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# Trend of the compensation policy and tactics for the development of mineral resources in China

## Introduction

Mineral resource exploitation inevitably causes serious damage to the ecological environment (Li et al. 2014; Lei et al. 2016). To effectively enact ecological management over mining-area environmental pollution, the Chinese government has taken various measures and aggressively pushed for the construction of payments for environmental services (PES) (Yang and Lu 2018; Ouyang et al. 2016). So far, China has established an overall PES framework with government-dominated funding sources, which is known as the system of ecological compensation (Pan et al. 2017).

The present regulations for ecological compensation for the exploitation of resources in China originate from the *Mineral Resources Law* (China 2019) prepared by China's national legislature body in the year of 1986 and the *Land Reclamation Act* (China 2011) enacted by the State Council in the year of 1988, which for the first time required complete land

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reclamation after mining in China. In the year 2003, the central government appropriated special funds for the mines' geological environment to support local governments in restoring the ecological environment of those closed contaminated mines. Owing to sufficient funding by the central government and the work of the environmental restoration of the mines, the mines' environment has greatly improved in quality; however, the central government has endured heavy financial pressure.

To relieve this financial pressure, the central government established the security deposit system for environmental restoration and management in the year 2012, which required mining enterprises to pay security deposits as the cost of ecological environment management. By the end of 2012, the security deposits paid by the mining enterprises amounted to 61.2 billion RMB which composed 62% of the required amount (China 2013). The fact that many mining enterprises did not pay the security deposit as requested indicated that companies have resisted the implementation of the policy of a security deposit.

In view of the problems existing in the implementation of security deposit systems, such Chinese ministries as the Ministry of Finance, the Ministry of Natural Resources, and the Ministry of Ecology and Environment jointly issued the *Guidance on Establishment of the Recovery Fund for Mine Ecological and Environmental Restoration* in the year 2017 (China 2017). In the Guidance, the security deposit was changed to a restoration fund, and the payment policy of the restoration fund was only a guiding opinion, which aims to delegate power from the central government to local governments. Under central government guidance, different provinces or cities can provide different financial compensation for the ecological environment of mining areas, according to their specific situation. The historical development of China's mining ecological compensation policy shows that solving conflicts among stakeholders is a key problem in determining this financial incentive.

The EU has been a pioneer in the field of environmental policies since the 1970s and has environmental acquisitions consisting of 500 directives, regulations and decisions (EEA 2015; Yildirim et al. 2021). In line with the Paris Climate Agreement, the governments of EU countries have declared that coal should be phased out by 2030 (IPCC 2014). Poland has already made achievements in protecting the ecological environment, including a government framework document published in 2009 (Ministry of Economy 2009).

However, although the draft Energy Policy of Poland (ME 2015) was presented in 2015, it was not adopted for many reasons (including change in the government). The EU has been exerting pressure on the Polish government to initiate policies for environmental protection, and Poland implemented the energy policy adopted by the Council of Ministers in 2017 focusing on the use of renewable energy sources and reductions in the consumption of energy resources.

The Millennium Ecosystem Assessment introduced a new framework for analyzing social-ecological systems that has had a wide influence on policy and scientific communities (Carpenter et al. 2009). Many scholars have researched the process of policy making through establishing models (Baker and Eckerberg 2013; Brunner and Gret-Regamey 2016; Pacini et al. 2004; Sutherland and Freckleton 2012) and evaluating how well the policy was working

(Chitaka et al. 2018; Mossalanejad 2012). The stages model has advantages in that it helps reveal how ecological restoration becomes embedded in the policy making process. Ecological restoration evaluation should therefore be ongoing, contextual, and not a one-off event (Baker and Eckerberg 2016).

Ecological compensation is an economic approach to the improvement of ecosystem services by coordinating the relationships among different stakeholders (Zhong et al. 2020; Moilanen et al. 2009; Curran et al. 2014). Some scholars argue that local governments (municipal governments and concerned district/county governments), as the core stakeholders, dominate the compensation process (Long et al. 2015). There are clear tensions between private and public institutions. At a broader level, conflicts between national and local governments also exist (Thompson and Friess 2019). The criteria for ecological compensation based on a life cycle approach may be beneficial in providing a holistic view for stakeholders through all stages of production (Chen et al. 2020). A game can be observed in the complex relationship between sources and recipients of ecological compensation among multiple stakeholders (Shu 2018).

The stakeholders involved in ecological compensation for mining areas achieve balance through strategy selection. In the process of managing continuous checks and balancing interests it is essential that changes in the direction of ecological compensation in mining areas are determined and the strategic choices of stakeholders are shifted in the direction of sustainable development. There is no evidence to show that the central government's strategy of devolving power to local governments will be conducive to the establishment of ecological compensation.

Evolutionary game theory has been widely used to explain the evolutionary process of conflicts among stakeholders under different strategies (Shi et al. 2021; Shen et al. 2021; Axelrod and Hamilton 1981; Taylor and Jonker 1978). By using evolutionary game theory, Feng et al. (Feng et al. 2002) analyzed the role of stakeholders in the ecological governance of the Yangtze River Basin in China (Li et al. 2017). Gao et al. (Gao et al. 2019) studied the impact of government decision-making on basin ecological compensation. Yang and Yang (Yang and Yang 2019) discussed the factors influencing the implementation of China's air pollution control policies by establishing a game model among the central regulatory authorities, local government officials and whistleblowers

However, few scholars use evolutionary game theory to analyze the impact of stakeholders in the field of ecological compensation for mineral resource exploitation. Only a few studies, such as Collins and Kumral (Collins and Kumral 2020) have discussed the challenges in modelling environmental management problems with game theory for the mining industry. Zhao et al. (Zhao et al. 2020b) studied the game mechanism between local governments and metal mining companies to analyze the factors that influence their strategies. However, national government supervision is critical to the achievement of the goals of environmental regulation policies (Sheng et al. 2020b). Research on the game between local governments and mining enterprises only investigates some stakeholders in the ecological compensation policy, which may lead to deviation in the final result affecting ecological governance.

Therefore, this paper introduces the central government as a core stakeholder into the game model of ecological compensation for mineral resource exploitation. From the perspective of balancing interests, as reflected in the ecological compensation policy, this paper works out the solution for equilibrium of the three parties in the game and thereby analyzes the constraints of the evolutionary stable strategy (ESS), resolves the potential conflicts of interest in the design of an ecological compensation policy, and realizes an ecological compensation policy for mineral resource development to sustainably develop the ecological environment of mining areas.

# 1. A tripartite evolutionary game model for China's ecological compensation system

## 1.1. Stakeholders in China's ecological compensation for mineral resource exploitation

According to China's current law, regulations and administrative structure, the stakeholders in the investigated policy-making and implementation process include the central government, local governments and mining enterprises. The central government urgently wants local governments and mining enterprises to cooperate on ecological compensation. Local governments represent local interests. Mining enterprises aim to maximize profits through the development of mineral resources. For the three-party evolutionary game model, this paper makes the following assumptions:

- The three stakeholders in the evolutionary game do not have equal power. The central government can supervise and punish local governments. The local government can supervise and punish mining enterprises.
- During the game process, the central government, local government and mining enterprises want to obtain the maximum benefit.
- The central government, local governments and the mining enterprises each have two alternative strategies, which are listed in Table 1.
- The stakeholders in the game process have limited rationality, meaning that they are able to consider certain statistical analyses and judge the relevant benefits under different strategies, but they lack the ability to foresee, predict and judge in advance.
- The three stakeholders cannot find the best strategy at the beginning but learn and observe through the process of the game to adjust their strategy until the balance is reached.
- This paper only considers a unilateral breach of contract between the central government and local governments and not a simultaneous breach of the contract between them.

Table 1. The strategies for each player in the tripartite evolutionary game

Tabela 1. Strategie dla każdego gracza w trójstronnej grze ewolucyjnej

| Stakeholders | Strategies |
|---|---|
| The central government | Supervision |
| | No supervision |
| Local governments | Protecting the ecological environment |
| | Not protecting the ecological environment |
| Mining enterprises | Paying the ecological compensation fee |
| | Not paying the ecological compensation fee |

Table 2. The parameters in the tripartite evolutionary game

Tabela 2. Parametry w trójstronnej grze ewolucyjnej

| Parameter | Description | Note |
|---|---|---|
| $C_1$ | Costs of local governments, including investment cost and management cost | $C_1 > 0$ |
| $C_2$ | Supervision costs of the central government, including the cost for monitoring the behaviour of local governments and mining enterprises | $C_2 > 0$ |
| $F_1$ | Central government punishment to the local government if it fails to fulfil its responsibility for ecological protection | $F_1 > 0$ |
| $F_2$ | Central government punishment to mining enterprises that fail to fulfil their responsibility of ecological compensation | $F_2 > 0$ |
| $P$ | Ecological compensation fees paid by the mining enterprises to both the local and central governments | $P > 0$ |
| $T$ | Overall ecological environmental benefits | $T > 0$ |
| $i$ | Ecological environmental benefits allocation coefficient: the proportion of ecological environmental benefits assigned to the central and local governments | $i \in [0,1]$ |
| $e$ | Ecological compensation fees allocation coefficient, which is the proportion of ecological compensation fees received by the central and local governments | $e \in [0,1]$ |
| $R_1$ | Benefits of the central government, including the reputation and management benefits received for protecting the ecological environment | $R_1 > 0$ |
| $R_2$ | Benefits of the central government from improving the standards of ecological environment protection, which forces enterprises to engage in research and development and innovation, bringing high-tech value-added benefits | $R_2 > 0$ |
| $x$ | The probability that local governments chooses to protect the ecological environment | $x \in [0,1]$ |
| $y$ | The probability that mining enterprises choose to pay the ecological compensation fees | $y \in [0,1]$ |
| $z$ | The probability that the central government chooses to supervise local governments and mining enterprises | $z \in [0,1]$ |

Table 3. The expected payoff of stakeholders in the tripartite evolutionary game

Tabela 3. Oczekiwana wypłata interesariuszy w trójstronnej grze ewolucyjnej

| | | | | The central government | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Supervision ($z$) | | | No supervision ($1-z$) | | |
| | | | | Local governments | Mining enterprises | The central government | Local governments | Mining enterprises | The central governments |
| Local governments | Protecting ecological environment ($x$) | Mining enterprises | Paying a compensation fee ($y$) | $Pe+Ti-C_1$ | $T-Ti-P$ | $P(1-e)+$ $+T+R_1+R_2-C_2$ | $Pe+Ti-C_1$ | $T(1-i)-P$ | $P(1-e)+T$ |
| | | | Not paying a compensation fee ($1-y$) | $Ti-C_1$ | $T-Ti-F_2$ | $T+R_1+R_2+F_2-C_2$ | $Ti-C_1$ | $T(1-i)$ | $T$ |
| | Not protecting ecological environment ($1-x$) | Mining enterprises | Paying a compensation fee ($y$) | $Pe+F_1$ | $-P$ | $F_1+P(1-e)-C_2$ | $Pe$ | $-P$ | $P(1-e)$ |
| | | | Not paying a compensation fee ($1-y$) | 0 | 0 | $-C_2$ | 0 | 0 | 0 |

### 1.2. Payoffs of stakeholders

On the basis of the hypothesis in Section 1.1, the expected payoffs of the three stakeholders are shown in Table 3. Table 2 shows the specifications of the parameters.

### 1.3. Stakeholders' replicator dynamics equation for the tripartite evolutionary game

Let variables $u_{11}$ and $u_{12}$ represent the expected payoffs of local governments for choosing the "protecting ecological environment" and the "not protecting ecological environment" strategies, respectively.

$$u_{11} = yz(Pe + Ti - C_1) + (1-y)z(Ti - C_1) + y(1-z)(Pe + Ti - C_1) + \\ + (1-y)(1-z)(Ti - C_1) = y(Pe + Ti - C_1) + (1-y)(Ti - C_1) \tag{1}$$

$$u_{12} = yz(Pe - F_1) + Pey(1-z) = yPe + yzF_1 \tag{2}$$

The replicated dynamic equation of local governments is as follows:

$$F(x) = \frac{dx}{dt} = x(1-x)(u_{11} - u_{12}) = x(1-x)(Ti - C_1 + yzF_1) \tag{3}$$

Similarly, let variables $u_{21}$ and $u_{22}$ represent the expected payoffs of mining enterprises for choosing the "paying ecological compensation fee" and "not paying ecological compensation fee" strategies, respectively.

$$u_{21} = xz[T(1-i) - P] - Pz(1-x) + x(1-z)[T(1-i) - P] - \\ -P(1-y)(1-z) = xT(1-i) - P \tag{4}$$

$$u_{21} = xz[T(1-i) - F_2] + x(1-z)[T \cdot (1-i)] = xT(1-i) - xzF_2 \tag{5}$$

The replicated dynamic equation of mining enterprises is as follows:

$$F(y) = \frac{dy}{dt} = y(1-y)(u_{21} - u_{22}) = y(1-y)(xzF_2 - P) \tag{6}$$

Let variables $u_{31}$ and $u_{32}$ represent the expected payoffs of the central government for choosing the "supervising ecological compensation" and "not supervising ecological compensation" strategies, respectively.

$$\begin{aligned} u_{31} &= xy\left[P(1-e)+T+R_1+R_2-C_2\right]+(1-x)y\left[F_1+P(1-e)-C_2\right]+ \\ &+x(1-y)\left[T+R_1+R_2+F_2-C_2\right]+(1-x)(1-y)(-C_2)= \\ &= yP(1-e)+x(T+R_1+R_2-C_2)+(1-x)yF_1+(1-x)(-C_2)+x(1-y)F_2 \end{aligned} \tag{7}$$

$$u_{32} = xy\left[P(1-e)+M\right]+(1-x)yP(1-e)+x(1-y)T = yP(1-e)+xT \tag{8}$$

The replicated dynamic equation of the central government is as follows:

$$F(z)=\frac{dz}{dt}=z(1-z)(u_{31}-u_{32})=z(1-z)\left[x(R_1+R_2)-C_2+(1-x)yF_1+x(1-y)F_2\right] \tag{9}$$

Equations (3), (6) and (9) constitute a tripartite dynamic replicator system (10), where the central government, local governments and mining enterprises are considered as decision-makers.

$$\begin{cases} F(x)=x(1-x)(Ti-C_1+yzF_1) \\ F(y)=y(1-y)(xzF_2-P) \\ F(z)=z(1-z)\left[x(R_1+R_2)-C_2+(1-x)yF_1+x(1-y)F_2\right] \end{cases} \tag{10}$$

The initial probability of each stakeholder choosing each strategy is different, and as the game progresses among the three stakeholders, they change the strategy after each round to obtain the maximum benefit. Therefore, the choice of strategy will change over time. Our purpose was to analyze the benefits of stakeholders by analyzing the results of a tripartite evolutionary game, i.e., the ESS.

## 2. Results

### 2.1. Equilibrium points and asymptotic stability

According to Lyapunov's system stability theory (Wang 1966), when the dynamic equation of the imitator is 0, the stable state of the system can be obtained. According to Equation (11), there are eight equilibrium points: $E_1(0,0,0)$, $E_2(1,0,0)$, $E_3(0,1,0)$, $E_4(0,0,1)$, $E_5(1,1,0)$, $E_6(1,0,1)$, $E_7(0,1,1)$, and $E_8(1,1,1)$. These special equilibrium points constitute the boundaries of the solution domain of the tripartite evolutionary game, which is $x(0) \in (0,1)$, $y(0) \in (0,1)$, and $z(0) \in (0,1)$.

$$\begin{cases} F(x) = x(1-x)(Ti - C_1 + yzF_1) = 0 \\ F(y) = y(1-y)(xzF_2 - P) = 0 \\ F(z) = z(1-z)\left[x(R_1 + R_2) - C_2 + (1-x)yF_1 + x(1-y)F_2\right] = 0 \end{cases} \tag{11}$$

Moreover, there is another equilibrium point $E_9$ inside the solution domain that satisfies Equation (12):

$$\begin{cases} Ti - C_1 + yzF_1 = 0 \\ xzF_2 - P = 0 \\ x(R_1 + R_2) - C_2 + (1-x)yF_1 + x(1-y)F_2 = 0 \end{cases} \tag{12}$$

According to Ritzberger and Weibull (Ritzberger and Weibull 1995) and Friedman's evolutionary game theory (Friedman 1998b), a strategy combination is asymptotically stable in the dynamic replicator system of the multi-party evolutionary game only when it is a pure-strategy Nash equilibrium (Friedman 1998a). Since $E_9$ is a mixed-strategy Nash equilibrium, it is not a stable point.

We need to judge the asymptotic stability of the other eight equilibrium points. According to Friedman's evolutionary game theory, by calculating the replicator dynamic system, the Jacobian matrix of the tripartite evolutionary game system is shown in Equation (13):

$$J = \begin{bmatrix} (1-2x)(Ti - C_1 + yzF_1) & x(1-x)zF_1 & x(1-x)yF_1 \\ y(1-y)zF_2 & (1-2y)(xzF_2 - P) & y(1-y)xF_2 \\ z(1-z)\left[R_1 + R_2 + (1-y)F_2\right] & z(1-z)\left[x(R_1 + R_2) + (1-x)F_1\right] & (1-2z)\left[x(R_1 + R_2) - C_2 + (1-x)yF_1 + x(1-y)F_2\right] \end{bmatrix} \tag{13}$$

According to Lyapunov's stability criterion (Lyapunov 1992), the equilibrium point is asymptotically stable when all eigenvalues are negative. The Jacobian matrix and its eigenvalues can be obtained for the 8 equilibrium points of the system, as shown in Table 4.

## 2.2. Game scenarios for China's ecological compensation for mineral resource exploitation

According to the results in Section 3.1, there are four possible game situations depicting ecological compensation for mineral resource exploitation in China. To directly observe the asymptotic stability of the ESS in the model, we will use numerical simulation to analyze the evolution of the decision-making process of the three stakeholders in the ecological

Table 4. The stability of equilibrium points in the tripartite evolutionary game

Tabela 4. Stabilność punktów równowagi w trójstronnej grze ewolucyjnej

| Equilibrium Point | Eigenvalues | | | Asymptotic Stability Condition |
|---|---|---|---|---|
| | $l_1$ | $l_2$ | $l_3$ | |
| $E_1(0,0,0)$ | $Ti - C_1$ | $-P$ | $-C_2$ | $Ti < C_1$ |
| $E_2(1,0,0)$ | $C_1 - Ti$ | $-P$ | $R_1 + R_2 + F_2 - C_2$ | $C_1 < Ti$, $R_1+R_2 + F_2 < C_2$ |
| $E_3(0,1,0)$ | $Ti - C_1$ | $P$ | $F_1 - C_2$ | unstable |
| $E_4(0,0,1)$ | $Ti - C_1$ | $-P$ | $C_2$ | unstable |
| $E_5(1,1,0)$ | $C_1 - Ti$ | $P$ | $R_1+R_2 - C_2$ | unstable |
| $E_6(1,0,1)$ | $C_1 - Ti$ | $F_2 - P$ | $C_2 - R_1 - R_2 - F_2$ | $C_1 < Ti$, $C_2 < R_1 + R_2 + F_2$, $F_2 < P$ |
| $E_7(0,1,1)$ | $Ti + F_1 - C_1$ | $P$ | $C_2 - F_1$ | unstable |
| $E_8(1,1,1)$ | $C_1 - Ti - F_1$ | $P - F_2$ | $C_2 - R_1 - R_2$ | $C_1 < Ti + F_1$, $P < F_2$, $C_2 < R_1 + R_2$ |

compensation for mineral resource exploitation. The parameter values are set according to the stability conditions, as shown in Table 5.

Table 5. The initial set of values for the parameters in the numerical simulation

Tabela 5. Początkowy zestaw wartości parametrów w symulacji numerycznej

| Scenario | Parameter | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_1$ | $C_2$ | $F_1$ | $F_2$ | $P$ | $R_1 + R_2$ | $T$ | $i$ | $x$ | $y$ | $z$ |
| 1 | 40 | 10 | 15 | 15 | 10 | 40 | 50 | 0.5 | 0.1 | 0.1 | 0.1 |
| 2 | 20 | 60 | 15 | 15 | 10 | 40 | 50 | 0.5 | 0.5 | 0.5 | 0.5 |
| 3 | 20 | 30 | 15 | 15 | 20 | 40 | 50 | 0.5 | 0.5 | 0.5 | 0.5 |
| 4 | 20 | 30 | 15 | 15 | 10 | 40 | 50 | 0.5 | 0.5 | 0.5 | 0.5 |

#### 2.2.1. Evolutionary stable strategy under scenario 1

There is only one equilibrium point $E_1(0,0,0)$ when $Ti < C_1$. The numerical simulation results are shown in Figure 1(a), the strategy curve of the three parties in the game eventually converges to 0. In this situation the central government would choose the strategy of "not supervising", while local governments would select the strategy of "not protecting the ecological environment", and mining enterprises would choose the strategy of "not paying the compensation fee". Scenario 1 is the least ideal scenario.

### 2.2.2. Evolutionary stable strategy under scenario 2

The equilibrium point $E_2(1,0,0)$ is the unique ESS when $C_1 < Ti$ and $R_1 + R_2 + F_2 < C_2$. The results are shown in Figure 1(b), the strategy curve of local governments converges to 1, which means that local governments will insist on protecting the local ecological environment, but the central government strategy will gradually evolve into non-supervision, and mining enterprises' strategy will gradually evolve into not paying a compensation fee.

### 2.2.3. Evolutionary stable strategy under scenario 3

The equilibrium point $E_6(1,0,1)$ is the unique ESS when $C_1 < Ti$, $C_2 < R_1 + R_2 + F_2$ and $F_2 < P$. The results are shown in Figure 1(c). The change curve of local governments and the central government converges to 1, and the change curve of the mining enterprises converges to 0, indicating that the central government would choose the strategy of "no supervision", local governments would select the strategy of "protecting the ecological environment", and mining enterprises would choose the strategy of "paying the compensation fee" in this circumstance. This strategy combination is an ESS, and Scenario 3 is also a less-than-ideal scenario.

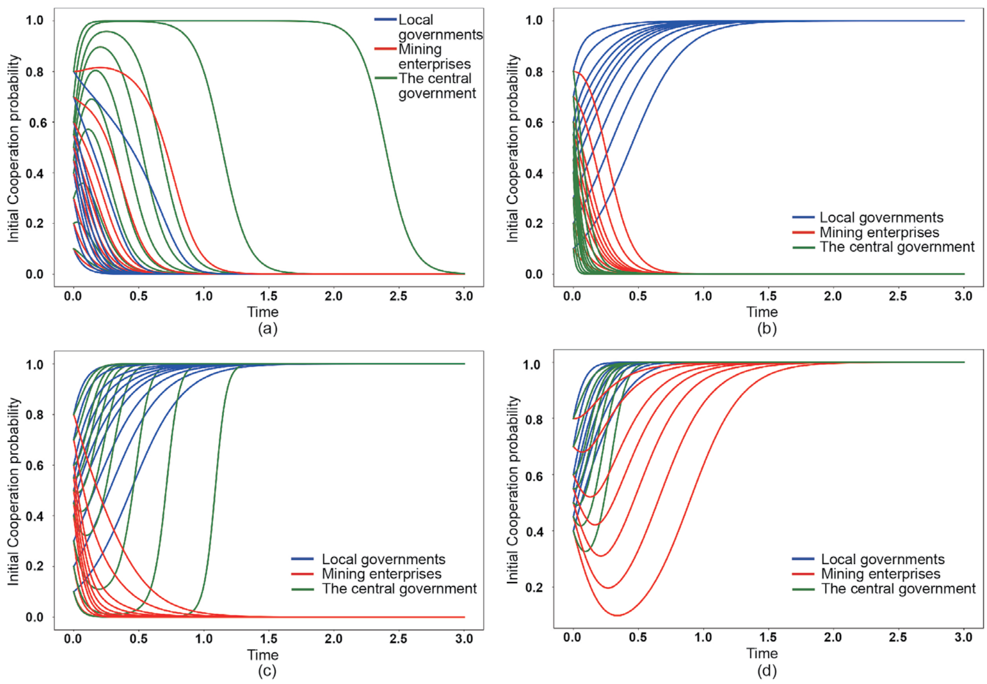


Fig. 1. Dynamic trend and stability analysis of stakeholders' strategy
(a) scenario 1; (b) scenario 2; (c) scenario 3; (d) scenario 4

Rys. 1. Dynamiczna analiza trendów i stabilności strategii interesariuszy
(a) scenariusz 1; (b) scenariusz 2; (c) scenariusz 3; (d) scenariusz 4

### 2.2.4. Evolutionary stable strategy under scenario 4

The equilibrium point $E_8(1,1,1)$ is the unique ESS when $C_1 < Ti + F_1$, $P < F_2$, and $C_2 < R_1 + R_2$. The results are shown in Figure 1(d). The simulation results show that the final strategy directions of the three parties is as follows: the central government engages in supervision; local governments choose ecological environment protection; the mining enterprises pay ecological compensation. Scenario 4 is the ideal scenario.

Through the analysis of the game scenario, equilibrium point $E_8(1,1,1)$ is identified as the most favorable combination of stable strategies to improve the ecological environment of the mining area. To achieve the optimal ESS, we use numerical simulation to analyze the sensitivity of the main parameters in the replication dynamic equation.

## 3. Empirical analysis of mining area

According to the tripartite evolutionary game model hypothesis of the central government, local government and mining enterprises, representative data on actual operations of the Sanshan Island mining area in Shandong Province of China are selected for empirical analysis to evaluate the system model. Based on field investigation (Wang 2019) and expert evaluation, the actual data are shown in Table 6, and the analysis results are shown in Figure 2.

Table 6. Empirical data of the Sanshan Island mining area. (Million Yuan/RMB)

Tabela 6. Dane empiryczne obszaru górniczego Sanshan Island (mln juanów/RMB)

| Parametr | Parameter | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_1$ | $C_2$ | $F_1$ | $F_2$ | $P$ | $R_1 + R_2$ | $T$ | $i$ | $x$ | $y$ | $z$ |
| Value | 4.00 | 12.00 | 3.00 | 10.00 | 8.29 | 48.00 | 19.83 | 0.5 | 0.5 | 0.5 | 0.5 |

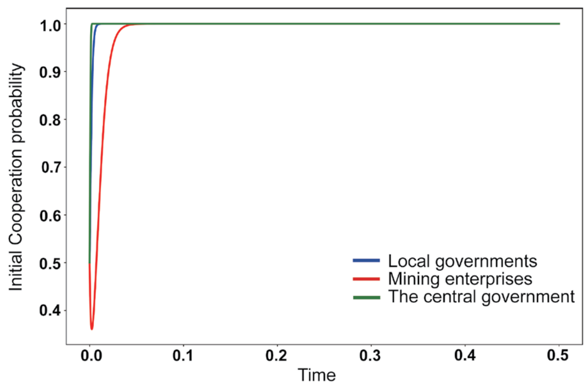


Fig. 2. Dynamic trend and stability analysis of stakeholders' strategy in Sanshan Island mining area

Rys. 2. Dynamiczna analiza trendów i stabilności strategii interesariuszy na obszarze górniczym Sanshan Island

As shown in Figure 2, the three parties in the game have converged to a probability level of 1, indicating that the strategies selected by the three parties are the central government's choice of supervision, the local government's choice of protecting the ecological environment, and the mining enterprises' choice of ecological compensation. The ecological compensation in the Sanshandao mining area is at a good level and has conditions for sustainable development, which is the result of the joint efforts of the three parties.

The measured data from the ecological environment of Sanshan Island are shown in Table 7. The ecological evaluation index included in this data adopts the ecological index in the technical specification for the ecological environment evaluation issued by the Ministry of Environmental Protection of the People's Republic of China. The overall change trend of the ecological situation is gradually improving, which is basically consistent with the analysis results of the ecological compensation game. The results of the analysis of the model are in good agreement with the actual situation, and the model shows a good level of effectiveness. The ecological status data come from the spatial distribution data on China's ecological status from 2015 to 2019 released by the Ministry of Natural Resources, as well as the China Statistical Yearbook and Shandong Statistical Yearbook from 2015 to 2019 (NBS 2020).

Table 7. Eco-environment quality in mining areas of the Sanshan Island

Tabela 7. Jakość ekośrodowiska na terenach górniczych Sanshan Island

| Year | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| Quality condition | Light pollution | Light pollution | Slightly pollution | Slightly pollution | No pollution |

### 3.1. Initial cooperation probability

To analyze the sensitivity of the initial cooperation probability (*ICP*) in the tripartite game model, the parameters in this model are fixed except for the initial cooperation probabilities. The values of parameters are set as shown in Table 8. According to the results shown in Figure 3(a), with an increase in the initial probability, less time is taken before the system stabilizes. Regardless of the initial probability, the central government is the first to reach steady state 1, followed by local governments, and finally, the mining enterprises. The initial probability has the largest impact on the mining enterprises, followed by local governments, and the impact on the central government is the smallest. In particular, it should be noted that when the initial probability is low, the mining enterprises will tend to not pay compensation for a period of time, where the lower the initial probability, the longer is this non-payment period.

## 3.2. Costs

### 3.2.1. Costs of local governments

To analyze the sensitivity to local governments' costs ($C_1$) in the tripartite game model, the parameters are fixed with the exception of $C_1$. The values of the parameters are listed in Table 8, with the results shown in Figure 3(b). Local governments are most affected by the input cost, while the mining enterprises and the central government are less affected. Once the equilibrium condition is broken, the central government quickly increases its supervision, but as time passes, the pressure on the central government continues to increase. At the same time, local governments are the first to choose not to protect the ecological environment, the mining enterprises are unwilling to pay ecological compensation, and finally, the central government rapidly shifts toward "no supervision".

### 3.2.2. Supervision costs of the central government

To analyse the sensitivity to the supervision costs of the central government ($C_2$) in the tripartite game model, the parameters in this model are fixed except $C_2$. The values of the parameters are listed in Table 8, with the result shown in Figure 3(c). Mining enterprises are greatly affected by the change in central supervision cost, while local governments are less affected. The increase in the supervision cost means that it takes a longer time for the central government to reach a stable state. Therefore, although the central government initially has a strong desire for ecological compensation in mining areas and is willing to pay a very high supervision cost, this practice cannot accelerate the realization of the steady state. Instead, despite the continuous investment of the central government in the supervision cost, it takes a longer time for the three parties in the game to reach the steady state.

## 3.3. Punishment

The central government punishment of the object of supervision is divided into two parts: punishment of local governments and punishment of the mining enterprises.

### 3.3.1. Punishment of local governments

To analyze the sensitivity to the punishment of local governments ($F_1$) in the tripartite game model, with the exception of $F_1$, the parameters in the model are fixed. The values of the parameters are listed in Table 8, with the result shown in Figure 3(d). From Figure 3(d), the system reaches stability at the equilibrium point $E_8(1,1,1)$. With an increase in the penalty value, the system grows more stable. In the game, local governments are the most sensitive to punishment.

#### 3.3.2. Punishment of mining enterprises

To analyze the sensitivity to the punishment for mining enterprises ($F_2$) in the tripartite game model, with the exception of $F_2$, the parameters in this model are fixed. The values of the parameters are listed in Table 8. According to the results shown in Figure 3(e), the cooperation probability decreases over time until it converges to $E_8$(1,1,1). With the increase in the penalty value, the system becomes more stable. Among all parties in the game, mining

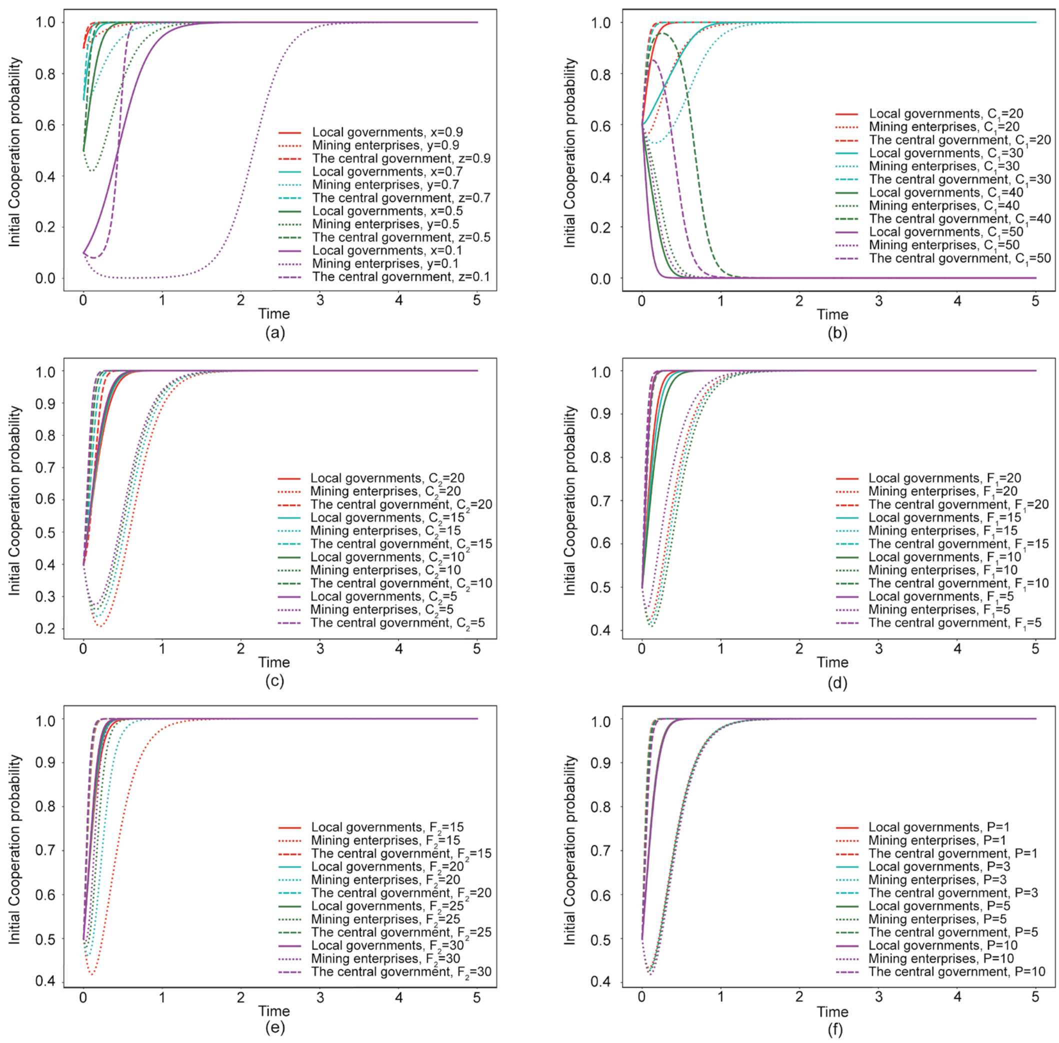


Fig. 3. The sensitive analysis of the tripartite evolutionary game model
(a) Initial cooperation probability; (b) $C_1$; (c) $C_2$; (d) $F_1$; (e) $F_2$; (f) $P$

Rys. 3. Analiza wrażliwości trójstronnego ewolucyjnego modelu gry
(a) początkowe prawdopodobieństwo współpracy; (b) $C_1$; (c) $C_2$; (d) $F_1$; (e) $F_2$; (f) $P$

enterprises are most sensitive to punishment. The analysis of punishment clearly shows that punishment can effectively restrain the behavior of local governments and mining enterprises and promote the implementation of the ecological compensation systems.

### 3.4. Ecological compensation fee

To analyze the sensitivity to the ecological compensation fee ($P$) in the tripartite game model, with the exception of $P$, the parameters in this model are fixed. The values of the parameters are listed in Table 8. According to the results shown in Figure 3(f), the cooperation probability decreases over time until it converges to $E_8(1,1,1)$. The lower the ecological compensation value, the more conducive it is to achieving a steady state. Therefore, reducing the payment amount for the ecological compensation will not only affect the trend in environmental improvement but will also help enterprises preserve their strength and protect the ecological environment.

Table 8. The set of values for the parameters in the numerical simulation

Tabela 8. Zestaw wartości parametrów w symulacji numerycznej

| Variable | Parameter | | | | | | | | Variable | Parameter | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_1$ | $C_2$ | $F_1$ | $F_2$ | $P$ | $R_1 + R_2$ | $Ti$ | $ICP$ | | $C_1$ | $C_2$ | $F_1$ | $F_2$ | $P$ | $R_1 + R_2$ | $Ti$ | $ICP$ |
| ICP | 20 | 10 | 15 | 15 | 10 | 40 | 25 | 0.9 | $F_1$ | 20 | 10 | 20 | 15 | 10 | 40 | 25 | 0.4 |
| | 20 | 10 | 15 | 15 | 10 | 40 | 25 | 0.7 | | 20 | 10 | 15 | 15 | 10 | 40 | 25 | 0.4 |
| | 20 | 10 | 15 | 15 | 10 | 40 | 25 | 0.5 | | 20 | 10 | 10 | 15 | 10 | 40 | 25 | 0.4 |
| | 20 | 10 | 15 | 15 | 10 | 40 | 25 | 0.1 | | 20 | 10 | 5 | 15 | 10 | 40 | 25 | 0.4 |
| $C_1$ | 20 | 10 | 15 | 15 | 10 | 40 | 25 | 0.6 | $F_2$ | 20 | 10 | 15 | 15 | 10 | 40 | 25 | 0.5 |
| | 30 | 10 | 15 | 15 | 10 | 40 | 25 | 0.6 | | 20 | 10 | 15 | 20 | 10 | 40 | 25 | 0.5 |
| | 40 | 10 | 15 | 15 | 10 | 40 | 25 | 0.6 | | 20 | 10 | 15 | 25 | 10 | 40 | 25 | 0.5 |
| | 50 | 10 | 15 | 15 | 10 | 40 | 25 | 0.6 | | 20 | 10 | 15 | 30 | 10 | 40 | 25 | 0.5 |
| $C_2$ | 20 | 20 | 15 | 15 | 10 | 40 | 25 | 0.4 | $P$ | 20 | 10 | 15 | 15 | 1 | 40 | 25 | 0.5 |
| | 20 | 15 | 15 | 15 | 10 | 40 | 25 | 0.4 | | 20 | 10 | 15 | 15 | 3 | 40 | 25 | 0.5 |
| | 20 | 10 | 15 | 15 | 10 | 40 | 25 | 0.4 | | 20 | 10 | 15 | 15 | 5 | 40 | 25 | 0.5 |
| | 20 | 5 | 15 | 15 | 10 | 40 | 25 | 0.4 | | 20 | 10 | 15 | 15 | 10 | 40 | 25 | 0.5 |

## 4. Discussion

Solving the contradictions that exist between the stakeholders in mineral resource development is the key to promoting the implementation of ecological compensation systems in mining areas. Governments at all levels need to effectively find their own core interests and those of mining enterprises in the process of formulating ecological compensation systems; by coordinating the multiple parties, they can achieve the goal of ecological compensation and maximize ecological benefits and social welfare. When the ecological compensation model of mining areas lacks the central government as a stakeholder, evaluation of the effect of implementing ecological compensation policies is inaccurate. Therefore, the supervision mechanism of the central government must be considered when designing the ecological compensation system.

By using evolutionary game theory to build a tripartite game model, the analysis results show that this model can effectively explain the process of change in the ecological compensation policy over time. First, China's primary goal after the reform and opening up was to develop the economy. Against this historical background, the central government's support for ecological protection is insufficient, and the responsibility for governance is entirely shifted to local governments. Aiming to develop the economy, local governments don't have high requirements for the environmental protection of mining enterprises. To pursue economic benefits, mining enterprises do not recognize that they should play a role in ecological compensation, and the central government does not provide policy support to improve local ecological benefits. According to the analysis results, under this condition, the ecological environment is bound to continue to deteriorate, which is basically consistent with reality. After 1978, a period of economic construction ensued, and extensive mining activities caused many environmental problems, including water pollution, soil pollution and air pollution (Li et al. 2009; Tang et al. 2017; Bian et al. 2010).

With the explosive growth of the economy, mining activities also led to the large reduction in the amount of cultivated land, threatening food security (Liu and Diamond 2005). In 2003, China set up a special fund for the geological environment of mines to control the past pollution of the ecological environment of mines. Special funds were allocated by the central government. Nine years after its implementation, the policy changed. The central government decided to collect funds from mining enterprises to jointly manage the environment. Through the analysis of game scenario 3, we can explain why this policy change occurred. The analysis of the impact of supervision cost in the model shows that although the central government initially has a strong willingness to pay for ecological compensation in mining areas this practice cannot accelerate the realization of a steady state. By contrast, with the continuous investment in the supervision cost by the central government, when the central government experiences greater financial pressure due to ecological protection and local governments have lower costs, they can reap more benefits. However, when the ecological benefits are high, the policies of the central government change, gradually evolving into non-supervision and non-investment, and the mining enterprises also evolve towards non-participation in ecological environment restoration. Therefore, although the central government has a strong willingness to protect the ecology, its efforts are not conducive to the sustainable development of ecological compensation in mining areas in the long run. Due to the lack of game research among stakeholders, a policy could be implemented with results that deviate from the original objectives.

In the current situation, the central government gives power to local governments. Under this policy, in what direction would the implementation effect of the ecological compensation policy develop? Of course, the aim is to evolve towards the optimal ESS. Through the game model, we can see that success depends upon whether the stability condition can be satisfied.

Firstly, the central government chooses to support local governments based on the policy, using the compensation terms of mining enterprises or financial loans to reduce the economic pressure of local investment. The results of the model simulation show that the distribution coefficient of ecological compensation between local governments and the central government has no influence on the ESS, which indicates that whether the ecological compensation from mining enterprises is given to the central government or local governments has no influence on the implementation of the ecological compensation policy. Cross-sector collaboration is required to remedy complex public problems (Bryson et al. 2006). Therefore, the central government can delegate the right to collect and use ecological compensation to local governments, which not only alleviates the economic pressure on local governments but also reduces the supervision and management cost of the central government. The reduction in the supervision cost is conducive to the long-term promotion of the ecological compensation system.

Secondly, in the collection of enterprise ecological compensation, local governments choose to reduce the standard appropriately to reduce the burden on enterprises, which is also conducive to the realization of the optimal ESS. Excessive fines may reduce enforcement (Chang et al. 2020). Moreover, the central government should accelerate industrial upgrading as much as possible. Through government subsidies and preferential policies, we can improve the level of green innovation (Zhou et al. 2020). Effective implementation of the energy efficiency plan (Zhou et al. 2010) increases the added value of high-tech industries and improves the standards of environmental protection, all of which will increase the central government's revenue in terms of the added environmental value; these measures are conducive to the realization of the best ESS. Another advantage of devolving the power to formulate specific policies to local governments is that local governments can set compensation collection standards according to their own development. Environmental policies with different degrees of enforcement have different impacts on the efficiency of ecological improvement in areas with different degrees of development (Ren et al. 2018).

However, there are also potential risks with this policy. According to the results of the model analysis, increasing the penalties for damage to the ecological environment when necessary is conducive to achieving appropriate ecological compensation. The altruistic punishment of defectors is a key motivation for the explanation of cooperation (Fehr and

Gächter 2002). However, the central government's loose policy on ecological compensation may lead it to miss the optimal time for ecological compensation. Based on past experience, the pursuit of extensive, continuous and loose institutionalization experiments can be understood as the key policy mechanism for China's economic rise (Heilmann 2008). Therefore, the continuous adjustment of policies would help governments to adapt to the changing environment. The management research should preferably focus on how different management tasks are organized and distributed, concentrating on the function of the system rather than the structure (Carlsson and Berkes 2005).

Finally, the purpose of ecological compensation is to produce ecological benefits, alleviate the impact of environmental damage caused by economic development, and ultimately improve people's daily living conditions. As an exhaustible resource, mineral resources are decreasing with their continuous development and utilization, which affect their use by future generations. Our use of energy in the twenty-first century must also be sustainable (Chu and Majumdar 2012). As public resources, clean water resources and pollution-free air are jointly owned and can be overused (Babu et al. 2011). The decrease in resources and the deteriorating environment are obviously creating unfair conditions for future generations. As a developing country, balancing economic development and ecological protection remains a challenge for China.

The limitations of this paper are firstly that we discussed the stakeholders that hold decision-making power but the residents of mining areas, as the party greatly affected by mining activities, did not participate in the discussion. In addition, we only set random parameters to simulate the strategy evolution process of stakeholders in ecological compensation, mainly due to the lack of actual data. In future research, we will consider more stakeholders in the model and use real data to check the results of stakeholders' interest coordination in ecological compensation.

## Conclusion

China has implemented an ecological compensation system for the mining of mineral resources. With the development of China's economy and the continuous improvement in the quality of the ecological environment, the existing ecological compensation system for mineral resource mining cannot achieve a balance between the different interests of the core stakeholders. Therefore, exploring the decision-making mechanism of stakeholders in the process of ecological compensation implementation will help to improve the design of ecological compensation systems. This study is aimed at the core stakeholders involved in the mining of mineral resources and constructs a tripartite evolutionary game model to study the decision-making process of stakeholders in the implementation of ecological compensation systems.

Policy effectiveness is determined by analyzing the results of policy implementation. Although the conclusion is more accurate, it is difficult to give targeted suggestions in the early stage of policy implementation so as to make timely adjustments. The identification of stakeholders involved in environmental protection and the analysis of their interest demands will help make policy implementation less difficult. Determining how to solve the contradictions between stakeholders still needs in-depth research. Therefore, we use evolutionary game theory to study the strategy evolution process of stakeholders in the process of policy implementation, to better explain the decision-making process of stakeholders, and to provide quantitative analysis results.

This study improves the modelling method used in the current literature on ecological compensation in the field of mineral resource development, as it only considers the game between local governments and mining enterprises, and introduces the central government, which is responsible for policy design, into the game model. In addition, the factors influencing the decision-making process are analyzed. The contributions are as follows:

- This study shows how to build an evolutionary game model for the stakeholders in mineral resource development to simulate ecological compensation game scenarios and ESSs under different scenarios.
- Through numerical simulation, this paper analyses the strategy evolution process of the stakeholders under four game scenarios.
- The factors influencing the optimal ESS were studied, including the initial willingness probability, cost, penalty and ecological compensation.

The results show that there is a best-case ESS in the game among the stakeholders in ecological compensation for mineral resource development. The effectiveness of the ecological compensation policy depends on the realization of the stable conditions, and the initial willingness of stakeholders will directly affect the ultimate stability. At the same time, local governments are most affected by the input cost, and the mining enterprises are most affected by the central supervision. Punishment can effectively restrict the behavior of local governments and mining enterprises and promote the implementation of an ecological compensation system. The higher the cost of central government supervision, the longer the time it will take for the three parties to achieve a steady state. Finally, reducing the payment for ecological compensation will not affect the trend in environmental improvement but will help enterprises preserve their strength and help to protect the ecological environment during economic development.

These results are of great significance for understanding the decision-making mechanism that should drive ecological compensation policies for mineral resource development under China's unique political system. Firstly, we should pay attention to the composition and compensation standard of local government input costs, so the central government should provide more policy support and green mining technology. Secondly, according to the characteristics of mineral resource development, the implementation of unified management and the establishment of efficient administrative agencies for ecological compensation management can reduce the cost of supervision. Thirdly, the standard of ecological compensation for mining enterprises should be appropriately reduced and their competitiveness should be strengthened to promote the implementation of the ecological compensation policy from a long-term perspective.

At present, China has made a positive commitment to reducing carbon emissions in the future, saying that emissions will peak in 2030 (Fang et al. 2019). It is urgent to put into place eco-environmental governance for the extractive industry – an important source of carbon emissions. According to the information released by China's Ministry of the Ecological Environment, many provinces and cities in China have begun to formulate specific plans (Zhao et al. 2020a), including more governance costs and more powerful government supervision measures. Therefore, in the context of this trend, we believe that ecological compensation is very likely to be implemented in China's environmental policies.

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## TREND OF THE COMPENSATION POLICY AND TACTICS FOR THE MINERAL RESOURCES DEVELOPMENT IN CHINA

Keywords

ecological compensation, mineral resource exploitation, tripartite evolutionary game, evolutionary stable strategy, sensitivity analysis

Abstract

China has been building an ecological compensation system to eliminate the contradiction between economic development and ecological protection. Aiming at conflicts of interest in the implementation of an ecological compensation policy for China's mineral resource development, this study established a tripartite evolutionary game model to simulate the ecological compensation scenario and determined the evolutionary stable strategy (ESS) under different scenarios; it uses numerical simulation to analyse the strategy evolution process of stakeholders and the influence of parameter changes on each strategy. The results show that there is an optimal ESS for ecological compensation for mineral resource development, which condition is $C_1 < Ti + F_1$, $P < F_2$, $C_2 < R_1 + R_2$. The initial cooperation intentions of stakeholders directly affected the final stable state. Local governments are most affected by the input cost, and mining enterprises are most affected by the supervision of the central government. Punishment can effectively restrain the behavior of local governments and mining enterprises and promote the implementation of ecological compensation systems. In addition, the higher supervision cost of the central government, the longer time it will take for the stakeholders to reach the stable state. Finally, reducing the payment amount for ecological compensation will not affect the trend in environmental improvement; in contrast, it is conducive to the preservation of enterprises' strength, economic development and ecological environment protection. The main findings of this study can help secure coordinate between the stakeholders in conflict and jointly formulate appropriate ecological compensation policy.

## TREND POLITYKI KOMPENSACYJNEJ I TAKTYKI WYKORZYSTANIA ZASOBÓW SUROWCÓW MINERALNYCH W CHINACH

Słowa kluczowe

kompensacja ekologiczna, eksploatacja surowców mineralnych, trójstronna gra ewolucyjna, strategia stabilna ewolucyjnie, analiza wrażliwości

Streszczenie

Artykuł dotyczy bardzo ważnego zadania, jakim jest pogodzenie celów ekonomicznych i środowiskowych w przemyśle wydobywczym Chin. Autorzy budują model uwzględniający interesy firm górniczych, samorządów i władz centralnych, wykorzystują do tego teorię gier. W ramach tych badań ustanowiono trójstronny ewolucyjny model gry do symulacji scenariusza kompensacji ekologicznej i określono strategię stabilną ewolucyjnie ESS (*Evolutionary Stable Strategy*) dla różnych scenariuszy; wykorzystując symulację numeryczną do analizy procesu ewolucji strategii interesariuszy oraz wpływu zmian parametrów na każdą strategię. Wyniki pokazują, że istnieje optymalny ESS dla ekologicznej kompensacji wykorzystania zasobów surowców mineralnych, którego stan to $C_1 < Ti + F_1$, $P < F_2$, $C_2 < R_1 + R_2$ (określenie parametrów podano w tabeli 2). Początkowe zamiary współpracy interesariuszy bezpośrednio wpłynęły na ostateczny stan stabilności. Samorządy lokalne są najbardziej dotknięte kosztami kapitałowymi, a przedsiębiorstwa górnicze – kosztami nadzoru rządu centralnego. Karanie może skutecznie powstrzymywać zachowania samorządów i przedsiębiorstw górniczych oraz promować wdrażanie systemów rekompensat ekologicznych. Dodatkowo, im wyższy koszt nadzoru ze strony rządu centralnego, tym dłuższy czas osiągnięcia stanu stabilnego przez interesariuszy. Wreszcie, zmniejszenie kwoty płatności na kompensację ekologiczną nie wpłynie na trend poprawy stanu środowiska, natomiast sprzyja zachowaniu siły przedsiębiorstw, rozwojowi gospodarczemu i ochronie środowiska przyrodniczego. Główne wnioski z tego badania mogą być przydatne w zapewnieniu koordynacji między zainteresowanymi stronami w konflikcie i wspólnym sformułowaniu odpowiedniej polityki kompensacji ekologicznej.