model will finally stabilize at  $x_2$ . The larger the  $-B/(A - B)$ , the more conducive it is for the evolutionary game system to converge to the equilibrium point (non-conspiracy, non-conspiracy).

### 3.3 Game Between Government Regulators and Interest Group 1

#### 3.3.1 Basic Assumptions and Model Building

We defined violations as rent-seeking unilaterally or colludingly by third-party monitoring agencies and internal agencies, so we assumed that the behavioral strategy set of the interest group 1 comprising third-party monitoring agencies and internal market monitoring organizations is {violation, non-violation}. The behavioral strategy set of interest group 2, namely, the government regulatory authorities that represent the appeal of the public interest, is {supervision, non-supervision}. In this model,  $y(t), z(t)$  stands for the probability of interest group 1 choosing violation and interest group 2 choosing supervision, while  $t$  is time and  $y(t), z(t) \in [0, 1]$ .  $Q$  indicates the probability of the violation of interest group 1 successfully being discovered when the government regulatory authorities choose to supervise. Similarly,  $Q'$  represents the probability of interest group 1's violations being discovered and punished when interest group 2 chooses not to supervise, and  $Q > Q'$ . When the violation of interest group 1 is exposed by the government regulatory authorities, the penalty it received is  $N$ , and  $M$  denotes the gain when its violation is not discovered. When the electricity market monitoring works well (including the

exposure of violations by interest group 1 and interest group 1 choosing non-violation), the positive effect acquired by interest group 2 is also  $M$ . In addition, the supervision cost of interest group 2 is  $C$ . Assuming that interest group 1 and interest group 2 are risk-neutral, the payoff matrix of this game model is shown in **Table 2**.

#### 3.3.2 Game Equilibrium Analysis

From **Table 2**,  $U_y$  stands for the expected return when interest group 1 chooses violation, and  $U_{1-y}$  represents the expected return when the non-violation is selected, and the average expected return is  $\bar{U}_1$ , so the equations are as follows:

$$U_y = z \cdot [Q \cdot (-N) + (1 - Q) \cdot M] + (1 - z) \cdot [Q' \cdot (-N) + (1 - Q') \cdot M], \tag{8}$$

$$U_{1-y} = 0, \tag{9}$$

$$\begin{aligned} \bar{U}_1 &= yU_y + (1 - y)U_{1-y} \\ &= y \cdot \{z \cdot [Q \cdot (-N) + (1 - Q) \cdot M] + (1 - z) \cdot [Q' \cdot (-N) + (1 - Q') \cdot M]\}. \end{aligned} \tag{10}$$

Therefore, the replicator dynamics equation of interest group 1 choosing violation is as follows:

$$\begin{aligned} G(y) &= \frac{dy}{dt} = y(U_y - \bar{U}_1) \\ &= y(1 - y) \cdot \{z \cdot [Q \cdot (-N) + (1 - Q) \cdot M] + (1 - z) \cdot [Q' \cdot (-N) + (1 - Q') \cdot M]\} \\ &= y(1 - y) \cdot [z \cdot (Q' - Q) \cdot (N + M) + Q' \cdot (-N) + (1 - Q') \cdot M]. \end{aligned} \tag{11}$$

Similarly,  $U_z$  is the expected return when the interest group 2 chooses supervision, and  $U_{1-z}$  denotes the expected return when it chooses non-supervision, and the average expected return is  $\bar{U}_2$ , and the equations are as follows:

$$U_z = y \cdot (Q \cdot M - C) + (1 - y) \cdot (M - C), \tag{12}$$

$$U_{1-z} = y \cdot (Q' \cdot M) + (1 - y) \cdot M, \tag{13}$$

$$\begin{aligned} \bar{U}_2 &= zU_z + (1 - z)U_{1-z} \\ &= z \cdot [y \cdot (Q \cdot M - C) + (1 - y) \cdot (M - C)] + (1 - z) \cdot [y \cdot (Q' \cdot M) + (1 - y) \cdot M]. \end{aligned} \tag{14}$$

Therefore, the replicator dynamics equation of interest group 2 choosing violation is as follows:

$$\begin{aligned} G(z) &= \frac{dz}{dt} = z(U_z - \bar{U}_2) \\ &= z(1 - z) \cdot [y \cdot M \cdot (Q - Q') - C]. \end{aligned} \tag{15}$$

Simultaneous **Equations 11** and **15** and **Eq. 16** can be obtained.



$$\begin{cases} G(y) = y(1-y) \cdot [z \cdot (Q' - Q) \cdot (N + M) + Q' \cdot (-N) + (1 - Q') \cdot M] = 0, \\ G(z) = z(1-z) \cdot [y \cdot M \cdot (Q - Q') - C] = 0. \end{cases} \quad (16)$$

By solving Eq. 16, all the strategic equilibrium solutions of the evolutionary game model can be obtained, which are  $E_1(0, 0)$ ,  $E_2(0, 1)$ ,  $E_3(1, 0)$ ,  $E_4(1, 1)$ , and  $E_5\left(\frac{C}{M \cdot (Q - Q')}, \frac{M - Q' \cdot (M + N)}{(Q - Q') \cdot (N + M)}\right)$ .

The Jacobian matrix is shown as Eq. 17.

$$J = \begin{pmatrix} (1-2y) \cdot [z \cdot (Q' - Q) \cdot (N + M) + Q' \cdot (-N) + (1 - Q') \cdot M] & y(1-y)(Q' - Q) \cdot (N + M) \\ (1-2z) \cdot [y \cdot M \cdot (Q - Q') - C] & z(1-z) \cdot y \cdot M \cdot (Q - Q') \end{pmatrix}. \quad (17)$$

According to Lyapunov stability theory, when the trace of the Jacobian matrix is less than 0 and the determinant is bigger than 0, the equilibrium point is the stability point. Based on the theory, an analysis of the stability of each local equilibrium point is conducted, and the results are shown in Table 3.

It is easy to obtain from the aforementioned analysis that  $X''$  represents the relative net payment of the government regulatory authorities choosing non-supervision and interest group 1 choosing violation.  $X'$  is the relative net payment of interest group 1 when government regulatory authorities choose supervision while interest group 1 chooses violation.  $Y' - Y'' - C$  stands for the relative net payment of interest group 1 choosing violation, and then, the government regulatory authorities choose supervision.

This study assumes that  $1 > Q > Q' > 0$  and  $C > 0$ , and  $X'' > X'$ ,  $M > Y' > Y''$ . Since the parameters are different, this study carries out an analysis on four cases.

**Case 1:** if the government authorities do not fully fulfill their regulatory responsibilities and  $C > A$ ,  $Q'$  tends to zero, the game system will converge to  $E_3(1, 0)$ . In this case, for interest group 1, no matter which strategy the government regulators choose, the relative net payment of interest group 1 always remains positive, so interest group 1 tends to violate the rules. As for the government regulators, whether the interest group 1 violates or not, the relative net payment of government regulators is always positive when they do not supervise, so they are prone to not to supervise, and the game system is ultimately stable at (violation, non-supervision).

**Case 2:** if the government authorities do not fully fulfill their regulatory responsibilities and  $Q'$  tends to zero,  $C < Y'$  and  $X' > 0$ , the game system will converge to  $E_4(1, 1)$ . Under this circumstance, whether the government regulators choose to supervise or not, the relative net payment of interest group 1 always stays positive; therefore, interest group 1 is inclined to violate the rules. As for the government regulators, whether interest group 1 violates the rules or not, the relative net payment that the regulatory department chooses to regulate is always positive; hence, the regulators tend to supervise. Also, the game system is finally stable at (violation, supervision).

**Case 3:** if the government authorities do not fully fulfill their regulatory responsibilities and  $Q'$  tends to 0,  $C < Y'$ ,  $X' < 0$ , neither interest group 1 nor government regulatory authorities would gain benefit. Consequently, there is no stable local equilibrium.

**Situation 4:** when the government authorities fully fulfill their regulatory responsibilities,  $X'' < 0$  and  $Y' - Y'' - C < 0$ , the game system will converge to  $E_1(0, 0)$ . In this context, whether the government regulatory authorities supervise or not, the relative net payment of interest group 1 for non-violation is always positive, so interest group 1 tends not to violate. For the government regulators, whether the interest group 1 violates the rules or not, the relative net payment that it chooses not to regulate is always positive; thus, the regulators tend not to supervise. Therefore, the game system is ultimately stable at (non-violation, non-supervision).

Combined with the reality of the electricity market operation, currently government regulatory authorities do not fully fulfill the regulatory duty and the cost of supervision is too high, given that the only incentive for them is their wages. In addition, it is also difficult for other market entities in the power market to supervise interest group 1; hence, the game system satisfies the conditions in case 1, converging to (violation, non-supervision), which is unsatisfying. In the game between interest group 1 and interest group 2, points  $E_1(0, 0)$  and  $E_4(1, 1)$  are superior to points  $E_3(1, 0)$ , among which  $E_1(0, 0)$  is the optimal strategic point. If the game is to stabilize at the local equilibrium point  $E_4(1, 1)$ , the penalty should be reduced to satisfy the condition of  $X' < 0$ , and the supervision cost  $C$  should be reduced to make  $C < Y'$ . If the game system is finally stable at  $E_1(0, 0)$ , the supervision should be strengthened, which means  $Q'$  should be increased, and penalty  $N$  should be increased too so that  $Y' - Y'' - C$  will change from positive to negative.

## 4 SIMULATION ANALYSIS

### 4.1 Simulation Study on the Game Between Third-Party Monitoring Agencies and Internal Market Monitoring Organizations

To analyze the impacts of different parameters on the evolutionary process specifically, we further used the MATLAB simulation tool to conduct the sensitivity analysis of the evolutionary game model proposed in Section 3.2. First, in order to explore the impact of government department supervision intensity on the strategic choice of internal market monitoring organizations and third-party monitoring agencies, this study carried out the numerical simulations of evolutionary game paths under different  $p$ -values. The initial values of parameters are set as  $F' = 20$ ,  $S' = 20$ ,  $F = 200$ ,  $S = 20$ ,  $P' = 0.8$ ,  $T' = 40$ ,  $T = 100$ , and  $P$  is set as 0.6, 0.8, and 1.0, respectively. The simulation results are shown in Figure 3. The horizontal axis represents the evolution time, and the vertical axis represents the proportion of third-party monitoring agencies and internal market monitoring organizations that chose the “conspire” strategy. As can be seen from Figure 3, as the collusion probability between third-party monitoring agencies and internal market monitoring organizations being detected by government regulatory departments increases gradually, both parties will turn to the strategy of “not conspire” more quickly under different initial probabilities of collusion, and finally, the game equilibrium converges to  $x = 0$ . In other words, the increase of  $P$  significantly

accelerates the game evolution convergence. With the increase in iteration steps, the third-party and the market monitoring agency finally choose not to collude. In addition, as the third-party monitoring agency and internal market monitoring organizations know that their behaviors will be strictly supervised by the government regulatory department, the probability of choosing the strategy “not conspire” for them will be higher.

The asymptotic stability analysis of the evolutionary game in **Section 3.2** shows that the game equilibrium between the third-party monitoring agencies and the internal market monitoring organizations is closely related to the cost and benefit under different strategic choices. In order to describe more intuitively the evolution trajectory of the game between third-party monitoring institutions and market monitoring institutions under different collusive benefits and different levels of punishment from government and public, respectively, we, then, further made the sensitivity analysis for each model parameter. In particular, we simulated the evolution path of game system equilibrium under different value combinations of  $F'$  and  $T'$ ,  $F$ , and  $T$ ,  $S'$ , and  $S$ , respectively. The  $p$ -value was set as 0.8. In the following analysis, except for the parameters under study, the values of other parameters were consistent with those previously set. The simulation results are shown in **Figures 4–6**. Still, the horizontal axis represents the evolution time, and the vertical axis represents the proportion of third-party monitoring agencies and internal market monitoring organizations that chose the “conspire” strategy. As can be seen from **Figure 4**, the higher the potential penalty faced by third-party monitoring institutions and internal market monitoring institutions, the higher the probability of both parties choosing the “not conspire” strategy, and the faster the game equilibrium converges to the point  $(0, 0)$ . In other words, higher financial penalties may force the monitoring agencies to make decisions that comply with relevant laws and regulations. Therefore, the government should consider increasing the financial penalty for the rent-seeking behavior of monitoring institutions so as to increase the potential economic cost of collusion between third-party monitoring agencies and internal market monitoring institutions and prevent their rent-seeking behavior.

When third-party monitoring agencies and internal market monitoring organizations choose not to implement effective inspection and tend to collude, they will suffer certain losses due to their bad reputation and reduced credibility among the public once their rent-seeking behavior is disclosed. It can be seen from **Figure 5** that when the value of the losses due to the adverse social influence increases, the evolution speed of both third-party monitoring agencies and internal market monitoring organizations in choosing “not conspire” will increase, which leads to the persistent choice of “not conspire” of both parties. In addition, as the monitoring agencies know that their behavior will be subjected to strict public supervision and the rent-seeking behavior will have a serious negative impact on their reputation, the probability that they choose the “not conspire” strategy will be higher. Therefore, the government can strengthen the information disclosure of non-compliant power monitoring agencies so as to give full play to the effective supervision role of the society. In addition, it is necessary to reduce the public’s tolerance for the illegal rent-seeking behavior of monitoring agencies so that the monitoring agencies will generate greater social pressure when they choose a “collusion” strategy. This will more effectively prevent the collusion

between third-party monitoring agencies and internal market monitoring organizations.

The impact of the benefit gained by the monitoring agencies for rent-seeking behaviors on the two stakeholders’ strategy selection process is shown in **Figure 6**. We can find that when the profit that both third-party monitoring agencies and internal market monitoring organizations may get from their collusion behavior is lower, the probability of the two stakeholders choosing the strategy “not conspire” will approach 1 more quickly in the long run. This illustrates that the lower potential benefits of collusion by the monitoring agencies are conducive to better realizing the functions of both third-party monitoring agencies and internal market monitoring agencies, thus conducting effective and fair monitoring of the operation of the electricity market.

## 4.2 Simulation Study on the Game Between Government Regulators and Interest Group 1

**Figure 7** shows the simulation results of equilibrium point  $E_1(0, 0)$  of the game between government regulators and interest group 1. The initial values of each parameter are set as  $Q = 0.2$ ,  $Q' = 0.4$ ,  $N = 50$ ,  $M = 15$ , and  $C = 5$ . It can be seen that as the number of iterations increases, the proportion of interest group 1 choosing not to violate regulations keeps on increasing, while the proportion of government regulatory departments choosing to regulate keeps on decreasing. We can also find that the probability of the two stakeholders choosing strategies “Non-Violation” and “Non-Supervision” will approach 1 more quickly in the long run. In **Figure 8**, we described the influence of the parameter  $Q$  on the evolutionary process of the two stakeholders’ strategies under the same parameter setting. It can be seen that as the probability of the violation of interest group 1 successfully being discovered when the government regulatory authorities choose to supervise gradually increases, the proportion of interest group 1 formed by third-party monitoring agencies and internal market monitoring agencies choosing not to violate regulations gradually increases. Also, the increase in  $Q$  significantly accelerates the convergence process of game equilibrium toward  $(0, 0)$ . Faced with stricter government supervision measures, the power monitoring agencies know that their collusive behaviors are more likely to be detected and will suffer certain losses. Then, they will tend to choose not to violate. Therefore, the severe crackdown on violations by the government regulatory authorities can play a certain deterrent effect on power monitoring agencies so that the psychological expectations of power monitoring agencies for their violations to successfully escape government supervision continue to decrease. As the behavior of power monitoring agencies becomes more standardized and the proportion of violations continues to decrease, the government is more inclined to not supervise, and the system equilibrium will tend to be stable at the point  $(0, 0)$ .

## 5 CONCLUSIONS AND SUGGESTIONS

At present, China’s electricity spot market is still in its initial stage, and the market rules need to be further improved. Some

unavoidable deficiencies or loopholes in the market rules give market participants the opportunity to manipulate the market. Therefore, only by closely monitoring the operation of the power market can the construction of the power market be further promoted. A set of the comprehensive regional power market monitoring system can make a difference in ensuring the effective operation of the electric power market, avoiding uneconomic incentives resulting in market design and making sure that laws and regulations are well obeyed during market operation. Currently, among all mainstream monitoring modes, the internal and external monitoring mechanism is a monitoring mode that is adapted to China's current national situation, the power grid situation, and the progress of the power spot market. However, restricted by China's power management system, the independence of third-party monitoring agencies cannot be guaranteed. Consequently, third-party agencies may yield to the temptation of profit or to the pressure exerted by stakeholders and conspire with internal monitoring organizations, resulting in power rent-seeking. Based on this fact, this study constructed the evolutionary game models between the third-party monitoring agency and the internal monitoring organization of the power market, as well as between the interest groups constituted by internal and external monitoring agencies and the government regulatory authorities, respectively. Through the analysis of the evolution of participants' strategies, the following conclusions have been drawn:

- (1) Third-party monitoring agencies and market internal monitoring organizations are more inclined to conspire with each other to seek profit, with the main reason being a relatively high profit can be obtained through conspiracy and power rent-seeking. Therefore, in order to prevent the conspiracy, it is necessary to reduce the profits they can get through conspiracy. In particular, the greater the probability that the government regulatory department finds the collusion of monitoring institutions and the economic penalty for the collusion, the greater is the negative social impact that monitoring institutions suffer from the disclosure of the violation, which is conducive to the evolution of the game system to the ideal state.
- (2) Third-party monitoring agencies tend to choose violation strategies because it is profitable to fabricate results or take the path of power rent-seeking with pollutant discharging enterprises. But the fundamental reason is that the independence of the third-party monitoring agencies cannot be guaranteed. For example, an interest relationship may be found between the staff of the third-party monitoring agencies and the monitored entities. Therefore, the key point of lowering third-party violation is to cut off such interest links and reduce the benefits obtained by third-party monitoring agencies obtained from illegal practices.
- (3) The cost of long-term supervision by government regulatory authorities is relatively high, and there are no additional rewards for them. So it is inevitable that there is no regulatory motivation, and long-term effective supervision cannot be conducted. For government regulators, although negligence will be punished, if the net income for fulfilling their duty of supervising is less than the penalty for negligence, then, non-supervision will be a better choice. Therefore, raising the cost of penalties for regulator failure can motivate the supervisors to perform their duties.

The key element for the effectiveness of the electricity market's internal and external monitoring mechanism lies in the independence of third-party monitoring agencies, and government monitoring can be carried out cost-effectively and effectively. Combined with the conclusions of this study, the following policy suggestions are put forward:

- (1) Continuously to improving relevant laws and regulations and continuously promoting the improvement of electricity market supervision laws and regulations; at the same time, efforts should be made to implement the requirements and penalties for the violations of various laws and regulations.
- (2) Local government can employ several part-time but professional and authoritative people to form a monitoring team. The team members are only responsible for reporting the monitoring results to the government regulators and are authorized to publish monitoring reports in fixed terms. At the same time, the trading center must guarantee the independence of internal monitoring personnel and cannot interfere with its work or review the monitoring result. In this way, the independence of monitoring agencies is guaranteed without paying too much cost.
- (3) Third-party monitoring agencies should be authorized by government regulatory authorities and publish monitoring reports regularly. Market trading and dispatching institutions have no right to neither intervene in "third party" monitoring nor review the monitoring report in advance. The trading center should charge the "market monitoring fee" to all market participants to offset the operation cost of "third-party" monitoring agencies and ensure their financial independence.

Based on the earlier research, subsequent research can explore the impact of the evolutionary stability strategies of each game subject on the market efficiency from the perspective of the electricity market. It is also advisable to explore the impact of the evolutionary stability strategy of each game player on social welfare.

## 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

LJ: responsible for model building and analysis. WL: responsible for variable selection and literature review. CC: responsible for data processing. JJ: responsible for textual content writing. WW: ideas; formulation or evolution of overarching research goals and aims and proposed innovative points.

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