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# Game Analysis of the Influence of the Miner under Carbon Emotion on the Intelligent Development Strategies of the SMEE in Coal Mines

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**Abstract:** The intelligent development of coal mines is a crucial way to achieve the safe, efficient, green, and low-carbon transformation of the coal industry and to reach the "double carbon" target, which is related to the life and health of miners, the stable development of enterprises and the national energy reform. As directly affected subjects, the cooperative attitudes of miners in different emotional states have a significant impact on the smooth implementation of intelligent coal mine renovation projects. Hence, we combined the RDEU theory and game theory, constructed a three-party evolutionary game model of the small and medium-sized energy enterprises (SMEE), the government, and the miner, considered the influence of the strategies made by the miner on the equilibrium strategy choices of other game subjects in the intelligent coal mine construction under the rational and irrational emotional states of the miner, and finally used MATLAB 2021 to simulate and analyze the impact of the evolution of the gaming system from 3 key elements: initial participation rate, construction costs, and government support. The study found the following: (1) The government will insist on actively promoting intelligent coal mine construction regardless of the miner's emotional state. (2) Both moderate pessimism and optimism will, to a certain extent, give a positive impetus to the development of intelligent coal mine construction. (3) The miner's emotions have a greater impact on SMEE than on the government's strategic behavior. (4) Excessive construction costs or low government support will make SMEE may reduce the enthusiasm of SMEE to carry out an intelligent construction of coal mines. Accordingly, corresponding suggestions and countermeasures are put forward, aiming to provide targeted and practical ideas for the efficient construction of intelligent coal mines in China, thereby accelerating the green and low-carbon transformation of energy.

**Keywords:** carbon emotion; intelligent coal mine; RDEU theory; evolutionary game theory

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## 1. Introduction

Climate change is a global challenge that transcends national borders. In response to climate change, 197 countries have come together to conclude the Paris Agreement, which aims to significantly reduce global greenhouse gas emissions and seek measures to further limit temperature rises by 1.5 °C [1]. As subjects directly involved in causing increased carbon emissions, environmental damage, and climate change, human beings' corresponding emotional responses subconsciously influence their choice of low-carbon behavior, as emotions lead to more moral insights about climate change and provide a higher degree of motivation for behavior that applies to us [2]. Intelligent coal mines, which are currently in a critical stage of alteration, are considered to be the core technology support for the high-quality development of the coal industry [3]. It is also a critical pathway to achieving intelligent, low-carbon, green, and secure energy, its development trend and speed will inevitably be influenced by the carbon sentiment of those involved in the alteration [4]. The development trend and speed of the process will inevitably be influenced by the carbon sentiment of the participants. Therefore, it is of great significance to study the influence of different carbon emotions on the intelligent reconstruction of coal mines to comprehensively promote the modern coal industry system characterized by intelligence, green, low carbon, and safety and to reasonably manage social carbon emotions.

In recent years, emotional impact research is gradually expanding into various fields. Sun et al. [5] considered patients' emotional factors in a study of the impact of constructions on a hierarchical medical system and found that patients made different decision-making choices when they were in a rational or irrational emotional state. Xiong et al. [6] analyzed the conflict evolution problem of urban demolition and relocation and found that emotional factors have a significant impact on the game equilibrium of group conflict. Xu et al. [7] constructed a game model between enterprises and the public in environmental NIMBY (Not-In-My-Back-Yard) conflicts, arguing that the emotions of participants not only affect their behavioral intention, but also influence the behavioral decisions of other participants. Among them, the relationship between emotions and guiding people to a low-carbon lifestyle has also received extensive academic attention. For example, the Broaden-and-Build theory of positive emotions suggests that positive emotions can help people acquire and engage in the cognitive knowledge necessary for environmental behavior [8], but positive information also has the potential to reduce our perceptions of risk in relation to carbon emissions [4]. The EPPM (Extended Parallel Process Model) suggests that fear, a negative emotion accompanied by high arousal, may cause people to change their behavior to mitigate or avoid the serious threats posed by climate change [9] and inspire environmental awareness. The assessment tendency framework suggests that grief may lead people to try to improve their own situation and to behave more supportive of welfare events [10]. It can be seen that people's emotional response to carbon emissions and climate change can influence people's psychological distance and risk perception of carbon emissions, and then determine the low-carbon behavior of micro-subjects.

Research on the factors influencing the modification of intelligent coal mines has also been carried out by domestic and international scholars from a number of perspectives. Wang et al. [11] pointed out that the deep integration of new-generation information technology with the coal industry is the future trend, and emphasized the importance of scientific and technological innovation to the intelligent modification of coal mines. Kang et al. [12] proposed that the training of high-quality and highly skilled personnel in the coal industry should develop in tandem with the transformation of intelligent coal mines. Luo et al. [13] analyzed and explored factors such as technology level and natural resource endowment as influencing factors on the trend of energy-intensive industries shifting in China. Zhang et al. [14] point out that the enactment of relevant policies and regulations in China has made intelligent unmanned mining technology one of the key technologies for coal mine production. Oleg Kazanin et al. [15] argue that the underutilization of high-performance mining equipment is an important factor affecting the development of intelligent coal mining technology. Li et al. [16] point out the problems in the alteration of digital mines in China at the level of enterprise production and management. Yuan et al. [17] explored the complex cause-and-effect relationships between factors affecting the intelligent construction of coal mines from a number of perspectives, including technology, organization, environment and resources. However, both internal and external influencing factors are almost always developed from the hypothetical perspective of the rational emotions of the participating subjects. Should the micro-action mechanism of carbon emotions, an irrational factor, affecting the development of intelligent coal mine construction also be considered? At the same time, the above-mentioned influencing factors are the direct cause of the fact that China's intelligent coal mine construction is still at the stage of cultivation and demonstration, with uneven overall development and difficulties in normal operation [11]. This poses a huge challenge to the process of building intelligent coal mines for large or state-owned energy enterprises, so how can small and medium-sized energy enterprises succeed in their energy transition in the face of the global 'zero carbon' trend and the difficulties of large companies, weak resource support and unprecedented competition?

In summary, this paper combines the RDEU (Rank Dependent Expected Utility) theory with game theory to explore the micro-level mechanism of the miner's strategic choice for intelligent coal mine construction under the influence of carbon sentiment. Firstly, we constructed an RDEU-game model among small and medium-sized energy enterprises (hereafter referred to as "SMEE"), the government and miners based on the current situation of intelligent coal mine construction in China. Secondly, we discussed the equilibrium results of the game under the combination of " SMEE, government and the miner are rational", " government and SMEE are rational, the miner is pessimistic", and "government and SMEE are rational, the miner is optimistic " under three heterogeneous combinations of emotions. Finally, by simulating the impact of 3 key elements on the strategy of the game subjects, namely subject participation, cost, and government support, we analyzed and verified the differences in the behavior of energy companies, government and the miner under the above three heterogeneous combinations of emotions.

In comparison with existing studies, this paper has the following innovations: (1) Based on the context of intelligent coal mine construction, it considers the changes in the miner's own decision-making choices under the influence of carbon emotion and the impact on the strategic choices of other participating subjects. (2) It adopts a game-theoretic approach to analyze and study the intelligent construction of coal mines in small and medium-sized energy enterprises that are currently at a disadvantage in terms of development conditions.

## 2. Theory and Model Construction

### *2.1. Description of the Conceptual Model of the Game*

The development of intelligent coal mines in China is closely linked to the active participation of the SMEE and the government, as intelligent coal mines are being transformed, the problems of the miner community are coming to the fore. The SMEE, as the builder of intelligent coal mine construction, is responsible for the financing, implementation, operation and management of intelligent coal mine construction. The government, as the guide of intelligent coal mine construction, is involved through policy formulation, publicity, the establishment of special funds to support the intelligent construction of coal mines and the regulation of the construction direction. The miner, as the intuitive experience of intelligent coal mine construction, has the most direct and fundamental impact on the intelligent construction of coal mines. Therefore, this paper selects SMEE, government and miners as the main participants (Figure 1).

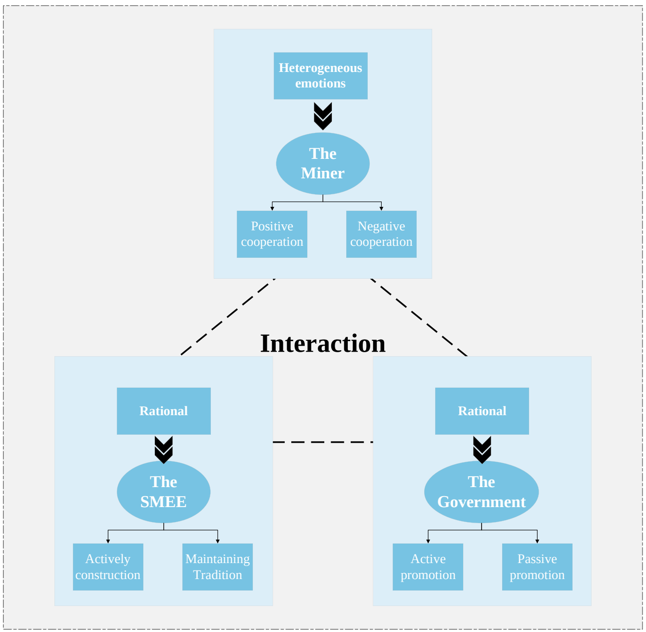



**Figure 1.** Conceptual diagram of the game model.

*2.2. Model Assumptions*

Based on the RDEU theory, we study the influence of carbon emotion on the subjects' making strategies in the development of intelligent constructions in coal mines. The hypothesis is as follows.

**Hypothesis 1 (H1).** *The government, the SMEE and miners are chosen as the three main participants in the intelligent coal mine construction project. The main body of the SMEE chooses the strategy of actively construction intelligent coal mine in the ratio of* $x$*, while choose the strategy of maintaining traditional coal mine production mode in the ratio of* $(1-x)$*. The main body of the government chooses the positive promotion strategy of intelligent coal mine in the ratio of* $y$*, while the negative promotion strategy in the ratio of* $(1-y)$*. The main miners choose the positive cooperation strategy with the intelligent coal mine in the ratio of* $z$*, while the negative cooperation strategy with the ratio of* $(1-z)$*. Where* $x$*,* $y$ *and* $z$ *all have functions of time* $i$*,* $0 \le x \le 1$*,* $0 \le y \le 1$*,* $0 \le z \le 1$*.*

**Hypothesis 2 (H2).** *The SMEE has two strategies: actively construct an intelligent coal mine or maintain the traditional coal mine production method, noted as* $\{C, NC\}$*. When the SMEE chooses* $C$ *strategy to pay for the cost* $C_a$ *of intelligent alteration (staff training and equipment replacement, etc.), it acquires alteration support* $C_b$ *from the government (financial subsidies and technical support, etc.). The miner's workload is assumed to be* $L$*, the ratio of safety and health benefits of the intelligent coal mine production method is* $Z$*, and the ratio of safety and health benefits of the traditional coal mine production method is* $Z_1$*, so the SMEE acquire the miner's health and safety work benefits as* $N = (Z - Z_1)L$*, while they will acquire high productivity benefits* $C_c$ *after completion and commissioning. If the SMEE chooses the* $NC$ *strategy to avoid the investment risks of intelligent construction* $C_d$ *(wasteful investment), but the progress of its peers may cause coal mines that maintain traditional production methods to gradually lose competitiveness in the industry, generating reputational and economic losses* $NC_e$*. The reality is that the current situation is not as good as it could be. In the absence of government subsidies and funding, few SMEE are currently voluntarily undertaking intelligent coal mine construction, and therefore benefit will be* $C_c - C_a + N < C_d - NC_e$*. In order to enhance the intelligent base capacity of coal mines, safety production guarantee capacity, etc., the provincial governments will implement to guarantee the subsidies and funding for each coal mine intelligent construction SMEE, so in the long run, SMEE will be happy to undertake intelligent coal mine construction, regardless of the choice of the miner, benefit will be* $C_c - C_a + N + C_b > C_d - NC_e$*.*

**Hypothesis 3 (H3).** *The government has two strategies: active promotion or passive promotion, noted as* $\{E, NE\}$*. If the government pursues the* $E$ *strategy, then it needs to bear the costs of policy development, promotion and implementation* $E_f$*. Support expenditure (financial subsidies and technical support, etc.) for constructions to SMEE that actively promote intelligent constructions to coal mines. If the government pursues the NE strategy, it will incur a certain amount of reputational damage to the government* $NE_g$*. In general, the reputation of the government is more important than the financial costs of policy implementation [18], and therefore* $E_f < NE_g$*. Regardless of the strategy chosen by the government, as long as the SMEE chooses to undertake the intelligent construction of the coal mines, the government will receive the national economic benefits and production safety guarantees* $G$ *once the project is completed and in operation, while the SMEE chooses not to proceed with the intelligent coal mine construction, the government will face a loss of national economic and production safety* $-G$ *due to the outdated coal mining technology.*

**Hypothesis 4 (H4).** *The miner has two strategies: positive cooperation and negative cooperation, noted as* $\{P, NP\}$*. The positive impact of active government promotion on employees is* $E_1$*, and conversely the negative impact is* $E_2$*. In practice, the government has a strong guiding force in the development of modern society, and with the development of the Internet and the improvement of institutions, government statements have a high influence on the population. Under the strategy of SMEE actively carrying out intelligent constructions in coal mines, if miner chooses the* $P$ *strategy,* *miner cooperate with technical training to receive skill enhancement and treatment enhancement* $P_h$, *the miner's health and safety benefits are increased by* $N = (Z - Z_1)L$, *but there is an upfront cost of time and effort* $P_i$ *to adapt to the new working style and environment. If the miner chooses the* NP *strategy, miners' non-compliance can generate treatment anxiety and unemployment risk* $NP_j$. *The reduced competitiveness of the industry can also lead to treatment anxiety and unemployment risks* $NP_j$ *if the SMEE maintains a traditional production strategy.*

### *2.3. Traditional Model Construction*

Based on the above assumptions, the returns of different combinations of strategies among the SMEE subjects, the government subjects, and the miner subjects are constructed (Table 1).

**Table 1.** Gain perception matrix.

| | | | | **Miner** | **Miner** |
|---|---|---|---|---|---|
| | | | | Positive cooperation (z) | Negative cooperation (1 − z) |
| **SMEE** | Actively construction (x) | **Government** | Active promotion (y) | $-C_a + C_b + C_c + N$<br>$G - E_f - C_b$<br>$E_1 + P_h + N - P_i$ | $-C_a + C_b + C_c$<br>$G - E_f - C_b$<br>$E_1 - NP_j$ |
| | | | Passive promotion (1 − y) | $-C_a + C_c + N$<br>$G - NE_g$<br>$-E_2 + P_h + N - P_i$ | $-C_a + C_c$<br>$G - NE_g$<br>$-E_2 - NP_j$ |
| | Maintaining Tradition (1 − x) | **Government** | Active promotion (y) | $C_d - NC_e$<br>$-G - E_f$<br>$E_1 - NP_j$ | $C_d - NC_e$<br>$-G - E_f$<br>$E_1 - NP_j$ |
| | | | Passive promotion (1 − y) | $C_d - NC_e$<br>$-G - NE_g$<br>$-E_2 - NP_j$ | $C_d - NC_e$<br>$-G - NE_g$<br>$-E_2 - NP_j$ |

Next, this paper will explore the impact of carbon emotion on the development of intelligent constructions in coal mines by RDEU-game theory.

### *2.4. Rank-Dependent Expected Utility Theory*

Evolutionary game theory, which first originated in biology, has been widely used in economics, management, manufacturing, safety and emergency assessment. However, all are based on a perfectly rational or finite rationality perspective, ignoring the influence of emotions as an irrational factor [19]. RDEU theory was originally developed by Quiggin [20] and is a utility theory that takes into account the psychological preferences and emotions of decision-makers. The emergence of the theory has filled a gap in game theory with regard to emotions. Under conditions of decision uncertainty and a high degree of randomness, a real-valued function defined by a utility function and a decision weight function is used to characterize the degree of decision-maker preference for different decisions [21,22]. Suppose that the set of benefits of a game party A under different combinations of strategies $X = \{x_i, i = 1, 2, \cdots, n\}$, and $P(X = x_i) = p_i$.

First, the benefits to party A of the game are ordered from largest to smallest, assuming $x_1 > x_2 > \cdots x_n$, defining the utility rank $RP_i$ for benefit $x_i$:

$$RP_i = P(X \le x_i) = \sum_{t \ge i}^{n} p_t, i = 1, 2, \cdots, n \quad (1)$$

Essentially, the utility rank $RP_i$ is the probability distribution function of the benefit $x_i$. This indicates that the greater the benefit of a strategy of party A, the greater its cumulative probability and the greater the weight of that benefit in the decision.

Next, define the decision wights $\pi(x_i)$:

$$\pi(x_i) = \omega(p_i + 1 - RP_i) - \omega(1 - RP_i) \quad (2)$$

Drawing on the emotion set by scholars in the study of regional health care settings [5], the paper also assumes an emotion function $\omega(x_i) = x_i^r$, here are the following three situations:

(1) r = 1 the game party has no emotion.

(2) r > 1 the game party shows optimism.

(3) 0 < r < 1 the game party shows pessimism.

Finally, based on the decision weights $\pi(x_i)$ and the utility function $u(x_i)$,the expression of the RDEU model $V_A$ for the game party A is derived as follows.

$$V_A = \sum_{i=1}^{n} \pi(x_i) u(x_i), i = 1, 2, \cdots, n \quad (3)$$

*2.5. Rank-Dependent Expected Utility Model*

Based on the above, the RDEU models for SMEE, government and miner under different strategies adopted are constructed (Tables 2–4).

**Table 2.** Ranking of the expected benefits of the SMEE.

| Effectiveness ($u(x_i)$) | Probability ($p_i$) | Rank ($RP_i$) | Decision Weights ($\pi(x_i)$) |
|---|---|---|---|
| $-C_a + C_b + C_c + N$ | $xyz$ | $1$ | $\omega(xyz)$ |
| $C_d - NC_e$ | $(1 - x)$ | $1 - xyz$ | $\omega(1 - x + xyz) - \omega(xyz)$ |
| $-C_a + C_c + N$ | $x(1 - y)z$ | $-xyz + x$ | $\omega(1 - x + xz) - \omega(1 - x + xyz)$ |
| $-C_a + C_b + C_c$ | $xy(1 - z)$ | $x - xz$ | $\omega(1 - x + xz + xy - xyz) - \omega(1 - x + xz)$ |
| $-C_a + C_c$ | $x(1 - y)(1 - z)$ | $x - xz - xy + xyz$ | $1 - \omega(1 - x + xz + xy - xyz)$ |

**Table 3.** Ranking of the expected benefits of the government.

| Effectiveness ($u(x_i)$) | Probability ($p_i$) | Rank ($RP_i$) | Decision Weights ($\pi(x_i)$) |
|---|---|---|---|
| $G - E_f - C_b$ | $xy$ | $1$ | $\omega(xy)$ |
| $G - NE_g$ | $x(1 - y)$ | $1 - xy$ | $\omega(x) - \omega(xy)$ |
| $-G - E_f$ | $(1 - x)y$ | $1 - x$ | $\omega(y + x - xy) - \omega(x)$ |
| $-G - NE_g$ | $(1 - x)(1 - y)$ | $1 - x - y + xy$ | $1 - \omega(y + x - xy)$ |

**Table 4.** Ranking of the expected benefits of the miner.

| Effectiveness ($u(x_i)$) | Probability ($p_i$) | Rank ($RP_i$) | Decision Weights ($\pi(x_i)$) |
|---|---|---|---|
| $E_1 + P_h + N - P_i$ | $xyz$ | $1$ | $\omega(xyz)$ |
| $E_1 - NP_j$ | $y - xyz$ | $1 - xyz$ | $\omega(y) - \omega(xyz)$ |
| $-E_2 + P_h + N - P_i$ | $x(1 - y)z$ | $1 - y$ | $\omega(y + xz - xyz) - \omega(y)$ |
| $-E_2 - NP_j$ | $1 - y - xz + xyz$ | $1 - y - xz + xyz$ | $1 - \omega(y + xz - xyz)$ |

For the SMEE, based on the relationship between parameters such as costs, benefits and subsidies, the benefits corresponding to their 5 strategies are ranked as follows. $-C_a + C_b + C_c + N > C_d - NC_e > -C_a + C_c + N > -C_a + C_b + C_c > -C_a + C_c$, which then generates the probability, rank and decision weights for each benefit for the energy firm (Table 2).

For the government, the relationship between parameters such as subsidy expenditure, policy advocacy costs and reputation loss, two cases can be discussed, $NE_g > E_f - C_b$, and $NE_g < E_f - C_b$. Since this paper mainly considers the influence of miners' emotions and assumes that the government is a rational subject, its benefit ranking has no effect on the decision weights, and the following example of $NE_g > E_f - C_b$, whose 4 strategies correspond to the benefit ranking: $G - E_f - C_b > G - NE_g > -G - E_f > -G - NE_g$, then generates the probability, rank and decision weights of each government benefit (Table 3).

For the miner, the benefits corresponding to their 4 strategies are ranked according to the relationship between the parameters of cost, benefit and risk as follows. $E_1 + P_h + N - P_i > E_1 - NP_j > -E_2 + P_h + N - P_i > -E_2 - NP_j$, and then generates the probability, rank and decision weights for each of the miner's benefits (Table 4).

First, the replication dynamics equation for the SMEE is constructed, and the expected return and overall average expected return of the SMEE choosing "Actively construction" are $u_{x1}$ and $EU_x$: The expected returns of,

$$u_{x1} = C_b y^{r_2} + N z^{r_3} + C_c - C_a \tag{4}$$

The RDEU function for the SMEE actively construction intelligent coal mine construction strategy is,

$$EU_x = (-C_a + C_b + C_c + N - C_d + NC_e)(xyz)^{r_1} + (C_d - NC_e + C_a - C_c - N)(1 - x + xyz)^{r_1} + (N - C_b)(1 - x + xz)^{r_1} + C_b(1 - x + xz + xy - xyz)^{r_1} - C_a + C_c \tag{5}$$

Similarly constructing the replication dynamic equations for the government and the miner, the expected benefits of the government choosing to "Active promotion" and the overall average expected benefits are $u_{y1}$ and $EU_y$ :

$$u_{y1} = (2G - C_b)x^{r_1} - G - E_f \tag{6}$$

The RDEU function for the government's strategy of actively promoting intelligent coal mine construction is,

$$EU_y = \left(-E_f - C_b + NE_g\right)(xy)^{r_2} + \left(2G - NE_g + E_f\right)x^{r_2} + \left(-E_f + NE_g\right)(x + y - xy)^{r_2} - G - NE_g \tag{7}$$

The expected return and overall average expected return for the miner choosing to "Positive cooperation" are $u_{z1}$ and $EU_z$:

$$u_{z1} = \left(N + NP_j + P_h - P_i\right)x^{r_1} + (E_1 + E_2)y^{r_2} - NP_j - E_2 \tag{8}$$

The RDEU function for the miner to cooperate with intelligent coal mine construction strategy is,

$$EU_z = \left(P_h + N - P_i + NP_j\right)(xyz)^{r_3} + \left(E_1 - NP_j + E_2 - P_h - N + P_i\right)y^{r_3} + \left(P_h + N - P_i + NP_j\right)(y + xz - xyz)^{r_3} - E_2 - NP_j \tag{9}$$

Combining the above equations yields the replicated dynamic equations for the actively construction by the SMEE, the active promotion by government and the positive cooperation by the miner's strategies, respectively.

$$\begin{aligned} Fx = \frac{dx}{dt} = x^{r_1} \quad & (u_{x1} - EU_x) \\ & = x^{r_1}\left[C_b y^{r_2} + Nz^{r_3} - (-C_a + C_b + C_c + N - C_d + NC_e)(xyz)^{r_1} - (C_d - NC_e + C_a - C_c - N)\right. \\ & \left.(1 - x + xyz)^{r_1} - (N - C_b)(1 - x + xz)^{r_1} - C_b(1 - x + xz + xy - xyz)^{r_1}\right] \end{aligned} \tag{10}$$

$$\begin{aligned} F(y) = \frac{dy}{dt} = y^{r_2}\left(u_{y1} - EU_y\right) = y^{r_2}\Big[ & (2G - C_b)x^{r_1} - E_f - \left(-E_f - C_b + NE_g\right)(xy)^{r_2} - \left(2G - NE_g + E_f\right)x^{r_2} - \\ & \left(-E_f + NE_g\right)(x + y - xy)^{r_2} + NE_g\Big] \end{aligned} \tag{11}$$

$$\begin{aligned} F(z) = \frac{dz}{dt} = z^{r_3} \quad & (u_{z1} - EU_z) \\ & = z^{r_3}\left[\left(N + NP_j + P_h - P_i\right)x^{r_1} + (E_1 + E_2)y^{r_2} - \left(P_h + N - P_i + NP_j\right)(xyz)^{r_3} - \right. \\ & \left.\left(E_1 - NP_j + E_2 - P_h - N + P_i\right)y^{r_3} - \left(P_h + N - P_i + NP_j\right)(y + xz - xyz)^{r_3}\right] \end{aligned} \tag{12}$$

## 3. Game Analysis

The stability of the strategy combinations of the subjects of the three-party game can be judged according to Lyapunov's first law. Ritzberger et al. [23] and Selten et al. [24] pointed out that a stable solution in a multi-group evolutionary game is a strict Nash equilibrium. At the same time, the strict Nash equilibrium must be purely strategic. The stability of the eight equilibria in the three-party evolutionary game under different emotional states of the miner will therefore be analyzed in the paper.

**Scenario 1. Rational miner, rational government, and rational SMEE.**

At this point all three parties to the game are in a rational state. Putting the sentiment parameter $r_1 = r_2 = r_3 = 1$ is brought into each replicated dynamic equation. Let $\mathrm{F(x)} = 0,\ \mathrm{F(y)} = 0, \mathrm{F(z)} = 0$, 12 replication dynamic equilibrium points can be obtained. Of these, there exist 8 replication dynamic equilibrium points for the three groups adopting pure strategies, namely $A_1$(0,0,0), $A_2$(0,1,0), $A_3$(0,0,1), $A_4$(1,0,0), $A_5$(1,1,0), $A_6$(1,0,1), $A_7$(0,1,1), $A_8$(1,1,1). There exist 4 replicative dynamic equilibria for the adoption of pure strategies by single populations, respectively, $A_9\left(0, 0, \frac{(\mathrm{C_a - C_c + C_d - NC_e})}{\mathrm{N}}\right)$, $A_{10}\left(0, 1, \frac{-(C_b - \mathrm{C_a + C_c - C_d + NC_e})}{N}\right)$, $A_{11}\left(\frac{-(\mathrm{E_f - NE_g})}{\mathrm{C_b}}, \frac{(\mathrm{C_a - C_c + C_d - NC_e})}{C_b}, 0\right)$, $A_{12}\left(\frac{-(\mathrm{E_f - NE_g})}{\mathrm{C_b}}, \frac{-(\mathrm{C_c - C_a - C_d + N + NC_e})}{\mathrm{C_b}}, 1\right)$. There are no mixed-strategy replication dynamic equilibrium points $(x^*, y^*, z^*)$. Under the assumptions, the $x,\ y,\ z$. The range of values of $[0, 1]$, it is clear that the above equilibrium points in $A_9,\ A_{10},\ A_{11},\ A_{12}$, there is no significance (Table 5).

**Table 5.** Strategic Portfolio Stability Analysis under Miners, Government and SMEE Rational Scenarios.

| Balancing Point | Eigenvalues | | | Signs | Stability |
|---|---|---|---|---|---|
| | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | | |
| $A_1$(0,0,0) | 0 | $\mathrm{NE_g - E_f}$ | $\mathrm{C_c - C_a - C_d + NC_e}$ | 0, +, − | Unstable |
| $A_2$(1,0,0) | $\mathrm{NE_g - E_f - C_b}$ | $\mathrm{C_a - C_c + C_d - NC_e}$ | $\mathrm{N + NP_j + P_h - P_i}$ | +, +, + | Unstable |
| $A_3$(0,1,0) | 0 | $\mathrm{E_f - NE_g}$ | $\mathrm{C_b - C_a + C_c - C_d + NC_e}$ | 0, −, ○ | satisfy condition ①, ESS |
| $A_4$(0,0,1) | 0 | $\mathrm{NE_g - E_f}$ | | 0, +, − | Unstable |
| $A_5$(1,1,0) | $\mathrm{C_b + E_f - NE_g}$ | $N + \mathrm{NP_j} + P_h - \mathrm{P_i}$ | $\mathrm{C_a - C_b - C_c + C_d - NC_e}$ | −, +, ○ | Unstable |
| $A_6$(1,0,1) | $\mathrm{NE_g - E_f - C_b}$ | $\mathrm{P_i - NP_j - P_h - N}$ | $\mathrm{C_a - C_c + C_d - N - NC_e}$ | +, −, + | Unstable |
| $A_7$(0,1,1) | 0 | $\mathrm{E_f - NE_g}$ | $\mathrm{C_b - C_a + C_c - C_d + N + NC_e}$ | 0, −, + | Unstable |
| $A_8$(1,1,1) | $\mathrm{C_b + E_f - NE_g}$ | $\mathrm{P_i - NP_j - P_h - N}$ | $\mathrm{C_a - C_b - C_c + C_d - N - NC_e}$ | −, −, − | ESS |

Note: ○ indicates that the positive and negative signs are uncertain; condition ①: $\mathrm{C_b - C_a + C_c - C_d + NC_e} < 0$.

There are 2 possible stable equilibrium strategies when miner is perfectly rational: $A_3$(0,1,0) and $A_8$(1,1,1).

(1) When condition ① is satisfied, the point (0,1,0) is the stable point of the replicated dynamic system.

When SMEE can hardly afford the cost of investing in the reconstruction of intelligent coal mines (staff training and equipment renewal, etc.) or when the production results are not good, the probability of the SMEE voluntarily carrying out intelligent reconstruction of coal mines decreases, the miner's strong attachment to the SMEE and the equal returns for miner under the two strategies, the replica system will eventually stabilize at (Maintaining Tradition, Active promotion, Negative cooperation). At this time, the intelligent construction of coal mines is entirely dependent on the independent policy actions of the government, and the willingness of the SMEE and the enthusiasm of the miner is not strong. To avoid worsening the situation, the government should introduce correct guidance policies, strengthen support for the SMEE, and advocate the joint construction of intelligent systems between the SMEE and large enterprises to establish a healthy digital transformation ecosystem and achieve the SMEE and the government should reduce the burden of investment.

(2) The point (1,1,1) is the stability point of the replicated dynamic system.

SMEE's strategy choice is stable to actively participate in the intelligent construction of coal mines, and the miner choses to positive cooperate, at which point the project was successfully implemented when government departments paid the capital costs and technical help to support the project, and the 3 game subjects reached a consensus that the replica system would eventually stabilize on (Actively construction, Active promotion, Positive cooperation).

**Scenario 2. Pessimistic miner, rational government, and rational SMEE.**

This situation implies that the miner is pessimistic in the process of playing the intelligent coal mine construction strategy. For the sake of analysis, assume that the emotional parameters of the miner $r_3 = 0.5$ and the government and the SMEE are rational participants, the emotion parameters of both parties are $r_1 = r_2 = 1$. Bringing the emotional parameters of the three parties of the game into the replicated dynamic equation yields the asymptotic stability of the pure strategy equilibrium point (Table 6).

There are 3 possible stable equilibrium strategies in a state of pessimism held by miners: $A_3$(0,1,0), $A_5$(1,1,0) and $A_8$(1,1,1).

(1) When condition ① is satisfied, the point (0,1,0) is the stable point of the replicated dynamic system.

On the basis of the construction cost or poor production effect, combined with the pessimism of miners on SMEE's consideration, the possibility of the SMEE and miners to voluntarily carry out intelligent coal mine transformation is low, and there is the phenomenon of government autonomy to actively promote intelligent coal mine construction, indicating that pessimism to some extent negatively affects the crisis awareness and psychological distance of the SMEE and miners on carbon emissions, and the replication system will eventually stabilize at (Maintaining Tradition, Active promotion, Negative cooperation).

(2) When condition ② is satisfied, the point (1,1,0) is the stable point of the replicated dynamic system.

Contrary to the strong correlation between the SMEE and the miner in the fully rational state, the SMEE senses the miner's pessimism, while considering the long-term benefits of safe and green production, and chooses to participate in intelligent coal mine construction projects. In addition, when the miner's pessimism influences them to make negative strategic choices, the replication system will eventually stabilize in (Actively construction, Active promotion, Negative cooperation). At this point, the SMEE, as the "backbone" of the staff, should take the initiative and conduct activities such as pep rallies and psychological counseling to alleviate the miner's negative emotions and appreciate the trend and benefits of intelligent coal mine construction.

(3) When condition ③ is satisfied, the point (1,1,1) is the stable point of the replicated dynamic system.

When miners are in a state of pessimism, satisfying $\theta_4 < 0$, the strategic choice of the SMEE stabilizes at actively promoting intelligent coal mine construction, and the miner realizes the importance of pre-preparedness for low-carbon behavior under appropriate pessimism, or is unable to sway corporate and government decisions and chooses to actively cooperate, at which point the project is successfully implemented at the cost of government departments to support it, and the replica system will eventually stabilize at (Actively construction, Active promotion, Positive cooperation).

**Scenario 3. Optimistic miner, rational government, and rational SMEE.**

This situation implies that the miner is optimistic in cooperating with the intelligent coal mine construction strategy. Assuming that the emotional parameters of the miner $r_3 = 2$ and the government and the SMEE are rational participants, the sentiment parameters of both parties are $r_1 = r_2 = 1$. Bringing the emotional parameters of the three parties of the game into the replicated dynamic equation yields the asymptotic stability of the pure strategy equilibrium point (Table 7).

The same as when the miner are in a pessimistic state, there are also three possible stable equilibrium strategies in the optimistic state, namely $A_3$(0,1,0), $A_5$(1,1,0) and $A_8$(1,1,1). $A_3$, $A_5$ and $A_8$ together indicate that the government maintains a strategic choice to actively promote intelligent coal mine construction, regardless of the emotional state of the miner and whether the SMEE and the miner make a common bias strategy or a differential strategy.

(1) When condition ① is satisfied, the point (0,1,0) is the stable point of the replicated dynamic system.

Similar to the results under the influence of pessimism, it is unlikely that the SMEE and the miner will voluntarily undertake intelligent coal mine construction, but the government has chosen to actively promote intelligent coal mine construction, possibly because optimism reduces the awareness of crisis and psychological distance between the SMEE and the miner regarding carbon emissions, and the replica system will eventually stabilize at (Maintaining Tradition, Active promotion, Negative cooperation).

**Table 6.** Strategic Portfolio Stability Analysis under Miner Pessimism, Government and SMEE Rational Scenarios.

| Balancing Point | Eigenvalues | | | Signs | Stability |
|---|---|---|---|---|---|
| | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | | |
| $A_1(0,0,0)$ | 0 | $NE_g - E_f$ | $C_c - C_a - C_d + NC_e$ | 0, +, − | Unstable |
| $A_2(1,0,0)$ | $+\infty$ | $NE_g - E_f - C_b$ | $C_a - C_c + C_d - NC_e$ | +, +, + | Unstable |
| (0,1,0) | 0 | $E_f - NE_g$ | $C_b - C_a + C_c - C_d + NC_e$ | 0, −, ○ | Satisfy condition ①, ESS |
| $A_4(0,0,1)$ | 0 | $NE_g - E_f$ | $C_c - C_a - C_d + N + NC_e$ | 0, +, − | Unstable |
| $A_5(1,1,0)$ | $-\infty$ | $C_b + E_f - NE_g$ | $C_a - C_b - C_c + C_d - NC_e$ | −, −, ○ | Satisfy condition ②, ESS |
| $A_6(1,0,1)$ | $\theta_1$ | $NE_g - E_f - C_b$ | $\theta_2$ | ○, +, ○ | Unstable |
| $A_7(0,1,1)$ | 0 | $E_f - NE_g$ | $C_b - C_a + C_c - C_d + N + NC_e$ | 0, −, + | Unstable |
| $A_8(1,1,1)$ | $\theta_3$ | $C_b + E_f - NE_g$ | $\theta_4$ | −, −, ○ | Satisfy condition ③, ESS |

Note: ○ indicates that the positive and negative signs are uncertain; condition; ①: $C_b - C_a + C_c - C_d + NC_e < 0$; condition ②: $C_a - C_b - C_c + C_d - NC_e < 0$; Condition ③: $\theta_4 < 0$; $\theta_1 = \frac{(C_a - C_c + C_d - NC_e)}{2} - \frac{(3N + NP_j + P_h - P_i)}{4} - \frac{((N + NP_j + P_h - P_i)^2 - 4N^2 - 4(N + NP_j + P_h - P_i)(C_c - C_a - C_d + N + NC_e) + 4(C_c - C_a - C_d + N + NC_e)^2 - 4N(NP_j + P_h - P_i))^{0.5}}{4}$; $\theta_2 = \frac{(C_a - C_c + C_d - NC_e)}{2} - \frac{(3N + NP_j + P_h - P_i)}{4} + \frac{((N + NP_j + P_h - P_i)^2 - 4N^2 - 4(N + NP_j + P_h - P_i)(C_c - C_a - C_d + N + NC_e) + 4(C_c - C_a - C_d + N + NC_e)^2 - 4N(NP_j + P_h - P_i))^{0.5}}{4}$; $\theta_3 = \frac{(C_a - C_b - C_c + C_d - NC_e)}{2} - \frac{(3N + NP_j + P_h - P_i)}{4} + \frac{(4(C_b - C_a + C_c - C_d + N + NC_e)^2 - 4(N + NP_j + P_h - P_i)(C_b - C_a + C_c - C_d + N + NC_e) + (N + NP_j + P_h - P_i)^2 - 4N^2 - 4N(NP_j + P_h - P_i))^{0.5}}{4}$; $\theta_4 = \frac{(C_a - C_b - C_c + C_d - NC_e)}{2} - \frac{(3N + NP_j + P_h - P_i)}{4} - \frac{(4(C_b - C_a + C_c - C_d + N + NC_e)^2 - 4(N + NP_j + P_h - P_i)(C_b - C_a + C_c - C_d + N + NC_e) + (N + NP_j + P_h - P_i)^2 - 4N^2 - 4N(NP_j + P_h - P_i))^{0.5}}{4}$.

**Table 7.** Strategic Portfolio Stability Analysis under Miner Optimistic, Government and SMEE Rational Scenarios.

| Balancing Point | Eigenvalues | | | Signs | Stability |
|---|---|---|---|---|---|
| | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | | |
| $A_1(0,0,0)$ | 0 | $NE_g - E_f$ | $C_c - C_a - C_d + NC_e$ | 0, +, − | Unstable |
| $A_2(1,0,0)$ | 0 | $NE_g - E_f - C_b$ | $C_a - C_c + C_d - NC_e$ | 0, +, + | Unstable |
| $A_3(0,1,0)$ | 0 | $E_f - NE_g$ | $C_b - C_a + C_c - C_d + NC_e$ | 0, −, ○ | Satisfy condition ①, ESS |
| $A_4(0,0,1)$ | 0 | $NE_g - E_f$ | $C_c - C_a - C_d + N + NC_e$ | 0, +, − | Unstable |
| $A_5(1,1,0)$ | 0 | $C_b + E_f - NE_g$ | $C_a - C_b - C_c + C_d - NC_e$ | 0, −, ○ | Satisfy condition ②, ESS |
| $A_6(1,0,1)$ | $NE_g - E_f - C_b$ | $\theta_5$ | $\theta_6$ | +, ○, ○ | Unstable |
| $A_7(0,1,1)$ | 0 | $E_f - NE_g$ | | 0, −, + | Unstable |
| $A_8(1,1,1)$ | $C_b + E_f - NE_g$ | $\theta_7$ | $\theta_8$ | −, −, ○ | Satisfy condition ④, ESS |

Note: ○ indicates that the positive and negative signs are uncertain; condition ①: $C_b - C_a + C_c - C_d + NC_e < 0$; condition ②: $C_a - C_b - C_c + C_d - NC_e < 0$; Condition ④: $\theta_8 < 0$;

$\theta_5 = \frac{(C_a - C_c + C_d - NC_e)}{2} - (2N + NP_j + P_h - P_i) - \frac{(2N(C_c - C_a - C_d + N + NC_e) - 2(N + NP_j + P_h - P_i)(C_c - C_a - C_d + N + NC_e) + 4(N + NP_j + P_h - P_i)^2 + N^2 + (C_c - C_a - C_d + N + NC_e)^2)^{0.5}}{2}$;

$\theta_6 = \frac{(C_a - C_c + C_d - NC_e)}{2} - (2N + NP_j + P_h - P_i) + \frac{(2N(C_c - C_a - C_d + N + NC_e) - 2(N + NP_j + P_h - P_i)(C_c - C_a - C_d + N + NC_e) + 4(N + NP_j + P_h - P_i)^2 + N^2 + (C_c - C_a - C_d + N + NC_e)^2)^{0.5}}{2}$;

$\theta_7 = \frac{(C_a - C_b - C_c + C_d - NC_e)}{2} - (2N + NP_j + P_h - P_i) - \frac{((C_b - C_a + C_c - C_d + N + NC_e)^2 + 4(N + NP_j + P_h - P_i)^2 + N^2 - 2(N + NP_j + P_h - P_i)(C_b - C_a + C_c - C_d + N + NC_e) + 2N(C_b - C_a + C_c - C_d + N + NC_e))^{0.5}}{2}$;

$\theta_8 = \frac{(C_a - C_b - C_c + C_d - NC_e)}{2} - (2N + NP_j + P_h - P_i) + \frac{((C_b - C_a + C_c - C_d + N + NC_e)^2 + 4(N + NP_j + P_h - P_i)^2 + N^2 - 2(N + NP_j + P_h - P_i)(C_b - C_a + C_c - C_d + N + NC_e) + 2N(C_b - C_a + C_c - C_d + N + NC_e))^{0.5}}{2}$.

(2) When condition ② is satisfied, the point (1,1,0) is the stable point of the replicated dynamic system.

In contrast with pessimism, the miner in a state of optimism make the decision choice to negatively cooperate with the intelligent construction of coal mines, most likely due to the poor management systems and unscientific models of the SMEE and the general ageing of traditional miners, who are not very receptive to new things and choose a negative cooperation strategy, while the SMEE are influenced by the optimism of the miner and increase their awareness of the crisis and psychological distance from carbon emissions. The replica system will eventually stabilize in (Actively construction, Active promotion, Negative cooperation). At this point, the SMEE should carry out internal reforms, improve and strengthen their management systems, and strengthen the green, safe and intelligent ideological education of ageing miners.

(3) When condition ④ is satisfied, the point (1,1,1) is the stable point of the replicated dynamic system.

With miners' optimism, when $\theta_8 < 0$ is satisfied, the strategic choice of the SMEE stabilizes at active participation in the intelligent construction of coal mines, the miner is optimistic about low-carbon behavior and have a cooperative attitude of active promotion of intelligent construction, at which time government departments strongly support the project, and the replication system will eventually stabilize at (Actively construction, Active promotion, Positive cooperation).

The existence of 3 identical possible stable equilibrium points for the miner in both pessimistic and optimistic emotional states suggests that intelligent construction of coal mines is the general trend, and that the emotional behavior of groups of miners may not play a role in guiding the decisions of the SMEE and the government. Alternatively, the optimistic or pessimistic moods of participants are to some extent influencing their crisis awareness and risk perception of low-carbon behavior.

## 4. Simulation Analysis

To visualize the evolution of the decision making of the SMEE, government and the miner subjects under the influence of different emotions of the miner, a simulation analysis will be carried out in MATLAB™. In conjunction with the previous section, reference is made to previous research [25–27] for reasonable values of the parameters within the specified range (Table 8).

**Table 8.** Parameter settings.

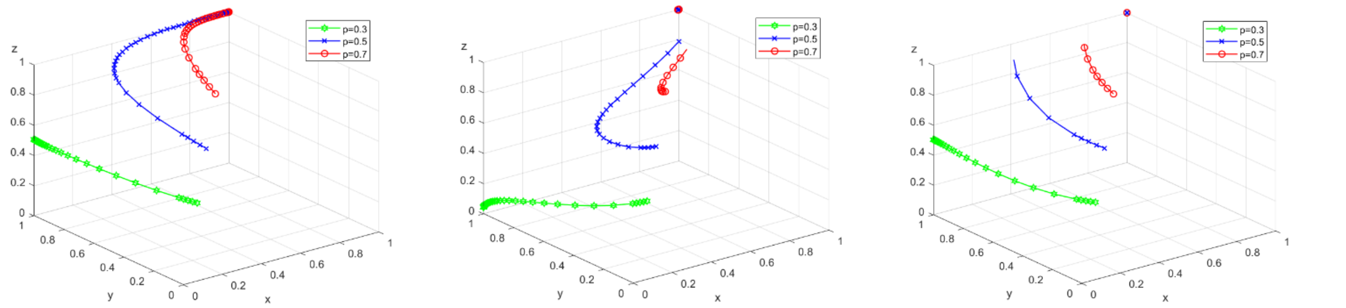
| **Parameters** | **x** | **y** | **z** | $C_a$ | $C_b$ | $C_c$ | $C_d$ | $NC_e$ | $E_f$ | $NE_g$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Initial value | 0.5 | 0.6 | 0.4 | 5 | 1.5 | 2 | 3 | 1.5 | 1 | 5 |
| Parameters | G | $E_1$ | $E_2$ | $P_h$ | N | $P_i$ | $NP_j$ | | | |
| Initial value | 10 | 3 | 2 | 0.5 | 4 | 0.5 | 0.5 | | | |

Considering the different emotional states of the miner, this study analyses the stability of strategy combinations among the SMEE, government and the miner in two contexts: (rational, rational, rational), and (rational, rational, emotional). Among them, sentiment can be specifically subdivided into pessimistic and optimistic, and different emotional states have different effects on strategy choice. Based on the parameter settings, this study will further analyze the evolutionary stability of strategy combinations under three specific contexts of (rational, rational, rational), (rational, rational, pessimistic) and (rational, rational, optimistic) after being influenced by different factors.

### 4.1. Impact of Initial Participation Rate

To analyze the strategy evolution process and results of the SMEE, government and the miner when the miners is in different emotional states with different participation rate(Figure 2), the initial participation rate of the 3 subjects were set as $\{x_0 = 0.3, y_0 = 0.3, z_0 = 0.3\}$;

$\{x_0 = 0.5,\ y_0 = 0.5,\ z_0 = 0.5\}$; $\{x_0 = 0.7,\ y_0 = 0.7,\ z_0 = 0.7\}$. Of these, 0.6 is the high ratio and 0.4 is the low ratio (Figure 2).




(**a**) (**b**) (**c**)

**Figure 2.** Strategy trajectories of the three game subjects in the 3 emotional states of the miner with different initial participation ratios. (**a**) $r_1 = r_2 = r_3 = 1$; (**b**) $r_3 < 1$, $r_1 = r_2 = 1$; (**c**) $r_3 > 1$, $r_1 = r_2 = 1$.

When all three parties are in a rational state, the SMEE and the miner will gradually increase their enthusiasm and acceptability of construction as the participation ratio increases, until it stabilizes at point (1,1,1). It is also clear that the higher the participation ratio, the shorter the time taken to make a positive strategy choice, suggesting that the active participation of all parties involved is essential for the intelligent and efficient transformation of coal mines.

Second, when the miner is in a pessimistic state, the low participation will make the government bear the pressure of intelligent construction alone. However, as the proportion of tripartite participation increases, the intention of the SMEE and the miner to make constructions gradually increases, eventually resulting in a tripartite sharing of responsibility for intelligent coal mine constructions, suggesting that the miner's pessimism about the existence of carbon emissions may increase the willingness of subjects to make constructions while the proportion of participation increases.

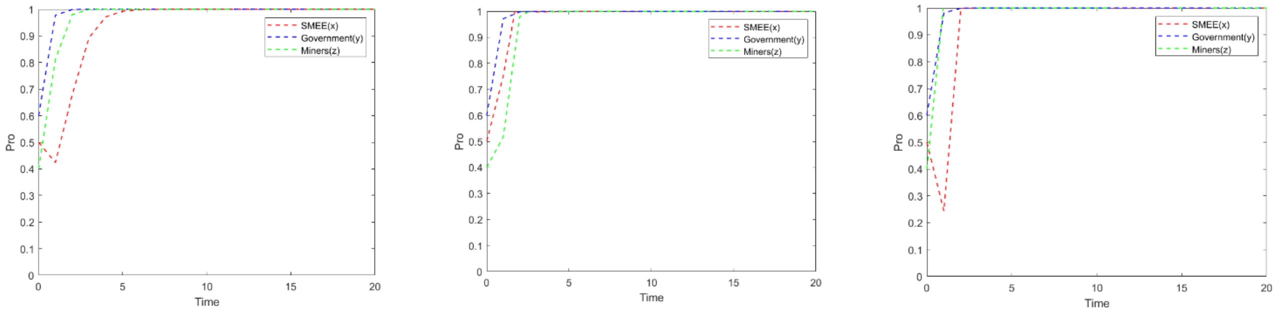
Finally, the higher the participation ratio when the miner is in a state of optimism, the closer the construction intention of the three subjects converges to the point (1,1,1), again suggesting that an increase in participation ratio may complement optimism and evolve into a motivation for intelligent coal mines construction.

### *4.2. Impact of Construction Costs*

Let the initial participation ratio of the three parties be $\{x_0 = 0.5,\ y_0 = 0.6,\ z_0 = 0.4\}$, the cost of intelligent construction of the coal mine $\{C_a = 4.6,\ 5,\ 5.9\}$, and analyze the strategy evolution process and results of the three game subjects under different carbon emotion states of the miner (Figures 3–5).

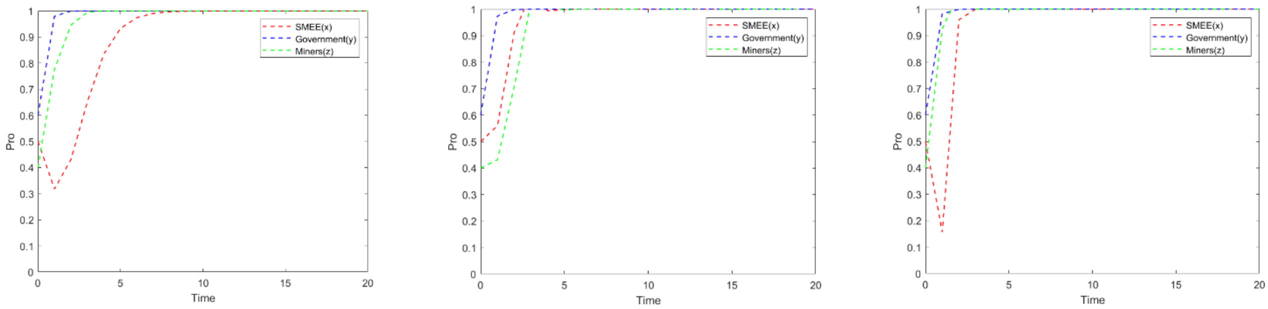
The evolution of the game system and the results of the different emotional states of the miners are different when the cost of intelligent construction of the coal mine is different.

Firstly, when the three parties are in a rational emotional state, the increase in the cost of intelligent coal mine construction will directly affect the enthusiasm of the SMEE for intelligent coal mine construction. When the cost of construction is low or medium, as the SMEE, the desire for stability may affect their willingness to convert in the early stage, while the social development trend makes them realize the importance of intelligent construction of coal mines, and their willingness to convert gradually increases and eventually stabilizes at 1. When the SMEE can hardly afford the high cost, they choose to avoid the risk of construction and give up the intelligent construction of coal mines. The government, on the other hand, has always taken a proactive approach to promoting intelligent construction of coal mines.



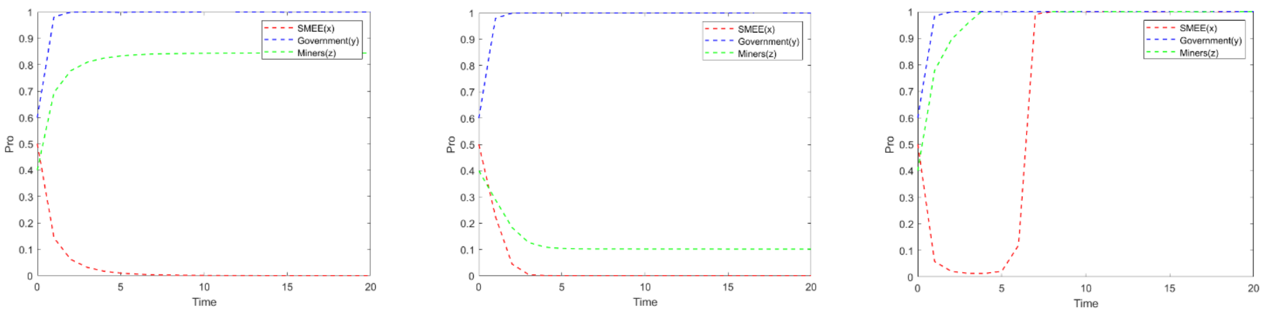

(a) (b) (c)

**Figure 3.** $C_a = 4.6$, strategy evolution process of the three game subjects under 3 emotional states of the miner. (**a**) $r_1 = r_2 = r_3 = 1$; (**b**) $r_3 < 1, r_1 = r_2 = 1$; (**c**) $r_3 > 1, r_1 = r_2 = 1$.




(a) (b) (c)

**Figure 4.** $C_a = 5$, strategy evolution process of the three game subjects under 3 emotional states of the miner. (**a**) $r_1 = r_2 = r_3 = 1$; (**b**) $r_3 < 1, r_1 = r_2 = 1$; (**c**) $r_3 > 1, r_1 = r_2 = 1$.




(a) (b) (c)

**Figure 5.** $C_a = 5.9$, strategy evolution process of the three game subjects under 3 emotional states of the miner. (**a**) $r_1 = r_2 = r_3 = 1$; (**b**) $r_3 < 1, r_1 = r_2 = 1$; (**c**) $r_3 > 1, r_1 = r_2 = 1$.

Secondly, when the miner is in a pessimistic state, there is a significant delay in the positive attitude of the miner choosing to cooperate with the intelligent construction of the mine compared to a rational state. In times of high construction costs, the miner may be ambivalent about whether their income will be affected, leading them to make a negative choice to cooperate.

Finally, when the miner is in a state of optimism, the intention of the SMEE to choose to maintain traditional coal mine production methods becomes increasingly evident as the cost increases, but optimism may influence their perception of the risk of carbon emissions, making the intention to participate gradually increase.

All in all, regardless of the emotional state of the miner and the cost of intelligent constructions, the government has always been clear that intelligent coal mines are an inevitable choice to achieve the goal of carbon peaking and carbon neutrality in view of the bigger picture, and as a profit-oriented the SMEE, the high cost of intelligent constructions will indeed seriously affect their motivation to change. As the SMEE, the development of the employees is closely related to the company, and therefore the company is to a certain extent affected by the emotions of the employees. All of the above is true in practice.

### 4.3. Impact of Government Support

The initial participation ratio of the three main parties is set at $\{x_0 = 0.5,\ y_0 = 0.6,\ z_0 = 0.4\}$, the government actively promotes the intelligent alteration of coal mines with financial subsidies, technical support, etc. $\{C_b = 0.6, 1.5, 3.6\}$, and analyze the strategy evolution process and results of the three game subjects under different carbon mood states of the miner (Figures 6–8).

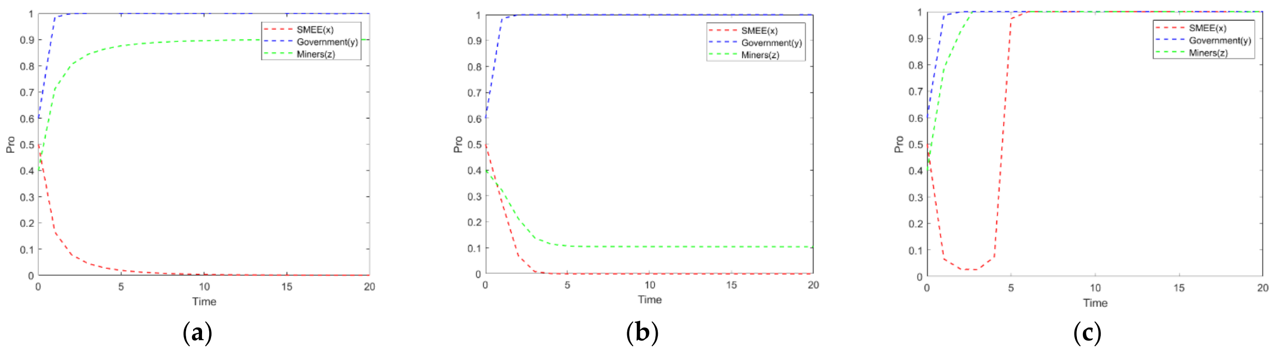



**Figure 6.** $C_b = 0.6$, strategy evolution process of the three game subjects under 3 emotional states of the miner. (**a**) $r_1 = r_2 = r_3 = 1$; (**b**) $r_3 < 1, r_1 = r_2 = 1$; (**c**) $r_3 > 1, r_1 = r_2 = 1$.

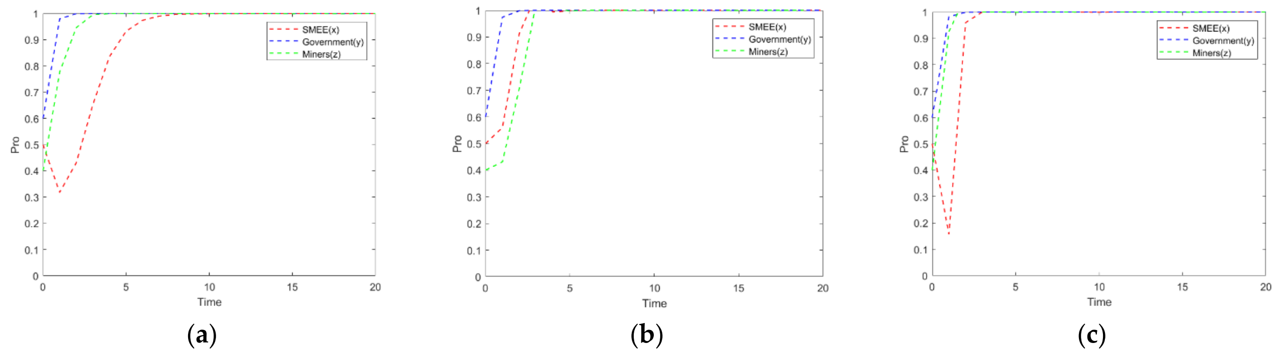



**Figure 7.** $C_b = 1.5$, strategy evolution process of the three game subjects under 3 emotional states of the miner. (**a**) $r_1 = r_2 = r_3 = 1$; (**b**) $r_3 < 1, r_1 = r_2 = 1$; (**c**) $r_3 > 1, r_1 = r_2 = 1$.

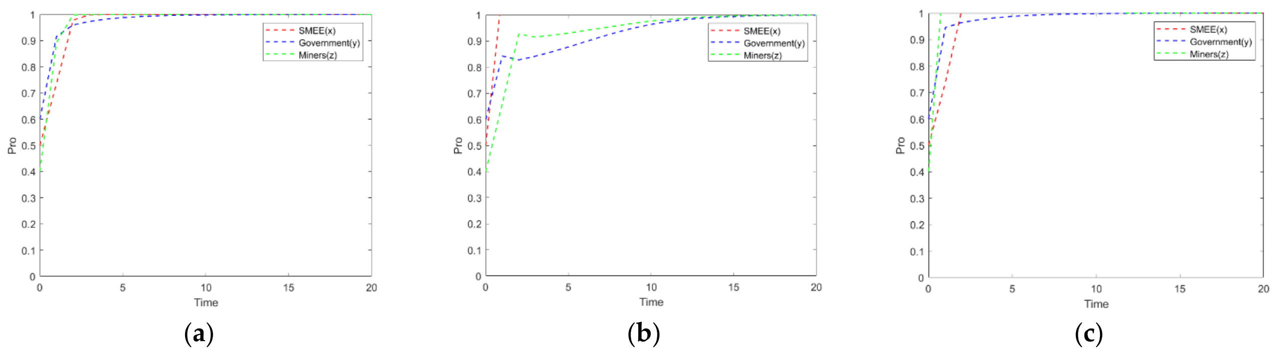



**Figure 8.** $C_b = 3.6$, strategy evolution process of the three game subjects under 3 emotional states of the miner. (**a**) $r_1 = r_2 = r_3 = 1$; (**b**) $r_3 < 1, r_1 = r_2 = 1$; (**c**) $r_3 > 1, r_1 = r_2 = 1$.

The evolutionary process and results of the game system in different emotional states of the miner under different circumstances such as government financial subsidies and technological support have differences, and even affect the government's enthusiasm to promote coal mine intelligence.

Firstly, when the three parties are in a rational emotional state, the SMEE and the miner may perceive the low level of government subsidies as a low level of government attention, thus affecting their motivation to cooperate. At the same time, the SMEE faced with high costs and low subsidies for the intelligent construction of coal mines, and their willingness to build was unstable in the early stages until the government increased its support, the SMEE and the miner will take the initiative to build and actively cooperate with the intelligent coal mine construction, but the high cost of subsidies caused a slight fluctuation in the stability of the government's willingness to actively build.

Secondly, when the miner is in a state of pessimism, the pessimism combined with the low level of support makes the participation of the SMEE and the miner in active constructions gradually decrease to stabilize. At this point, the high cost of assistance may be more than the government can afford and fluctuate more significantly.

Finally, when the miner is in a state of optimism, optimism became a quality motivator for the SMEE and the miner to actively undertake intelligent coal mine constructions, even though low help efforts influenced the SMEE's early choices, but over time re-established motivation after participation hit rock bottom. The high level of support reinforced the determination of the SMEE to undertake intelligent construction of coal mines, stabilizing the strategy to engage in construction in a short period of time.

In conclusion, the government, as a 'rational ecologist', is not easily influenced by the miner's emotions, and although the high level of financial subsidies and technical support affects the government's willingness to push forward, it ultimately insists on intelligent coal mine construction, the results also show that neither optimism nor pessimism has an absolute impact on the subject. As the SMEE with a weak foundation, their enthusiasm for construction is limited by the costs involved if they lose the attention and support of the government.

## 5. Conclusions and Recommendations

### *5.1. Conclusions*

The aim of this paper is to investigate the impact of carbon emotion on the game behavior of the SMEE, government and the miner in a dual carbon context. To achieve this objective, RDEU theory is used to quantify the miner's emotions as irrational factors, and a game model is combined to analyze and simulate the game equilibrium strategy under three heterogeneous combinations of emotions: " SMEE, government and the miner are rational", " government and SMEE are rational, the miner is pessimistic ", and " government and SMEE are rational, the miner is optimistic". The results show that: (1) Regardless of the emotional state of miners, the government will insist on actively promoting the intelligent construction of coal mines. (2) Both moderate pessimism and optimism will, to a certain extent, give a positive impetus to the intelligent construction of coal mines. (3) The influence of the miner's emotions on the SMEE is greater than that on the government's strategic behavior. (4) For the SMEE, the high cost of intelligent coal mine construction or the low level of government subsidies and technical support may sap their enthusiasm for intelligent coal mine construction.

### *5.2. Insights and Recommendations*

Based on the above conclusions, the following insights were obtained.

(1) Give full play to the role of policy guidance and direction, and strengthen the attention to the SMEE. In recent years, the state and various places have successively issued some policy documents, standards and norms related to the intelligent construction of coal mines, established a coal intelligent expert database, held coal mine intelligent construction promotion meetings, etc. However, for SMEE, which is the main force of national economic and social development, there are more principles and fewer rules, more

thresholds and less benefits, resulting in the effect of the policy implementation process is greatly reduced. Hence, the government should strengthen its ideological understanding, increase its attention to the SMEE, and solidly promote the implementation of various policy measures to help them cope with difficulties and improve their market competitiveness.

(2) Create an appropriately pessimistic or optimistic carbon mood to guide the miners in the SMEE to value intelligent coal mine construction. There are no absolutes in terms of emotional impact, appropriate negative emotions may motivate profit-oriented companies to take on their social responsibility [28], while positive environmental sentiment may inspire subjects to develop a stable and long-term positive emotional association with low-carbon ideas [29]. Consequently, the promotion of carbon emotion in all miners in the SMEE through awareness-raising will, to a certain extent, contribute to the promotion of intelligent coal mine construction.

(3) The SMEE and the miner should keep the same frequency of thinking in order to achieve common development. The development value of the SMEE is the ultimate embodiment of its staff value collection. To achieve the goal of intelligent coal mine construction, enterprises should expand their patterns to develop together with the miner. Only when both sides complement each other will they reach the point of mutual success.

(4) Enhance the support for the SMEE by giving reasonable financial subsidies and technical support. In the face of intelligent coal mine construction, financial and technical problems have become the biggest difficulties for the SMEE. The government should not ignore the market position of the SMEE, it should step up its efforts to encourage the SMEE facing difficulties. Nevertheless, in order to protect social welfare, it is important to avoid exceeding the threshold of subsidies that would cause government indebtedness and slow down the construction progress. Ideas such as co-build of intelligent systems between SMEE and large enterprises can be expanded to achieve the effect of reducing the burden on SMEE and government expenditure.

Based on the above conclusions and recommendations, this study innovatively integrates RDEU theory and game theory into the intelligent coal mine construction plan, which will provide more universal construction ideas and construction options for the SMEE, the government, and the miner, and help China accelerate the green and low-carbon energy transition.

### 5.3. Limitations

There are several limitations to this study. (1) This study only explored the conditions of sufficient stability among the three participants-the SMEE, the government, and the miner-given the heterogeneous sentiments of miners. Conversely, considering more complex situations, heterogeneous sentiments among the SMEE and the government are also possible. (2) In the long run, the implementation of smart coal mine construction strategies will be an evolving process, and the strategic interactions among the SMEE, the government and the miner will show a more complex and dynamic process. The research needs to be continuously adjusted and optimized based on more complex internal and external factors. (3) Extensive and valid recommendations have been made in the study. Subsequently, further refinement of the model and optimization of the recommendations may be required on an ongoing basis, depending on the actual situation in society. These issues pose a great challenge for future research.

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