

Research Article

Game Research on Coal Mine Workers' Off-Post Behaviors

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In order to seek for causes and solutions of off-post behaviors of coal miners, static and evolutionary games were utilized on the basis of an established strategy simulation model between coal mine enterprise and coal miners. These games were used to determine the revenue matrix of two game parties given off-post behaviors of coal miners from two levels (coal miners and coal mine enterprise). Thus, equilibrium and dynamic evolutionary analyses of the two parties should be conducted. Results indicated that, in the enterprise's perspective, inspection cost and punishment intensity are important factors that influence the safety production and economic benefit of coal mine enterprises; in the coal miners' perspective, wage loss and the constraint degree it generates are essential factors. Furthermore, these factors constitute a key to solving off-post behaviors of coal miners. Reasonability of the established simulation model was analyzed and verified on the basis of off-post behaviors of workers from a coal mine that belongs to Yanzhou Coal Mining Co., Ltd. The coal mine enterprise should enhance the inspection of safety production and establish scientific and complete off-post punishment mechanism. Moreover, the coal mine enterprise should provide proper compensation, treatment, and reward policies of workers to reduce the off-post behaviors of workers from a coal mine enterprise effectively.

1. Introduction

Safe production and occupational health have constantly been the focus of attention in industrial development, especially in the coal industry with a high rate of accidents [1, 2]. Coal miners are faced with more dangerous and more severe working environment than workers from other industries. Frequent coal mine accidents seriously affect the safety situation of China's coal industry and sustainable socioeconomic development as a whole [3, 4]. In recent years, survey and analysis reports over several coal mine accidents in China have confirmed that off-post problems of coal miners play a key role.

Over the years, the Chinese government has continuously intensified the safety management of coal mine enterprises, thus considerably improving coal mine safety production. Many domestic and foreign experts and scholars have conducted several studies that focused on coal mine safety management and anti-accident planning simulation; Kinilakodi and Grayson [5] found that many unsafe factors result in accidents and occupational injuries, thereby threatening the

coal mine enterprise production. Sanmiquel et al. [6] used Weka software in analyzing a coal mine disaster in Spain and obtained several behavioral patterns in accordance with certain rules to help coal mine enterprises formulate appropriate accident-prevention policies and effectively reduce accidents and casualties. Mahdevari et al. [7] proposed an evaluation method based on fuzzy TOPSIS and addressed health and safety concerns of underground workers in a coal mine. This method can support the formulation of coal mine management measures and provide a proper balance between different problems, such as coal mine safety and cost.

Zheng et al. [8] studied the behavior of senior managers toward safety in the mining industry and believed the behavior of senior managers plays a significant role in the safe operation of the mining industry. Wang et al. [9] utilized the basic principles of evolutionary game to establish the exit mechanism of regional high-energy-consuming industries innovatively, thereby placing the emphasis on analyzing the influencing factors of the strategy selection of game subjects that can demonstrate the influence of decision parameters

of evolution results through numerical simulation. Tong et al. [10] expounded basic features and properties of unsafe behaviors of coal miners from eight dimensions (i.e., time, behavioral track, position, behavioral properties, behavioral individuals, degree, unsafe behaviors, and profession); furthermore, these authors effectively improved the safe data processing ability through clustering and correlation analyses, thus providing data support and management foundation for safety management.

Existing studies have indicated that many domestic and foreign scholars have emphasized the unsafe factors of coal mines, coal mine safety production plan, and health of coal miners. Thus, these studies have explored only empirical statistics and analysis with strong subjectivity and have failed to realize an in-depth dynamic analysis of causes for off-post behaviors, including simulation studies of off-post behaviors of coal miners. In fact, an off-post problem is related to individual differences of off-post subjects, that is, among specific occupational groups, where individual interest and job demands fail to match with actual work, thereby causing burnout and eventually off-post behaviors. Off-post behaviors of coal miners will result in low efficiency of enterprise safety output and a decline in economic benefit; furthermore, off-post behaviors in several key posts will result in safety hazards that cannot be identified and disposed of timely, thus triggering accidents, death, personal injury, and other severe consequences [11–13]. Therefore, analyzing the causes of coal miners' off-post behaviors and seeking for solutions will be crucial to improving safety production and economic benefit of coal mine enterprises.

From the angle of behavioral simulation, static and evolutionary game methods were adopted in this study to establish a game model between off-post behaviors of coal miners and enterprise safety inspection. The remainder of this paper is organized as follows: Section 2 establishes the off-post behavioral simulation model between coal miners and coal mine enterprises. In addition, a static game of the revenue matrix of the two game parties is analyzed. Section 3 presents a dynamic analysis of the evolutionary game of coal miners and coal mine enterprise. Based on an empirical analysis of a coal mine enterprise that belongs to Yanzhou Coal Mining Co., Ltd., Section 4 lists a revenue matrix of enterprise inspection; moreover, this section determines that, “under two off-post probabilities of coal miners, an off-post phenomenon of coal miners will be even serious when an enterprise's right of safety inspection is valid or insufficient and an overall safety production output is inefficient; when an enterprise enhances the inspection intensity, most coal miners stand rapidly and remain at their posts and perform their duties, and the enterprise can guarantee safety production.” In the next Section 5, evolutionary game, compared with static game, has advantages in coal mine safety inspection, then we discuss the stable state between off-post behaviors of coal miners and enterprise inspection intensity, solve the off-post problems of coal miners at the lowest cost, and provide three constructive measures of preventing off-post behaviors of coal miners. Section 6 provides the conclusions drawn from this study.

2. Static Game of Complete Information

2.1. Game Model Establishments. A stable state, under which coal miners stick to their posts, leads to a game balance between stakeholders under certain constraint conditions. The following parameters are proposed on this basis: (1) The game has two parties (i.e., coal miners and coal mine enterprise); (2) the game presents two action sets (i.e., $A_1 = \{\text{on-post, off-post}\}$ and $A_2 = \{\text{inspection of coal mine enterprise, no inspection}\}$); (3) the total income of coal miners is T ; (4) the probability for off-post-induced accident is h , and the accident loss of off-post coal miners is L ; (5) the punishment of off-post behaviors of coal miners is P ; (6) if on-post coal miners are affected by off-post ones, then their external loss is W ; (7) the normal benefit of coal mine is N , and the inspection cost of off-post behaviors is C ; (8) when an accident occurs, enterprise loss is B , including accident loss, governmental punishment on the enterprise, and social influence. A cost–benefit matrix is established on the basis of the abovementioned factors, as listed in Table 1.

2.2. Equilibrium Analyses of the Game Model. A mixed strategy Nash equilibrium (MSNE) analysis of Table 1 is conducted in accordance with an actual situation to determine the influence factors of off-post behaviors of coal miners.

If $hL \leq W \leq hL + P$ and $C \leq P$, then the analysis is performed under the following circumstances:

If the probability of inspecting the coal mine enterprise is smaller than, greater than, or equal to $(W - hL)/P$, then the optimal choice of coal miners is to come off, stick to, or remain in the post, respectively.

If the on-post probability of the coal miner is smaller than, greater than, or equal to $(P - C)/P$, then the optimal choice of the coal mine enterprise is inspection, no inspection, or no influence at all, correspondingly.

θ is set as the on-post probability of the coal miner, while $(1 - \theta)$ is the probability for the coal miner to select to come off the post; γ is the probability for the coal mine enterprise to perform the inspection, while $(1 - \gamma)$ is the probability for the enterprise not to select inspection.

The mixed strategy adopted by the coal miner is set as $\sigma_\omega = (1 - \theta, \theta)$.

The mixed strategy of the coal mine enterprise is $\sigma_i = (\gamma, 1 - \gamma)$.

Moreover, an expected utility function of the coal miner is

$$\begin{aligned} v_\omega(\sigma_\omega, \sigma_i) &= (1 - \theta) [\gamma(T - P - hL) + (1 - \gamma)(T - hL)] \\ &\quad + \theta [\gamma(T - W) + (1 - \gamma)(T - W)]. \end{aligned} \quad (1)$$

The differential of the abovementioned equation is solved, and the optimal first-order condition of the coal miner is obtained as

$$\begin{aligned} \frac{\delta v_\omega}{\delta \theta} &= - [\gamma(T - P - hL) + (1 - \gamma)(T - hL)] \\ &\quad + [\gamma(T - W) + (1 - \gamma)(T - W)]. \end{aligned} \quad (2)$$

$\delta v_\omega / \delta \theta = 0$ is set, and $\gamma = (W - hL)/P$ is obtained.

TABLE I: Revenue matrix of gaming parties.

| Item | | Coal mine enterprise | |
|-------------|----------|----------------------------------|------------------|
| | | Inspection | No inspection |
| Coal miners | Off-post | $T - P - hL$ $P + N - C - hB$ | $T - hL, N - hB$ |
| | On-post | $T - W, N - C$ | $T - W, N$ |

Similarly, the expected utility function of the coal mine enterprise is

$$v_i(\sigma_\omega, \sigma_i) = \gamma(1 - \theta)(P + N - C - hB) + (1 - \gamma)[(1 - \theta)(N - hB) + \theta N]. \quad (3)$$

The optimal first-order condition is

$$\frac{\delta v_i}{\delta \gamma} = (1 - \theta)(P + N - C - hB) + \theta(N - C) - [(1 - \theta)(N - hB) + \theta N]. \quad (4)$$

$\delta v_i / \delta \gamma = 0$ is set, and $\theta = (P - C)/P$ can be obtained.

θ and γ are probabilities, and the following inequalities exist:

$$\begin{aligned} 0 &\leq \theta \leq 1 \\ 0 &\leq \gamma \leq 1. \end{aligned} \quad (5)$$

The following inequalities can be obtained by combining Equations (3) – (5):

$$\begin{aligned} hL &\leq W \leq hL + P \\ C &\leq P. \end{aligned} \quad (6)$$

The differential function is smaller than 0, and θ is approximate to 0 when $\gamma < (T - hL)/P$; θ is approximate to 1 when $\gamma > (T - hL)/P$; similarly, γ is approximate to 1, and the mixed strategy is verified when $\theta < (P - C)/P$.

The MSNE analysis requires that the two game parties select pure strategies at specific probabilities [14–16]; that is, either the coal miner that selects coming off the post or the enterprise that performs the inspection has certain decision-making probabilities. Whether the coal miner selects coming off the post is not decided by his/her own interest but by inspection intensity of the enterprise.

3. Evolutionary Game

3.1. Dynamic Analyses of Coal Miners. The abovementioned game assumes that the coal miner is completely rational and can make the right choice according to the income maximization principle. However, realizing complete rationality and information conditions of the participant in real economic life is difficult [17]. Evolutionary game theory compensates for omniscient and omnipotent defects of game parties under complete rationality to enhance the theoretical foundation of the whole game by taking game parties with bounded

rationality as the basis for game analysis [18]; the game model is presented in Table I.

If the coal miner's on-post probability is x and that of the coal mine enterprise to inspect off-post behaviors is y , then the utility and average expectations when the coal miner adopts two strategies are

$$\begin{aligned} \tau_{off\ post} &= y(T - P - hL) + (1 - y)(T - hL) \\ &= T - yP - hL \\ \tau_{on\ post} &= y(T - W) + (1 - y)(T - W) = T - W \quad (7) \\ \tau_{average} &= \tau_{off\ post}(1 - x) + \tau_{on\ post}x \\ &= (1 - x)(T - yP - hL) + x(T - W). \end{aligned}$$

$\tau_{off\ post}, \tau_{on\ post}$: The utility of coal miner adopts two strategies, $\tau_{average}$: The average expectations of coal miner adopt two strategies.

The replicator dynamics equation of the on-post coal miner is

$$\begin{aligned} \frac{dx}{dt} &= x(\tau_{on\ post} - \tau_{average}) \\ &= x(x - 1)(W - hL - yP). \end{aligned} \quad (8)$$

(1) A state under any x value is identified when $W - hL - yP = 0$ (i.e., $y = (W - hL)/P$).

(2) $x = 1$ refers to two stable states when $W - hL - yP \neq 0$ (i.e., $y \neq (W - hL)/P$).

(3) $x = 0$ is a state when $W - hL - yP > 0$ (i.e., $y < (W - hL)/P$).

(4) $x = 1$ is a state when $W - hL - yP < 0$ (i.e., $y > (W - hL)/P$).

The following equations can be obtained when $F(x) = dx/dt$ is set:

$$\begin{aligned} F(x) &= x(x - 1)(W - hL - yP). \\ F'(x) &= (2x - 1)(W - hL - yP). \end{aligned} \quad (9)$$

According to stability theorem of the differential equation and nature of evolutionary stability strategy, x^* is an evolutionary stability strategy when $F(x^*) = 0, F'(x^*) < 0$. The following equation is set:

$$\begin{aligned} \frac{dF(x)}{dx} &= 0 \\ F'(x) &< 0. \end{aligned} \quad (10)$$

The positive and negative natures of $W - hL - yP$ will be discussed after the equation set is solved:

$x = 0$ is a stable state when $W - hL - yP > 0$ and $y < (W - hL)/P$.

$x = 1$ is a stable state when $W - hL - yP < 0$ and $y > (W - hL)/P$.

Under bounded rationality, the selection process of the coal miner is a dynamic change process, and a dynamic y of the coal mine enterprise directly influences the coal miner's strategy choice; the stable state is mainly related to factors, such as punishment degree, externality influence of on-post behavior, and coal miner loss after an accident [19].

3.2. Dynamic Analysis of the Coal Mine Enterprise. The utility function and average utility when the coal mine enterprise adopts two strategies are expressed as follows:

$$\pi_{inspection} = x(N - C) + (1 - x)(P + N - C - hB)$$

$$\pi_{no\ inspection} = xN + (1 - x)(N - hB) \quad (11)$$

$$\pi_{average} = y\pi_{inspection} + (1 - y)\pi_{no\ inspection}.$$

The replicator dynamics equation of the inspection conducted by the coal mine enterprise is

$$\begin{aligned} \frac{dy}{dt} &= y(\pi_{inspection} - \pi_{average}) \\ &= y(y - 1)(C + xP - P). \end{aligned} \quad (12)$$

If $F + xP - P = 0$ (i.e., $x = (P - C)/P$), then it is a stable state under any y value.

If $F + xP - P \neq 0$, then $y = 0$, $y = 1$ are two stable states.

If $F + xP - P > 0$ (i.e., $x > (P - C)/P$), then $y = 0$ is a stable state.

If $F + xP - P < 0$ (i.e., $x < (P - C)/P$), then $y = 1$ is a stable state.

The verification process is the same as the dynamic analysis of the process of coal miners.

The coal mine enterprise will finally be at a stable state in full consideration of the various factors. Its stable state is related to the off-post probability x of coal miners and is jointly decided by inspection cost, off-post punishment, occurrence probability of an off-post-induced accident, and loss caused by the absence of inspection.

3.3. Evolutionary Stability Analysis of the Two Game Parties. The following system is established in accordance with evolutionary game analyses of coal miners and coal mine enterprise and developed to explain the interaction between two game parties further:

$$F(x) = \frac{dx}{dt} = x(x - 1)(W - hL - yW) \quad (13)$$

$$F(y) = \frac{dy}{dt} = y(y - 1)(W + xP - P).$$

After solving, stable points of the system $F(x, y)$ are A (0,0), B (0,1), and C (1,0).

Proof. With the change in the position of Point E, $X_E = (P - C)/P$ and $Y_E = (W - hL)/P$ are set. In addition, the position of Y_E in the coordinate axis will be discussed under the following circumstances:

$$(1) \begin{cases} 0 < X_E < 1 \\ Y_E < 0, \end{cases}$$

$$(2) \begin{cases} X_E < 0 \\ 0 < Y_E < 1, \end{cases}$$

$$(3) \begin{cases} X_E < 0 \\ Y_E > 1, \end{cases}$$

$$(4) \begin{cases} 0 < X_E < 1 \\ Y_E < 0, \end{cases}$$

$$(5) \begin{cases} 0 < X_E < 1 \\ 0 < Y_E < 1, \end{cases} \quad (14)$$

$$(6) \begin{cases} 0 < X_E < 1 \\ Y_E > 1, \end{cases}$$

$$(7) \begin{cases} X_E > 1 \\ Y_E > 0, \end{cases}$$

$$(8) \begin{cases} X_E > 1 \\ 0 < Y_E < 1, \end{cases}$$

$$(9) \begin{cases} X_E > 1 \\ Y_E > 1. \end{cases}$$

Table 2 lists the values of X_E and Y_E inequalities.

The nonexistence of the inequalities under Circumstances (7) – (9) presented in Table 3 results in the absence of their replicator phase diagrams. Figure 1 illustrates that system $F(x, y)$ converges to A, B, and C, and the following game results can be obtained:

Figure 1(a) depicts a convergence to (1, 0), and the strategic choices of the two parties are on-post and no inspection. Figure 1(a) demonstrates that the coal miner comes off-post at the beginning, and the coal mine enterprise strictly inspects the off-post event. When the enterprise inspection department performs an effective inspection and strictly enforces laws, off-post coal miner loss is large ($W < hL$). Moreover, the coal mine with bounded rationality takes on-post strategy through a long-term repeated game, and the coal mine enterprise gradually turns into a stable non-inspection state given a soaring inspection cost ($C > P$).

Figures 1(b) and 1(c) exhibit a convergence to (0, 0) (i.e., off-post and no inspection). The coal mine enterprise selects

TABLE 2: Values of X_E and Y_E inequalities.

| | | | |
|----------------------|-----------------------|------------------------------------|---------------------------|
| Inequality condition | $X_E < 0$ $C > P$ | $0 < X_E < 1$ $C < P$ | $Y_E > 1$ Nonexistent |
| Inequality condition | $Y_E < 0$ $W < hL$ | $0 < Y_E < 1$ $hL < W < hL + P$ | $Y_E > 1$ $W > hL + P$ |

TABLE 3: Systems of value inequalities under the nine circumstances.

| | | | |
|---------------|------------------------------|------------------------------|-------------|
| Value | $X_E < 0$ | $0 < X_E < 1$ | $X_E < 1$ |
| $Y_E < 0$ | $C > P$ $W < hL$ | $C < P$ $W < hL$ | Nonexistent |
| $0 < Y_E < 1$ | $C > P$ $hL < W < hL + P$ | $C < P$ $hL < W < hL + P$ | Nonexistent |
| $Y_E < 1$ | $C > P$ $W > hL + P$ | $C < P$ $W > hL + P$ | Nonexistent |

not to inspect and allow the natural occurrence of the off-post accident when the inspection cost is large ($C > P$); however, the on-post coal miner is significantly affected ($W > hL$ and $W > hL + P$). Under this circumstance, the coal miner slowly opts to come off-post, and two game parties stabilize. If this circumstance experiences long-term development, then it will certainly threaten the safety of coal miners and the development of a healthy enterprise, thus prompting a change in strategies.

Figure 1(d) displays a convergence to (1, 0), thus indicating that the coal miner is gradually turned from off-post to on-post strategy and then reaches a stable state when the off-post loss is large ($W < hL$). The enterprise will opt not to inspect to avoid wasting resources, following the reduction off-post accidents, even if the inspection cost is small ($C < P$), and the two parties reach (on-post, no inspection) a stable state.

Figure 1(e) presents a divergence, thereby indicating that the two game parties are unable to reach a stable state.

Figure 1(f) illustrates a convergence to (0, 1) (i.e., off-post and inspection). The inspection cost is minimal ($C < P$), and the enterprise inspects off-post behaviors, but the inspection department fails to perform its duties with gross neglect of duty; thus, off-post loss is smaller than on-post loss ($W > h + P$). The coal miner gradually comes off-post under this circumstance. Finally, the two parties tend to be under off-post and inspection states. □

4. Case Analysis

A coal mine subordinate to Yanzhou Coal Mining Co., Ltd. is used as an example, and the coal mine has approximately 200 coal miners with an annual income of RMB 80,000 each. The normal revenue of the coal mine is RMB 150 million, and the inspection cost of the safety inspection department is set as RMB 150,000. Statistics demonstrate that accidents caused by off-post behaviors account for 40% with a total loss of approximately RMB 10 million; this coal mine implements a punishment-centered management mode, and

the punishment amount of off-post coal miners is calculated at approximately RMB 300,000 [20].

Parameter values during accidents can be initially determined on the basis of the abovementioned results: T=RMB 16 million; L=RMB 15 million; h=0.4; P=RMB 300,000; W = RMB 100,000; N=RMB 150 million; C=RMB 150,000 million; and B=RMB 10 million. At the time, $X_E = (P - C)/P = 0.5 > 0$, $Y_E = (W - hL)/P < 0$, and when $0 < X_E < 1$, $Y_E < 0$, the system converges to (1, 0) in accordance with the abovementioned analysis (i.e., on-post and no inspection). The inspection revenue matrix of the coal mine enterprise can be obtained in accordance with the parameters presented in Table 4:

According to the revenue matrix, $1510 < 1590$ and $1540 < 1590$. The final choice of the coal miner is “on-post,” regardless if the coal mine enterprise performs the inspection or not because the miner can obtain the maximum revenue only when coming on-post. The coal mine enterprise, when the coal miner is on-post, gains a large profit when selecting no inspection. The profit difference is RMB 150,000. Therefore, the corresponding action combination is (on-post, no inspection).

Based on the analysis of evolution laws, $X_E = (P - C)/P = 0.5$ (i.e., $0 < X_E < 1$).

$$\text{If } x > X_E,$$

$$\text{and } x = 0.8 \text{ is used,} \tag{15}$$

$$\text{then } \frac{dy}{dt} = 6y(y - 1).$$

Figure 2 demonstrates that a change curve of y with time t is obtained after solving the integral of Equation (15), and the coal mine enterprise has gradually turned initially from off-post inspection to no inspection under different initial probabilities when the on-post probability of the coal miner is 0.8. The off-post inspection cost is minimal ($C < P$), and the coal mine enterprise inspects off-post behaviors at the beginning. However, a few off-post events remain, and most coal miners stick to their posts and perform their

TABLE 4: Inspection revenue matrix of a coal mine enterprise (unit: RMB 10000).

| Coal miner | Item | Coal mine enterprise | | | | |
|------------|----------|----------------------|------------|-------|---------------|-------|
| | | Off-post | Inspection | | No inspection | |
| | Off-post | | 1510 | 14615 | 1540 | 14600 |
| | On-post | | 1590 | 14985 | 1590 | 15000 |

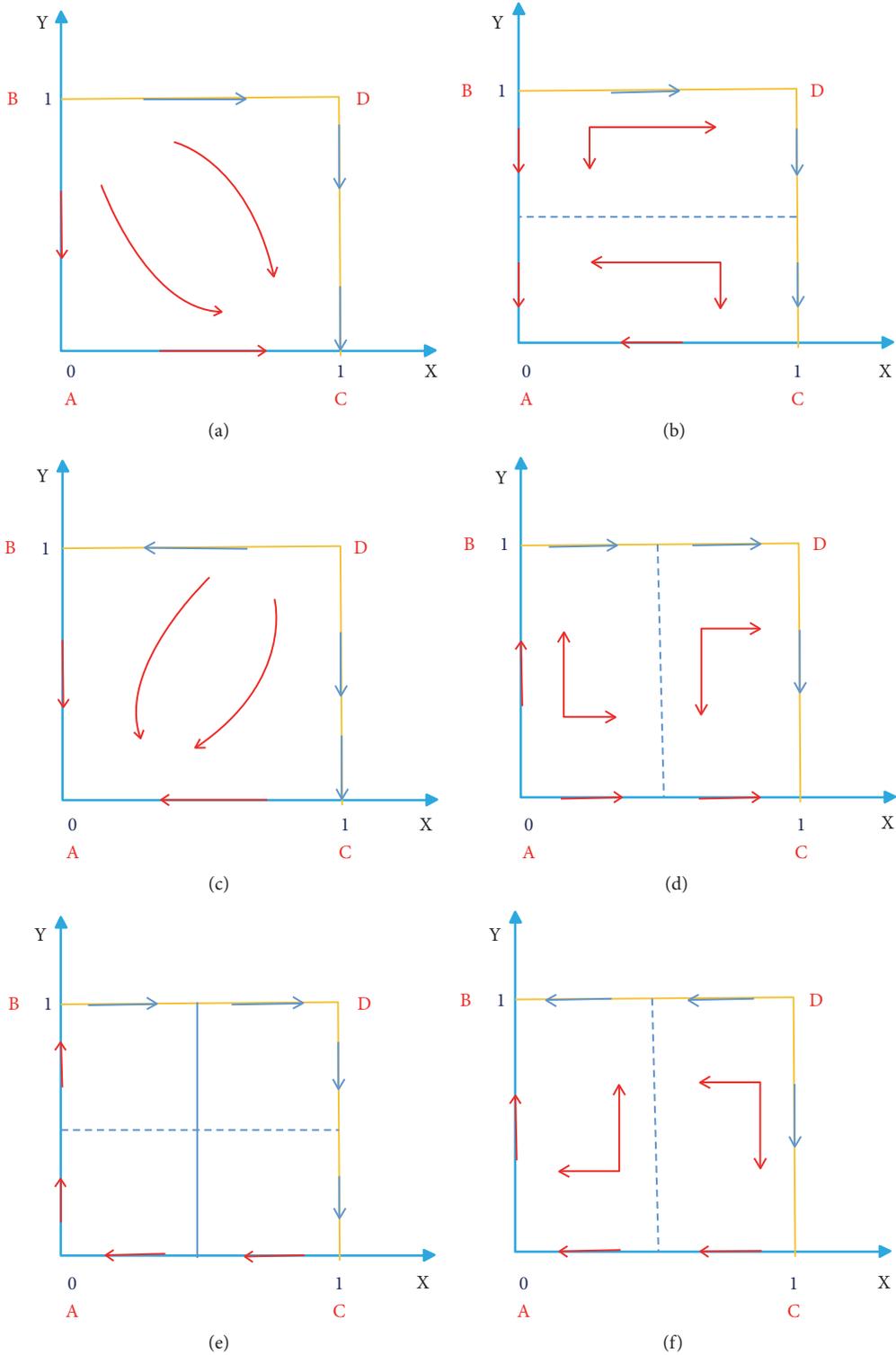


FIGURE 1: Dynamic evolutionary trends of coal miners and enterprise strategies under different conditions.

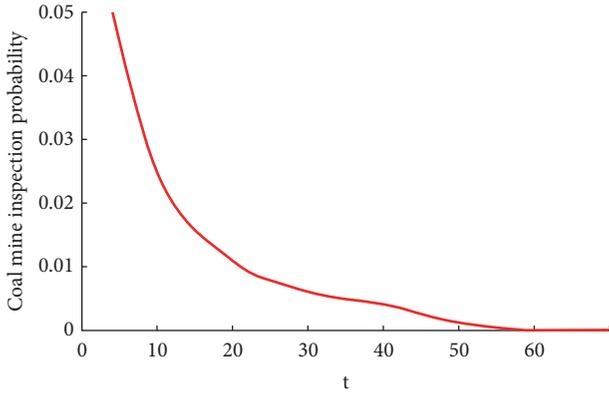


FIGURE 2: Change relation of strategy (y) with time under $x = 0.8$.

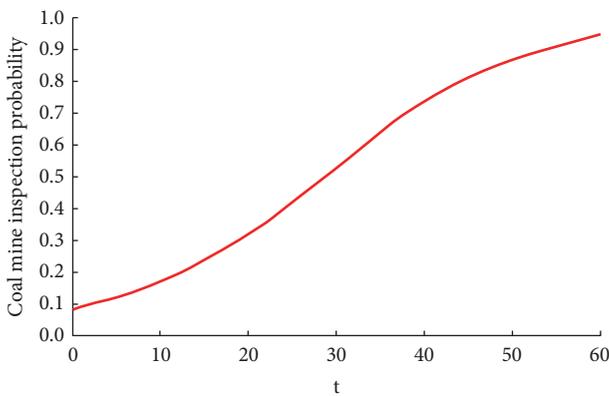


FIGURE 3: Change relation of strategy (y) with time under y .

duties. Certainly, a specialized off-post inspection is a waste of resources. After a long-term game, the coal mine enterprise changes its strategy and gradually tends to be at a stable non-inspection state.

$$\begin{aligned} &\text{If } x < X_E, \\ &\text{and } x = 0.3 \text{ is used,} \\ &\text{then } \frac{dy}{dt} = 4y(1 - y). \end{aligned} \tag{16}$$

Figure 3 exhibits that a change curve of y with time t is obtained after solving the integral of Equation (16). Moreover, the coal mine enterprise has gradually turned from no inspection at the beginning to off-post inspection when off-post probability is 0.7; on one hand, off-post problem is severe, and most coal miners come off-post, thus severely affecting the enterprise benefit; on the other hand, off-post inspection cost is minimal ($C < P$). The coal mine enterprise formulates measures and gradually develops into a stable inspection state to curb the occurrence of off-post behaviors effectively.

In summary, starting from two angles (i.e., revenue matrix and evolution analysis), the final stable states are coal miners coming on-post and coal mine enterprise not conducting an inspection. Furthermore, their strategies, which

are identical with evolution laws of the two game parties, can interact with each other. Therefore, the established game model is confirmed of reasonability.

5. Discussion

Static game theory is the study of strategic decision-making. Specifically, it is a study of mathematical models of conflict and cooperation between two decision makers. However, it has an important assumption for the players that the players are intelligent and rational, which is inconsistent with the actual situation. If static game theory is used alone, the evolution of safety behavior in equilibrium can be obtained, but the evolution state of safety behavior in each period cannot be better observed.

Evolutionary game theory was developed to overcome the disadvantages of static game theory when analyzing the bounded rationality of players and the dynamic process of game playing. Evolutionary game theory can be summarized as follows: It combines game theory with dynamic evolution process analysis, which is the application of game theory in the evolution of biological life forms. It differs from static game theory in that it pays more attention to the dynamics of strategic change, not only by the quality of various competitive strategies, but also by the frequency of various competitive strategies in the population.

In the process of coal mining safety inspection in China, participants are bounded by rationality. They dynamically change their strategies by observing and comparing the returns of others and then adjust their strategies. Therefore, evolutionary game theory is more suitable for studying the long-term dynamic game of bounded rational participants in China's coal mine safety inspection system.

First, strategy choices of stakeholders fluctuate repeatedly when the punishment strategy is static payment. Bringing the punishment degree to a large scale can rapidly control the occurrence of off-post behaviors of coal miners within the short term. However, eventually, the large-scale punishment only aggravates the fluctuation of off-post behaviors of coal miners and complicates the control of the game process. Second, a dynamic punishment strategy can effectively inhibit fluctuation in the game between coal mine enterprise and coal miners. Moreover, this strategy can reduce potential safety hazards caused by uncertainty when the punishment strategy is dynamic payment [21].

Off-post behaviors of coal miners are mainly related to their income and enterprise inspection intensity. An income that is below the ideal value will make the coal miners feel easily languid to select coming off-post; when enterprise input is insufficient with evident inspection loopholes and defects, the coal miners will be at the off-post state extensively, and safety production cannot be realized. Therefore, the following measures may be implemented to solve off-post problems based on the abovementioned cause analysis:

Properly increase wage, treatment, and reward policies for workers. The above-established game model implies that coal miners will opt to come on-post when their actual income reaches a critical value, regardless of whether the enterprise selects safety inspection or not. At the time, the

enterprise will not inspect, and the coal miners will come on-post. Thus, the economic benefits of both game parties reach maximum values.

Intensify enterprise inspection of safety production. Off-post loss of coal miners is large when the enterprise inspection department performs an effective inspection and strictly enforces laws. Coal miners with bounded rationality tend to use on-post strategy through the long-term repeated game, whereas the coal mine enterprise tends to be at a stable non-inspection state considering a soaring inspection cost.

Establish a scientific and complete off-post punishment mechanism. The introduction of punishment variables indirectly increases the income of on-post coal miners and fills the void of enterprise loss. Therefore, the enterprise inspection department must seriously manage off-post accident and elevate the punishment degree.

6. Conclusion

Effective execution of the coal mine safety management system is analyzed from the perspective of system-related personnel to improve the safety management situation of the coal mine. Static and incomplete information dynamic game models are used to study whether coal mine enterprise and coal miners select the safety management system under different circumstances. The results indicate that coal miners will not consciously comply with the safety management system when the on-post loss is higher than their critical cost. Moreover, they will demonstrate a fluke mind if it exceeds the critical cost. In addition, workers will continuously improve their qualities and cognitive level when the system cognition influences the remuneration. The coal mine enterprise manager conducts a safety inspection and encourages coal miners to implement safety production only when the revenue caused by safety production is higher than that caused by unsafe production. Therefore, the coal mine enterprise must emphasize and motivate safety production and improve safety cognition and labor skills of coal miners. In addition, the government and society must supervise and support the coal mine enterprise. This strategy is an important means of improving the effectiveness of the coal mine safety system. A simulation of the off-post behaviors was conducted in this study under the perspective of coal mine enterprise and coal miners. Data sources remained lacking despite using mature static and evolutionary game models. Therefore, realizing a comprehensive cognition of the safety supervision level of the entire coal industry is difficult. Future studies can further explore into other directions of the safety management of coal mine enterprises.

Data Availability

The open data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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