Problem Chosen	2022	Team Control Number
F	MCM/ICM Summary Sheet	2228517

Together to the future

summary

The planetary space is abundant in mineral resources. In order to jointly solve the problem of the depletion of the earth's mineral resources and promote the welfare of mankind, we have established a set of global equity measurement model based on the history of human's exploration of resources.

Based on **J.S.Adams's Equity Theory**, we set up three first-level indexes of **opportunity equity (OE), procedural equity (PE) and distributive equity (DE)** and eleven second-level indexes to measure whether a country has achieved a kind of **subordinate relative equity**. We compare the asteroid mining exploration to **the colonization and resource plunder in the Great Voyage period**, **the polar resource exploration** and **marine mineral resource exploration**, and use the index data of seven countries in the intersection of these three periods to establish the model.

Specifically, when modeling the index of opportunity equity, we comprehensively determine the weight of its secondary indexes by using **Analytic Hierarchy Process (AHP)** as the main method and **Entropy Weight Method (EWM)** as the auxiliary method, and then use **TOPSIS Method** to determine the final score of OE. Then we use the **Principal Component Analysis Method (PCA)** and **Markov Chain (MC)** to scientifically model the secondary indicators.

Our overall model idea is: for a specific period, data collection and analysis are carried out for the three-level indexes of each sample country, and then the values of the second-level indexes and the first-level indexes are gradually obtained. A function expression is used to calculate the country's score of comprehensive equity and measure the **Deserved Resources Proportion (DRP)**. At the same time, the **Vested Resources Proportion (VRP)** of 7 sample countries is obtained through data survey. At last, we set up a **similarity analysis model** referring to the **Clustering Analysis Method (CA)**, to conduct the similarity analysis on DRP and VRP values of all sample countries, and finally reflects global equity through the similarity coefficient obtained.

Through model test, we found that the results deviate greatly from our expected value because we ignored the influence of redistribution when calculating the score of comprehensive equity of each country. Therefore, we optimize the model into a **utility model with parametric constraints based on the Income Redistribution Principle of welfare economics**. The optimized model has a high degree of adaptation after re-examination. We also carried out an analogical **Lorenz Curve** fitting to show that the redistribution contributes to a humanized equity.

We propose that the vision of the world after the feasibility of asteroid mining can be divided into two stages: **initial stage and mature stage**. In the initial stage, we use **Time-Series Analysis (TSA)** to judge the difference of indexes before and after the feasibility of asteroid mining by an assumed critical year of 2035, and calculate the impact of the feasibility of asteroid mining on global equity. In the mature stage, based on the **Market Competition Theory**, we assume that enterprises enter the asteroid mining market as exploration subjects and may derive secondary markets. Through **control variates**, we analyze the influence of each index on the global equity under the change of exploration conditions.

Finally, in order to share the development opportunities, we put forward the corresponding politic optimization scheme for asteroid mining, which is based on the detected global equity score changes and refers to the **payment model of ecological resources exploitation on outer continental shelf**. We argue that these solutions can effectively promote global equity, let all humanity join hands and embrace the bright future together.

Keywords: global equity; resources exploration; AHP; EWM; vision; economics; policy

Catalogue

1. Introduction

1.1 Background

[1] According to the prediction of the United Nations Population Fund (UNPF), the annual increase in the global population will remain above 86 million, and the world population will reach 8.7 billion by 2050. Human demand for oil, coal and natural gas is increasing day by day. In addition, the mineral resources on earth such as heavy metals are also very limited, and also face depletion as the mining intensity and demand increase. However, the resources outside the earth are extremely rich, and the available resources are much more than those on the earth. Planetary space is rich in mineral resources and rare metals, and even vacuum resources, radiation resources and ultra clean resources. In order to solve the problem of the depletion of the earth's mineral resources, it is imperative to develop and utilize rich space resources, so space mining will also emerge as the times require.

However, the current understanding of space mining is almost at the stage of "near science fiction". Does the unknown technology and high cost support our ability to develop? Will the future development subject be the state or commercial institutions? At the same time, the current Multilateral Governance Mechanism for space resources development is not complete and clear, and the relevant rules need to be clarified. According to the 1967 United Nations outer space treaty, space exploration should promote the welfare and interests of all countries and should be regarded as the common territory of all mankind, regardless of the level of economic and scientific and technological development of all countries. Therefore, on the assumption that asteroid mining is feasible at some time in the future, we should strive to promote a global equity to ensure and promote human peace and reduce inequality - which is also one of the basic objectives of the United Nations.

Therefore, it is necessary to develop a common balance model to judge whether countries can achieve a global equity in the corresponding field of resource development.

1.2 Problem analysis

We need to define global equity and build a model to integrate economic development, technological progress and other factors to measure whether a relative level of equity has been achieved among countries in a certain field of resource development, and use the available historical data of international resource development to test whether our model is reasonable. After that, we should consider that when asteroid development officially enters the international resource development market, due to the emerging evaluation indicators and requirements in terms of technology and environment, it will cause some imbalance in global equity. We will use the existing model to evaluate the reason and degree of this imbalance and try to solve it. With the progress of the times, we will use the existing models to create a more adaptive and professional method, so that it can respond to the dynamic changes of data in the field of asteroid mining more timely and accurately. Finally, through the optimization and supplement of the framework model, we will put forward reasonable suggestions from the perspective of international policy, so as to truly realize the asteroid development and benefit mankind.

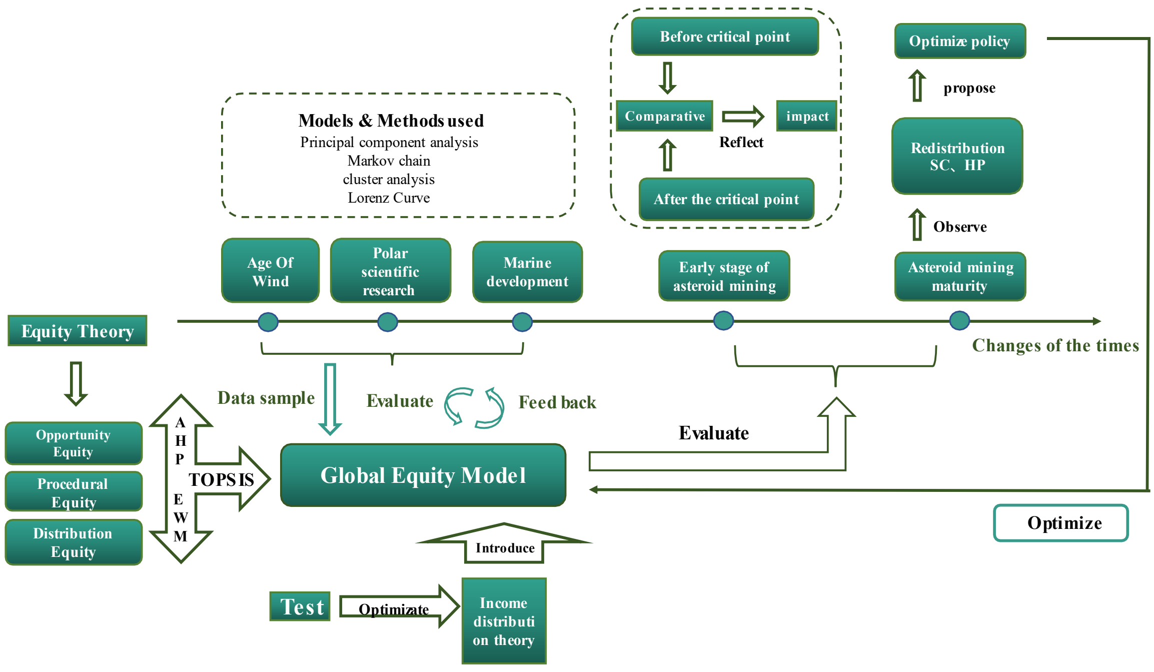


Figure1 Flow chart

1.3 Background assumptions

In order to simplify the problems, we make several assumptions as follows, each of which is justified.

- The national equity system is similar in marine mining, polar scientific research, maritime colonization and asteroid mining.
- The country's economic development level is stable and will not change in the short term.
- Each country will try its best to use its resource endowments for asteroid mining.
- Each country adopts macro policies to improve the equity index.
- The response speed of countries to the Convention reflects the degree of recognition of the Convention.
- The yield rate of ore is random and has nothing to do with the national technical development level.
- The international situation is stable. For example, the war and the black swan incident of covid-19 will not be taken into account. Decisions between countries do not affect each other.
- All indicators are relative values and have no absolute significance. When the index is positive, the index value is stronger than the critical value of the current system; When the index is negative, the index value is weaker than the critical value of the current system.

1.4 Indicators

Symbol	Notation
OE	Opportunity Equity
PE	Procedural Equity
DE	Distribution Equity
ED	degree of economic development
SATD	level of scientific and Technological Development in a certain field
SC	social system and social culture
GL	geographical location
HP	historical pollution
μ	the purity of resources
α	the weight parameter of PE
β	the parameter to show the degree of redistribution
DR	deserved resources
DRP	deserved resources proportion
VP	vested resources
VRP	vested resources proportion
Ω	the degree of global equity

2. Global Equity

2.1 Model background

[2]According to Adams's equity theory, we believe that global equity is a humanized and community-based relative equity, that is, we should not only evaluate the fairness between countries according to the criteria of how much we invest and how much we gain, but also strive to promote the common development of mankind without borders. This relative equity should be reflected in three aspects: opportunity equity, procedural equity and distribution equity. We take this as a model to establish three first-class indicators.

Figure2 Cloud chart of index words

Since asteroid mining has not been directly realized, in order to make the data comprehensive and the interpretation degree of the model more convincing, we compare the asteroid mining development to the resource development in three different periods of the world: colonization and resource looting during the great navigation period, polar resource exploration in this century and recent marine mineral resource exploration and mining, using the relevant data of these three periods to establish the model.

In each resource development period, there are countries that are mainly involved in or involved in it, as shown in the three sets below. The countries shown in the intersection set should be the source countries of the model data. According to this intersection and the searchability, authenticity and accuracy of the comprehensive data, we selected seven countries including Brazil, South Africa, India, Russia, China, the United States and the United Kingdom as our sample countries.

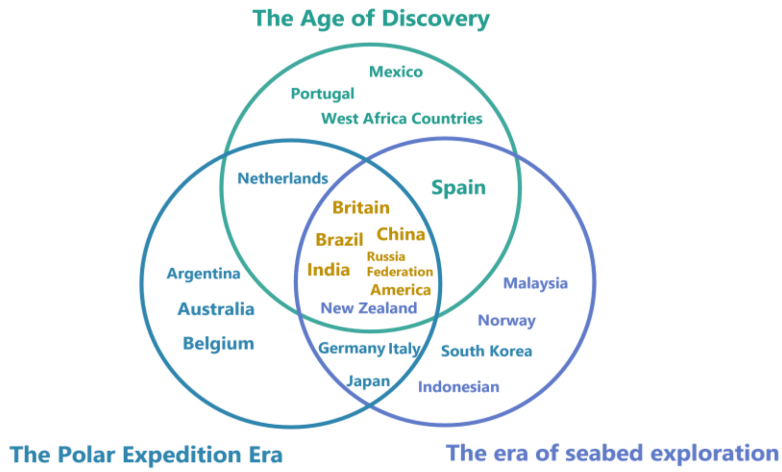


Figure3 Intersection diagram

Next, we will establish appropriate evaluation models for the three primary indicators and secondary indicators one by one.

2.2 Model 1 Opportunity Equity

Opportunity Equity is an ideal state, which means that each country has the same qualification in international resource exploitation, and will not lack opportunities due to external objective factors. However, this does not mean that each country can have the same amount of mining, which depends on the degree of economic development of the country, the level of scientific and technological development in a certain field, social system and social culture, geographical location and historical pollution.

Next, we will establish appropriate evaluation models for these secondary indicators one by one.

2.2.1 Evaluation model of economic development degree

The impact of economic development indicators on opportunity equity is reflected in that the higher the degree of economic development, the better the foundation of secondary and tertiary industries and the higher the level of development investment. Therefore, considering the different influence of the secondary and tertiary industries in the field of resource development, we give them different weights, and establish a simple linear model to reflect ED in the field of resource development with the GDP of the secondary and tertiary industries.

	Period III	Period II	Period I
China	6429. 475682	49570. 41104	82
Russian Federation	6604. 08493	6055. 156078	67
USA	90425. 1754	78956. 07193	24
Brazil	60610. 10811	7595. 296725	17
India	9804. 173815	8203. 932644	11
South Africa	1318. 58794	1392. 854865	9
UK	12427. 99945	12825. 51132	85

Period I : the colonization and resource plunder in the Great Voyage period
Period II : the polar resource exploration
Period III : marine mineral resource exploration

2.2.2 Evaluation model of scientific and technological development level in a field

The impact of scientific and technological development level indicators in a certain field on opportunity equity is reflected in that the more countries master the core technology level in the field of resource development, the more likely they are to manufacture relevant equipment or study advanced technical principles in the field of resource development. [3]According to the scientific research report in the field of deep-sea mineral resources development, we preliminarily listed 11 tertiary indicators that may have a great impact. Next, we use the principal component analysis method to reduce the dimension, and finally get the four most representative comprehensive indicators. According to the difference in the weight distribution of each explanatory variable in the expression of the comprehensive index, we try to explain the dimensions represented by the four comprehensive indexes in a practical sense, even if they are unobservable in the mathematical sense of the model.

The four principal components obtained after our analysis are innovation input, innovation output, innovation application and innovation environment. Next, we get the weights of the four principal components in the country's comprehensive marine scientific and technological innovation index through simple analytic hierarchy process:

Innovation Investment: 0.2427; Innovation output: 0.2806;

Innovative application: 0.2636; Innovation environment: 0.2129

Combined with the existing data of each sample country, we calculate the score of scientific and technological development level of each country in the period of deep-sea mineral resources development as follows:

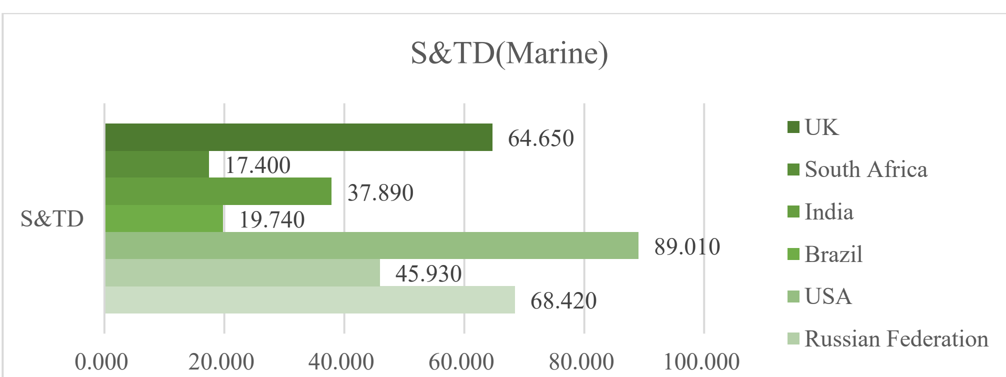


Figure4 S&TD（Marine）

Finally, we conduct similar principal component analysis and weight analysis for the remaining two periods, and obtain relevant values through the existing data.

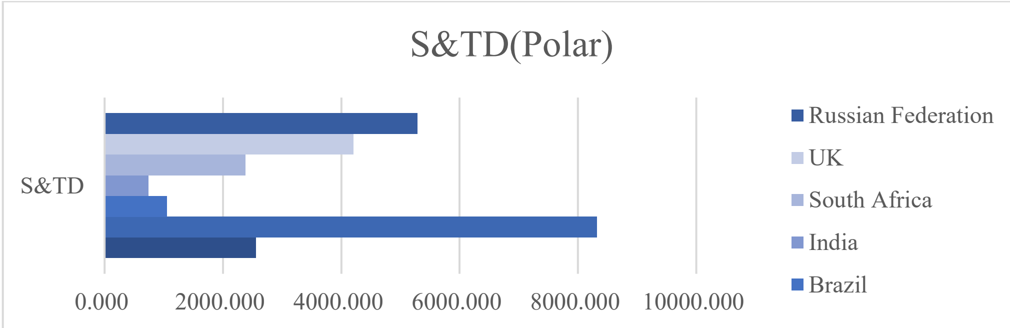


Figure5 S&TD（Polar）

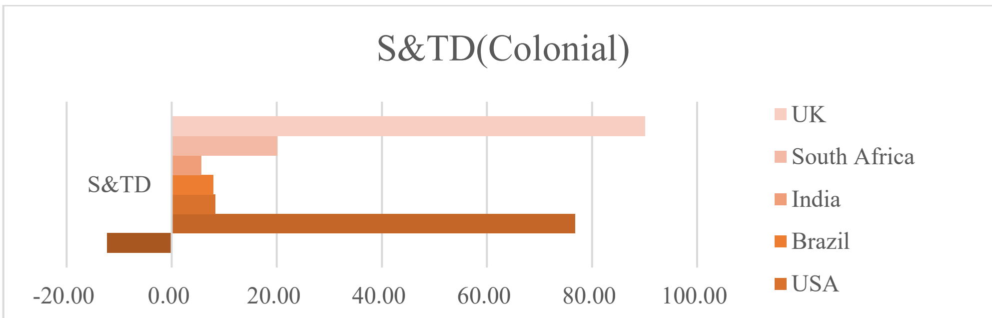


Figure6 S&TD（Colonial）

2.2.3 Geographical location evaluation matrix

The impact of geographical location indicators on opportunity equity is reflected in that for any kind of resources, when carrying out their relevant scientific research, exploration and mining, their difficulty is inherently affected by the geographical location of the country. The closer it is to the resource location, the easier it is to develop resources or spend less time on resources. Therefore, we conducted a scientific assessment for each sample country according to the geographical and spatial distribution of a resource studied, and used the score of this assessment to reflect its opportunities in the field of resource development.

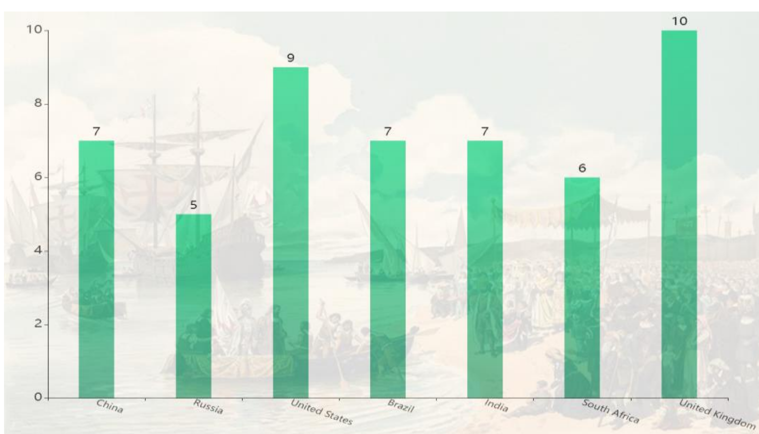
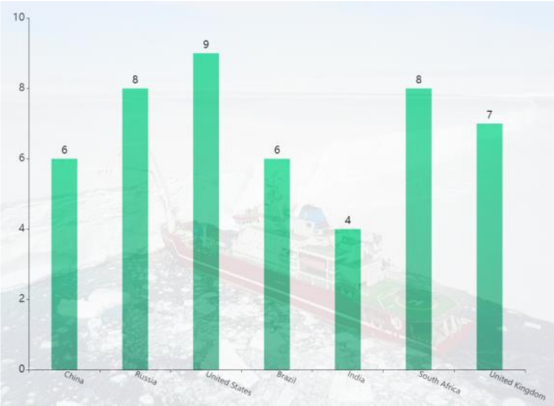


Figure 7 Geographical location evaluation during
the period of maritime colonization and resource Plundering



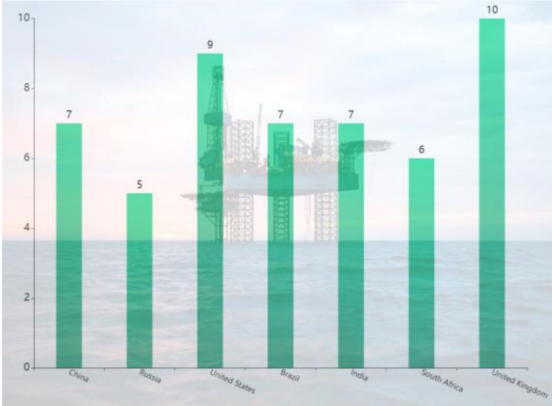


Figure8 Geographical location evaluation during polar scientific research in this century (Left)

Figure9 Geographical location evaluation during recent marine mineral exploration and mining (Right)

2.2.4 Social system and socio-cultural evaluation model

The impact of social system and socio-cultural indicators on opportunity equity is reflected in that countries or regions with different national characteristics have different aspirations for resource development or are willing to pay development costs. The more open or radical countries are, The more willing they are to pay more or provide more help in the development of certain resources, so as to make the global development level more advanced.

Therefore, we score the sample countries according to the social and cultural theory. Each score is an integer within [0,10]. 0 represents extreme conservatism and 10 represents extreme openness. Among them, the country with the value of [0,3] is conservative, the country with the value of [4,7] is mixed, and the country with the value of [8,10] is open.

In addition to the real-time cultural scores of each sample country, we believe that its future cultural development trend should also be taken into account. For example, if a country's real-time score is 2, that is, a conservative country, but it has an open political plan in the near future, it is bound to make a series of efforts to this end. Therefore, in the field of resource development, it will appropriately increase the development cost it is willing to pay. Therefore, we use Markov chain model to predict the changes of social and cultural types in each country in 10 years, and reflect its cultural development trend. The process is as follows. The transition probability matrix is as follows：

$$P = \begin{bmatrix} 0.8 & 0.15 & 0.05 \\ 0.3 & 0.5 & 0.2 \\ 0.05 & 0.25 & 0.7 \end{bmatrix} \tag{1}$$

Finally, we give the real-time score of social culture and the weight of social and cultural development trends 0.65 and 0.35 respectively, and calculate the final evaluation score of each sample country at the social system and cultural level in each period in a linear way.

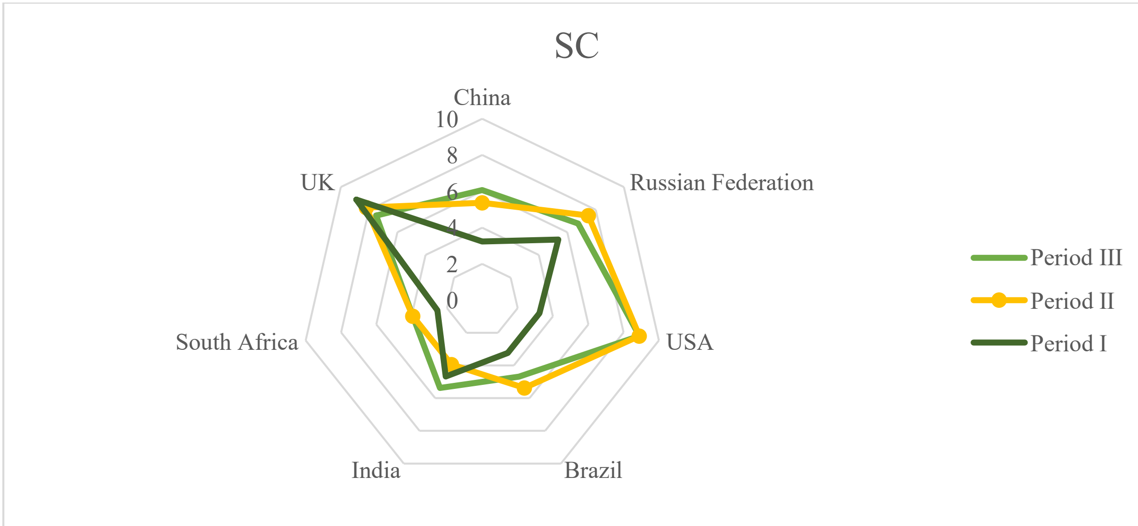


Figure10 SC（Three periods）

2.2.5 Evaluation matrix of historical pollution index

The impact of historical pollution index indicators on opportunity equity is reflected in that in the past history of resource development, if a country can not well balance the relationship between economic development and nature protection, resulting in varying degrees of environmental pollution, in order to respond to global carbon peak and carbon neutralization, the more it should reduce the country's access to international resource development. In other words, this indicator is a negative indicator. [4]According to the international environmental pollution data provided by the World Health Organization, we summarized the past pollution index of each sample country from four dimensions, and determined the negative feedback result of the country through regression.

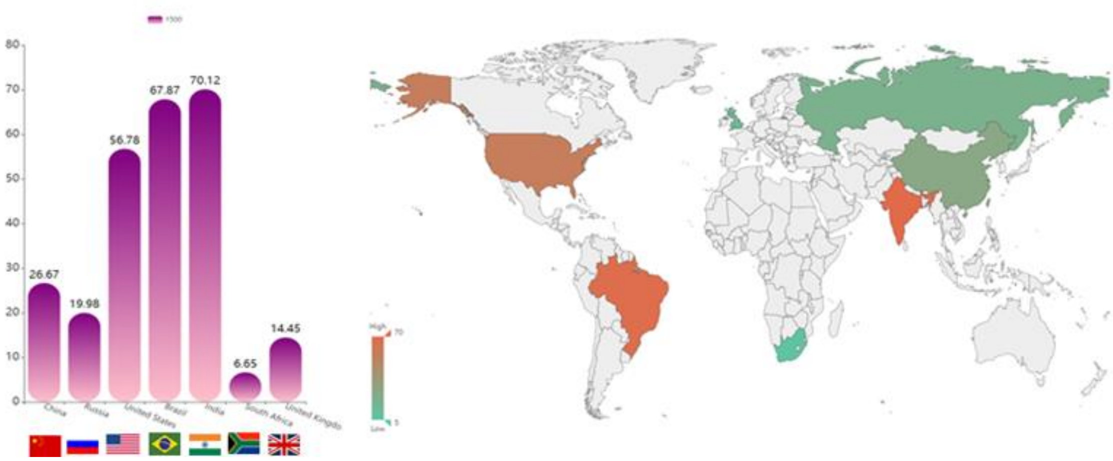


Figure11 Historical environmental pollution index during the period of maritime colonization

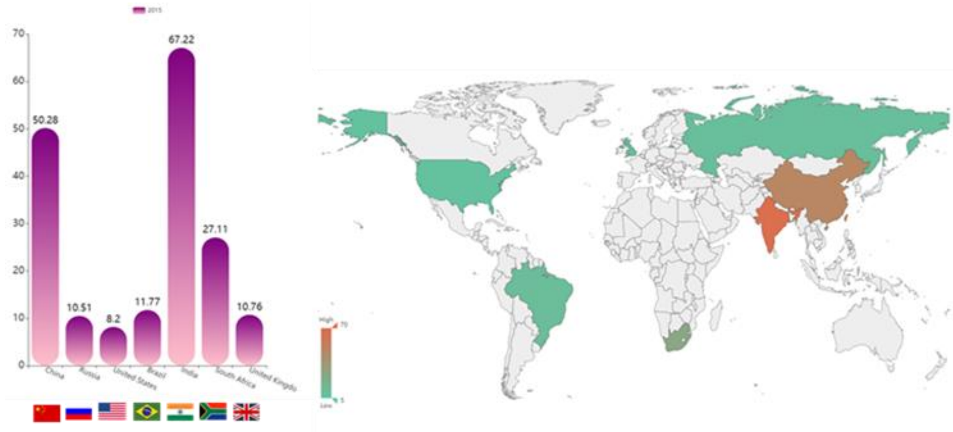


Figure12 Historical environmental pollution index during polar scientific research in this century

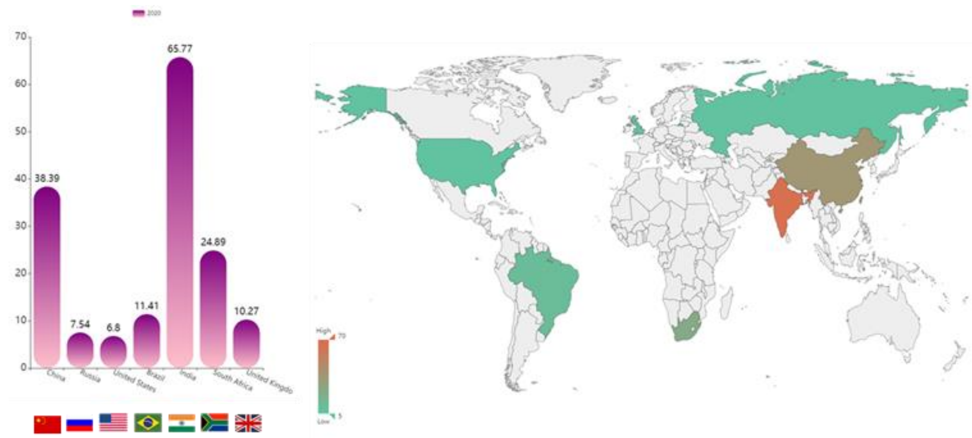


Figure13 Historical environmental pollution index during the recent exploration of marine resources

2.2.6 Model 1 Analysis

The above is our modeling process of five secondary indicators in opportunity equity. Through our input of tertiary index data, we get the evaluation results of each secondary index in the sample countries as follows.

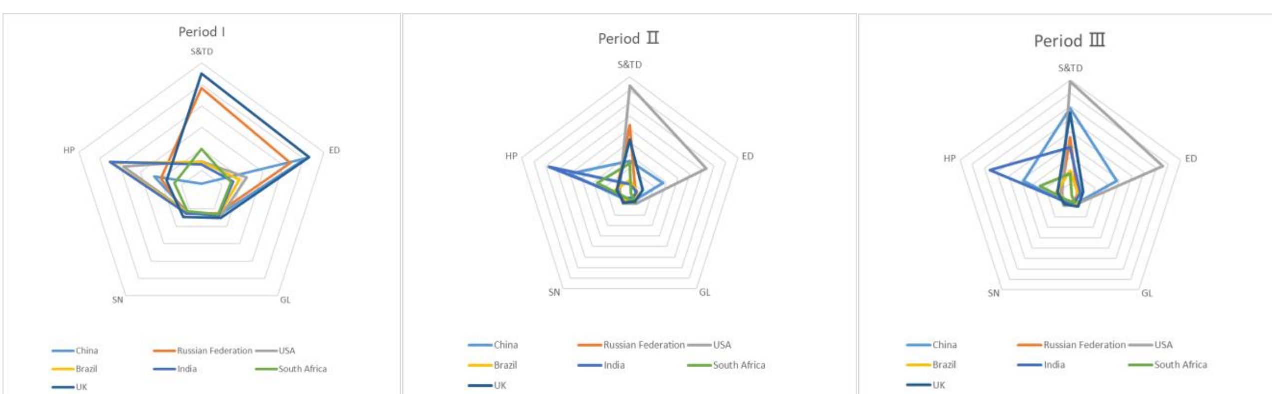


Figure14 Secondary index scoring chart

It should be pointed out that the evaluation result here is not its final score, but its characteristic attributes in different dimensions.

Opportunity Equity（OE）	Degree of economic development	Scientific and technological development level	geographical position	Social system and social culture	Historical pollution index
Degree of economic development	—				
Scientific and technological development level	—	—			
geographical position	—	—	—		
Social system and social culture	—	—	—	—	
Historical pollution index	—	—	—	—	—

Figure15 Grade I index scoring table

Next, we consider using analytic hierarchy process (AHD) to determine the weight of five secondary indicators when interpreting [X1]. In order to invite professors to fill in the matrix of relative importance in the questionnaire, as shown in the above figure, we need to construct the matrix of relative importance of professional judgment, and get the following results:

$$\begin{bmatrix} 1 & 7 & 1 & 3 & 6 \\ 1/7 & 1 & 1/7 & 1/6 & 1/2 \\ 1 & 7 & 1 & 4 & 8 \\ 1/3 & 6 & 1/4 & 1 & 3 \\ 1/6 & 2 & 1/8 & 1/3 & 1 \end{bmatrix} \tag{2}$$

The resulting weight matrix is as follows:

$$A = \begin{bmatrix} 0.357 \\ 0.038 \\ 0.400 \\ 0.147 \\ 0,058 \end{bmatrix} \tag{3}$$

$$C \cdot R = \frac{0.036}{1.12} = 0.032 < 0.01 \tag{4}$$

It should be noted that the C.R. value of this weight matrix is 0.032, which has passed the consistency test.

At the same time, we consider that although we have tried our best to reduce the influence of subjective components, the characteristics of analytic hierarchy process still have subjective limitations. Therefore, we introduce Entropy Weight Method to conduct weight analysis again from a completely objective point of view. The new weight matrix is as follows:

$$B_3 = \begin{bmatrix} 0.194517495 \\ 0.253092139 \\ 0.133582974 \\ 0.240548626 \\ 0.178258766 \end{bmatrix}, B_2 = \begin{bmatrix} 0.174170025 \\ 0.28004567 \\ 0.08481679 \\ 0.182481176 \\ 0.278486338 \end{bmatrix}, B_1 = \begin{bmatrix} 0.158827564 \\ 0.292809044 \\ 0.131646662 \\ 0.126093469 \\ 0.29062326 \end{bmatrix} \tag{5}$$

When analyzing the results of entropy weight method, we observed that its weight on the index of historical environmental pollution degree is too high, which is contrary to common sense, which is caused by the objective limitations of entropy weight method.

After comprehensive consideration, we believe that the final weight evaluation should be dominated by analytic hierarchy process and supplemented by entropy weight method, with weights of 0.8 and 0.2 respectively. The final weight matrix is as follows:

$$C_3 = \begin{bmatrix} 0.35609543 \\ 0.364178137 \\ 0.14751825 \\ 0.069161101 \\ 0.063047083 \end{bmatrix}, C_2 = \begin{bmatrix} 0.354834005 \\ 0.341609134 \\ 0.134563358 \\ 0.066896235 \\ 0.102097268 \end{bmatrix}, C_1 = \begin{bmatrix} 0.358903499 \\ 0.336218428 \\ 0.144316595 \\ 0.078509725 \\ 0.082051753 \end{bmatrix} \tag{6}$$

Finally, we use TOPSIS method to make the final score. In the process of applying TOPSIS method, we define: the degree of economic development, the level of scientific and Technological Development in a certain field and geographical location are benefit indicators, the degree of historical pollution is cost indicators (which can be negative), social system and social culture are interval indicators, and the optimal partition is [6,8]. Under this condition, we transform the indicators into benefit indicators and normalize them.

Calculate the proximity of each evaluation object to the best and worst scheme in the form of distance:

$$\tilde{X_{ij}} = \frac{x_{ij} - min\{x_i\}}{max\{x_i\} - min\{x_i\}} \qquad \tilde{X_{ij}} = \frac{max\{x_i\} - x_{ij}}{max\{x_i\} - min\{x_i\}} \tag{7}$$

$$OE_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{8}$$

In this step, we introduce the final weight matrix obtained previously, and calculate the score of OE of each country. The closer the score is to 1, the more resources the country should have in the initial allocation under the condition of Opportunity Equity.

2.3 Model 2 Procedural fairness

Procedural fairness is to ensure and realize fairness. It is a system design for the event handling process, which ensures that it is fair to the stakeholders and parties of the event. Specifically, in the context of the field of international resource development, it means that the development subject does not exist in this process, which leads to unfair and unreasonable results in the process of international resource development due to the artificial deviation and "back door" of the rules of international resource development. If it exists, it will affect the distribution results of the country. Therefore, procedural fairness is also one of the guarantee conditions to ensure fair distribution. Based on the understanding of procedural fairness, we introduce two secondary indicators: Degree of recognition ρ、Degree of order η.

2.3.1 Identification evaluation model

The degree of recognition refers to whether the sample countries are willing to accept the internationally recognized resource development conventions in a certain field and pay a certain cost in order to maintain the fairness of these conventions. Here, we use the response speed of the sample countries to several resource treaties with greater international influence and recognition as the basis to reflect the degree of recognition of the country.

[5][6]We have collected relevant data of resource and environmental protection conventions such as the Convention on biological diversity, the Cartagena Protocol, the Stockholm Convention, the Rotterdam Convention, the Basel Convention and the Paris Convention, including the time when the

convention was put forward, the signing time or access time of the sample countries, and whether the sample countries withdrew from the Convention. After analysis, we get the scores for each country's recognition degree (speed) of the Convention. The higher the score, the higher the recognition degree.

2.3.2 Evaluation model of order degree

The degree of orderliness refers to the positive role or negative impact of the sample countries in the maintenance of the international order in the past history. Comprehensively considering the relevant international behavior, international public opinion and international evaluation of seven sample countries, the scores are obtained. The score range is [0,10]. The higher the score, the more likely the country is to comply with international treaties.

2.3.3 Model 2 Analysis

Based on the scores of recognition and order of the sample countries, we introduce the following equation to evaluate the procedural fairness score of each sample country.

$$PE_i(abs) = \rho_i * \eta_i \tag{9}$$

Finally, in order to consider the internal dimensional consistency of the follow-up model, we standardize the scores of each sample country. The standardization logic is: regard the score of the sample country with the highest score as the maximum value of 1, and use the ratio of the scores of other sample countries to the highest score as the final procedural fairness index score.

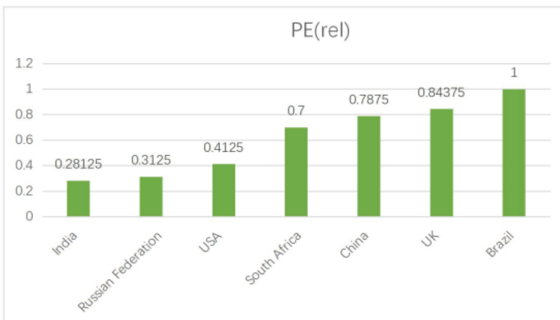


Figure16 PE（rel）

2.4 Model 3 Fair distribution

Opportunity Equity refers to the fairness of the treatment and distribution obtained by people after participating in social activities. The fairness of the result is an important indicator to measure whether it is fair or not. Result fairness is the fundamental purpose of people's pursuit of fairness, that is to say, only result fairness can win the support of the people, and it is the ultimate embodiment of the concept of fairness.

We believe that the results of resource development will be affected by the unequal distribution of resources, resulting in different data such as output and quality. Therefore, we introduce resource purity μ， This is a random variable with a normal distribution with a variance of 0.5 and an expectation of 0.1. Resource purity μ It reflects the excellence of relevant resources mined by the sample countries, which is an objective value that is not affected by exploration and mining technology.

In order to simplify the model, we only consider the purity of resources for fair distribution at this stage μ。

2.5 Model 4 Global equity model

2.5.1 Model4.1 A simple limited utility model with parameters

Based on the evaluation modeling of the above three primary indicators, we will study and explore an appropriate function expression to explain the comprehensive fair score of each sample country in different periods of international resource development.

We believe that opportunity fairness and procedural fairness are relatively independent in the comprehensive fairness score, so it can be expressed by a linear equation about OE and PE, where DE is represented by μ And we believe that OE, as an indicator of opportunity equity, has a strong correlation with the distribution equity indicator of DE, so μ Multiply with OE. On this basis, we assume that the weight parameter of PE is α， The obtained function expression is as follows:

$$DR_i = \mu OE_i + \alpha PE_i \tag{10}$$

According to the above, the OE and PE scores of each sample country in three different resource development periods have been obtained, and the corresponding comprehensive fair score can be obtained by substituting them into the model.

2.5.2 Model4.2 Similarity analysis model of analogical clustering analysis method

In order to get an indicator that can best describe the degree of global relative equity, we choose to calculate the proportion of resources that have been obtained and the proportion of resources that should be obtained by each sample country in different resource development periods, and reflect the current degree of global equity through the closeness between them.

For the acquired resources in different resource development periods of each sample country, we choose the following data to reasonably reflect: in the period of large-scale maritime colonization and resource plunder, we choose the degree to which each sample country is affected by colonization and resource plunder (this impact can be positive or negative); The number of scientific research stations that have been built in each sample country during the polar scientific research period of this century; In the recent period of marine mineral development, the resource exploration mining area occupied by each sample country is selected. The data obtained are as follows:

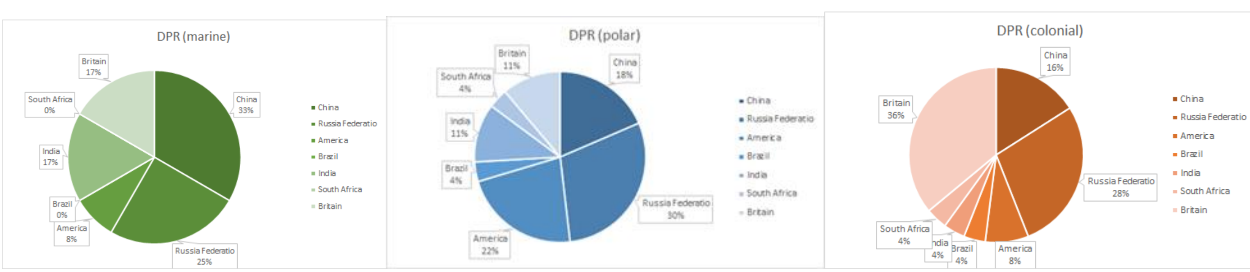


Figure17 DP&DPR

For the proportion of due resources in different resource development periods of each sample country, the proportion of the comprehensive fair score obtained in 2.5.1 above in the total score of all sample countries in this period can be well presented.

So far, for each resource development period, we have obtained two data sets containing seven values, representing the proportion of resources that have been obtained and the proportion of resources that should be obtained in the seven sample countries. Next, as long as we reasonably analyze the similarity between the two data sets, we can reflect the degree of global equity in the period of resource development. At this time, the degree of fairness is expressed by a value in the value range of [0,1]. The closer the value is to 1, the more fair it is.

In order to achieve this goal, we compared the index used to compare the similarity between two sample classes in cluster analysis method: included angle cosine. The specific calculation method is as follows:

$$C_{ij} = \frac{\sum_{k=1}^{n} x_{ki} x_{kj}}{(\sum_{k=1}^{n} x_{ki}^2)(\sum_{k=1}^{n} x_{kj}^2)} \tag{11}$$

The obtained similarity coefficient C_{ij} and the global equity index Ω can be regarded as equivalent in mathematical analysis.

To sum up, we have obtained the respective global equity degree Ω_i (i = 1,2,3) of the three resource development periods. Each Ω is obtained from the relevant data known in that period, but there are still an unknown parameter, α.

To get this parameter, we need to build an equation. At this time, through the existing authoritative academic research of history and sociology, we come to the conclusion that the approximate value of global equity Ω_1 in the era of maritime colonization and resource plundering is 0.2; Ω_2 in the era of polar scientific research period 0.6； Ω_3 in the era of The marine development period is 0.5 (this is due to the anti-globalization trend caused by the epidemic).

The unknown value obtained is:

$$\alpha = -20.5793500530308 \tag{12}$$

So far, the preliminary establishment of our global equity evaluation model has been completed. The key logic is: for a specific resource development period, collect and analyze the data of the three-level indicators of each sample country, and then gradually obtain the values of the second-level indicators and the first-level indicators. Through model 4 expression 1 (at this time α is an obtained value) calculate the country's comprehensive fair score and measure the proportion of resources that the DRP should receive. At the same time, the proportion of acquired resources in VRP of each sample country is obtained through data investigation. Finally, the similarity analysis is carried out for the DRP values of all sample countries and the VRP values of all sample countries. Finally, the similarity coefficient equivalent reflects the degree of global equity.

2.6 Model inspection

2.6.1 Matching degree test for existing models and data

In 2.5.2, we get a preliminarily determined parameter α Next, we will use the data of the remaining two resource development periods to test the suitability of this model. Will be obtained α Value is substituted into the expression, and the obtained Ω_2, Ω_3 values are as follows:

$$\alpha = -20.5937, \Omega_2 = 0.4605, \Delta_2 = -0.1395, \Omega_3 = 0.6937, \Delta_3 = 0.1397 \tag{13}$$

By comparing with the value of Ω_2, Ω_3 in 2.5.2, we find that the value obtained by the current model is quite different from the ideal value and can not be ignored. Therefore, we believe that the existing model has some defects.

2.6.2 Improvement scheme for existing model

We consider improving the existing model by considering the impact of secondary distribution when calculating the comprehensive fair score of countries. For secondary distribution, we refer to the difference of willingness to pay theory in the income redistribution theory of economics. The theoretical explanation is as follows:

[7]according to the principle of income redistribution in economics, the rich are more willing to pay for public goods and the poor are less willing to pay. For example, the institutional environment in which clean environment, property rights and transaction rules are respected and maintained. Similarly, if international governmental organizations adopt tax and welfare subsidies in the field of asteroid mining, the income generated in a distribution process will be reduced to a certain extent The income gap has the effect of income redistribution in a sense, and can promote the global relative equity we want.

Therefore, the final form of secondary distribution in the model is:

First, in a specific period of resource development, for those countries with large opportunity equity score OE, the secondary distribution weakens its value; For those countries with small Opportunity Equity score OE, the value is enhanced by secondary distribution.

Second, the greater the OE of a country, the higher the degree of weakening; The smaller the OE, the higher the degree of enhancement.

In order to achieve the expected effect, we make the following modifications to the mathematical model: In order to achieve these two desired effects, firstly, we give an index to OE in the original expression; secondly, we define the form of this index as a cubic polynomial related to OE; finally, we set a new unknown parameter β. Finally, a new comprehensive fair score expression is obtained:

$$DR_i = \mu OE_i^{\beta(2x-1)^3+1} + \alpha PE_i \qquad (14)$$

Then, we choose two values determined in 2.5.2: the degree of global equity in the period of great maritime colonization and resource plundering Ω_1 and the degree of global equity in the period of polar resource research in this century Ω_2. α、 β is a binary system of equations with unknown quantities and solved. The results are as follows:

$$\alpha = 9.90332, \beta = -53.4382 \qquad (15)$$

2.6.3 Matching degree test for the optimized model

By analogy with the process in 2.6.1, we use the data of recent marine mineral resources exploration and mining period to test the suitability of this model. Will be obtained α、 β Value is substituted into the expression, and the obtained Ω_3 value is as follows:

$$\Omega_3 = 0.521, \Delta_3 = 0.021 \qquad (16)$$

The deviation between the final estimated value and the ideal value is 0.021, and the deviation rate is 4.2%, which is acceptable. Therefore, the expression of comprehensive fairness for a country in the improved model is:

$$DR_i = \mu OE_i^{-53.4382(2x-1)^3+1} + 9.90332PE_i \tag{17}$$

Through the two models before and after optimization, the comprehensive fair scores of each sample country in the recent period of marine mineral resources exploration and exploitation are calculated.

By analogy with the drawing principle of Lorentz curve in economics, we draw two curves that can approximately reflect the distribution function of due resources in all sample countries. This curve is closer to y = x, which means that global equity tends to humanized equity on the basis of strict "distribution according to work".

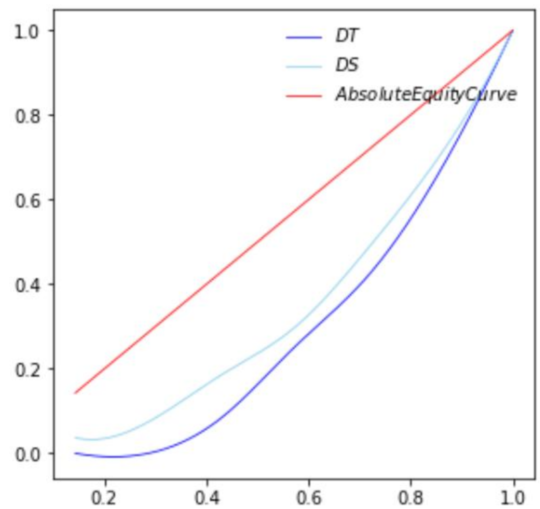


Figure18 Fitted Lorentz curve

2.6.4 Model sensitivity analysis

This part aims to test the sensitivity of the model to the sample countries and prove that the model is applicable to all countries in the world rather than only the seven sample countries we selected. In addition, we collected the relevant data of New Zealand in the intersection map of 2.1 and used it to randomly replace one of the seven sample countries to recalculate the global equity index. The final average difference rate is 3.842%, which roughly shows that the model has an effect on all countries in the world.

3. Model analysis after the feasibility of asteroid mining

3.1 Vision

Our vision of the world after the feasibility of asteroid mining is divided into two stages: initial stage and mature stage. Based on the past exploration speed of human society to the world and the current situation of the times, it is assumed that the initial stage, that is, the formal feasibility of asteroid mining, is 2035. In 2035, the newly established global asteroid mining association issued international laws to specify the quotas, mining specifications and operation management of asteroid mining countries.

At the initial stage, the state mining was operated by state-owned enterprises. Mining technologies such as open-pit mining, underground mining, ore screening and ore smelting are monopolized by large state-owned enterprises. At the initial stage of mining, this method can help stabilize the market, standardize mining behavior, crack down on illegal mining behavior, and lay a good foundation for subsequent market development. At the same time, undeveloped asteroids do not have perfect infrastructure and environmental governance in the initial stage. The way of government management can effectively solve these problems.

3.2 Global Equity Evaluation in 2034

3.2.1 Background assumptions

In this part, we will deduce the global equity in 2034, that is, before the feasibility of asteroid mining. To this end, we propose the following assumptions:

- In 2034, the exploration of marine mineral resources will enter a mature stage, and the world's technological development in related fields will tend to be saturated.
- In 2034, for the sample countries with sufficiently high technical level, they can try their best to avoid negative impact on the environment when exploring marine mineral resources, and may even take measures to help restore the ecological environment.
- By 2034, each sample country has made different preparations for asteroid mining to be feasible, especially in aerospace technology and mining technology. However, since marine mineral resources are still the most important international public resources, the impact of these factors on global equity can be ignored.

3.2.2 Index prediction based on time series regression analysis

Among the currently determined secondary indicators, we believe that the level of economic development and historical pollution index are two non-linear indicators that are difficult to evaluate simply. Therefore, we choose the first-order autoregressive time series analysis method to predict the values of these two secondary indicators in 2034.

Ⅰ. For the economic development level of each sample country, [8][9]we collected the data from 1988 to 2020, and then the fitted curves of GDP forecast of each sample country in the next 15 years are as follows.

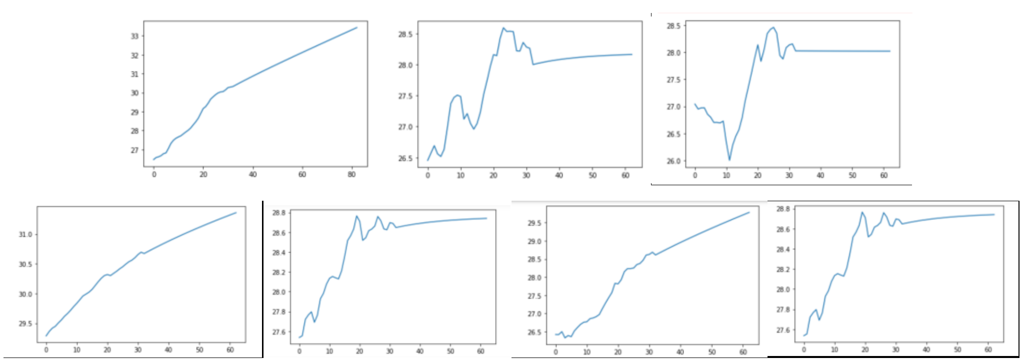


Figure19 GDP forecast

Ⅱ. For the historical pollution degree of each sample country, we collected the data from 2011 to 2020, and then the fitted curves of HP forecast of each sample country in the next 15 years are as follows.

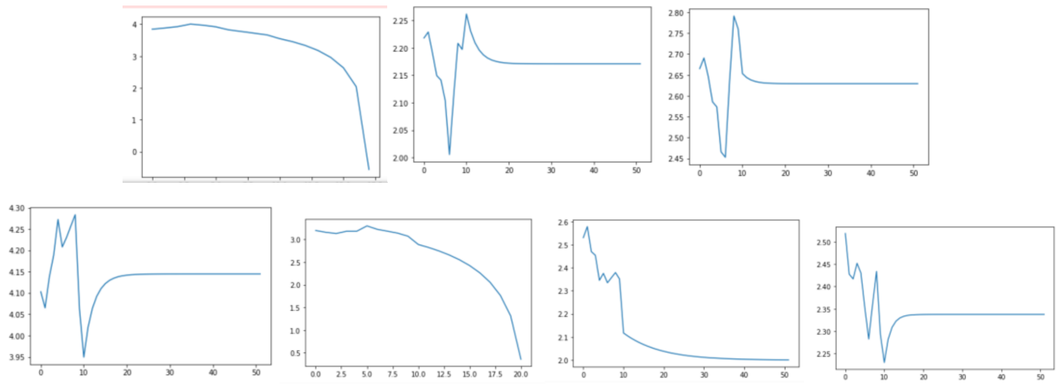


Figure20 HP forecast

It is worth noting that the historical pollution index is sometimes negative in the fitting process, which indicates that the sample country has played a positive role in the marine ecological environment in that year, and the greater the absolute value of the negative value, the greater the positive role. This is consistent with the second hypothesis we put forward in 3.2.1.

3.2.3 prediction of general indicators

Next, we predict the remaining secondary indicators.

Ⅰ. Marine Science and technology innovation index

For the marine scientific and technological innovation index of each sample country in 2034, we simply predict the marine scientific and technological innovation index of each sample country in 2019 through the above analysis. The specific method is to set a constant multiplier λ and multiply it with the present value to obtain the predicted value in the future. After combining various factors and the first hypothesis proposed in 3.2.1, we set this constant as 1.2. Then we get the final predicted value of marine scientific and technological innovation index of each sample country in 2034.

Ⅱ. Geographical location evaluation

For the geographical location evaluation of each sample country in 2034, based on the third assumption in 3.2.1, that is, marine mineral resources are still the most important international public resources, we believe that its predicted value is the same as the present value. As shown in figure9 in 2.2.3.

Ⅲ. Social system and social culture

For the social system and social culture of each sample country in 2034, we choose to combine two main factors to score. The first is the individual trend of cultural change in the history of the sample countries, and the second is the general trend of general liberalization of human society. Then we get the final real-time scores of each sample country in 2034.

As in 2.2.4, we still use the comprehensive scoring method including Markov chain model to obtain the comprehensive social system and social culture scores of each sample country in 2034.

Substituting the above scores into the optimized global equity model obtained in the first question, the predicted value of global equity in 2034 is 0.7361.

3.3 Global equity evaluation at the initial stage of asteroid mining

3.3.1 Background assumptions

In this part, we will deduce the global equity in 2035, when asteroid mining is initially feasible. To this end, we propose the following assumptions:

In 2035, the world will enter the period of asteroid mining. Due to the short time span between 2034 and 2034, it can be considered that the two indicators of economic development, social system and social culture of each sample country are approximately unchanged.

In 2035, the historical pollution index in 2034 is no longer applicable because the scope of ecological environment starts to change from earth to space.

In 2035, asteroid mineral resources will replace marine mineral resources and become the most important international public resources. Therefore, the technical index related to deep-sea mineral development is no longer applicable, but the development degree index of aerospace technology and mining technology of each sample country at this time.

3.3.2 Prediction of secondary indicators in asteroid mining Era

Ⅰ. For the scientific and technological development degree of each sample country in the field of asteroid mining, we use the combination of aerospace technology and mining technology to evaluate. [10]We have collected the launch of launch vehicles and spacecraft development and launch of each sample country at present (2022), as well as the investment in the development of energy technology, so as to reflect its aerospace technology and mining technology scores respectively. Then we get the data and final score.

Next, we analogize the strategy of I in 3.2.3. Similarly, we set a constant multiplier ε and multiply it by the present value to obtain the future predicted value. However, we believe that as a relatively emerging field, aerospace technology development has not yet reached saturation, so it has great potential for improvement, while the technological development of mining industry has reached approximate saturation. Therefore, after integrating various factors, we set the multiplier of aerospace technology as 1.5 and the multiplier of mining technology as 1.2. Finally, we get the predicted values of aerospace technology index and mining technology index of each sample country in 2035.

As for the relevant technologies of asteroid mining industry, we believe that aerospace technology and mining technology have the same important influence. Therefore, we set the weight of these two indicators to 0.5, and obtained the predicted value of asteroid mining technology index of each sample country in 2035 through linear expression.

Ⅱ. For the geographical location assessment of each sample country, the main factors we consider are whether its territory is suitable for spacecraft launch and recovery and the difficulty of site selection. Thus, we get the final score of each sample country in the field of asteroid mining.

Ⅲ. For the historical pollution index of each sample country, we believe that due to the existence of the second hypothesis in 3.3.1, we cannot continue to use the curve obtained by time series regression in 3.2.2. Considering that 2020 is the initial stage of the development of deep-sea mineral mining industry, the historical pollution index of each sample country at this time is comparable to that in 2035, that is, the initial stage of the development of asteroid mining industry. At the same time, because the earth has been the home of human emotional sustenance since ancient times, we are conservative in exploring it. However, due to the limited development of space colonization technology, taking space as a living space is still not considered, so human beings may cause greater pollution due to lack of rationality when exploring space. Therefore, we multiply the historical pollution index in 2020 by 1.5 times as the predicted value of the historical pollution index of each sample country in 2035.

Similarly, substitute the above scores into the optimized global equity model obtained in the first question, and calculate the predicted value of global equity in 2035 is 0.706.

3.4 Summary

Through the prediction results of global equity in 2034 and 2035 in 3.2 and 3.3 respectively, we can find that when asteroid mining is rationalized and replaces deep-sea mineral mining as the most important resource development field, global equity decreased by 0.0301, which is 4%.

4. Sensitivity analysis of customized model

4.1 Assumption of changes in conditions during the mature period of asteroid mining

In the second research question, the condition we selected when assuming the asteroid mining vision is the initial stage, i.e. 2035. Considering the development degree and speed of asteroid mineral development, we believe that it will enter a mature period in a few years, and the corresponding conditions will change as follows.

In the mature stage, the government sells mining rights through bidding and auction, and determines the behavior of miners according to the bidding results - that is, introducing commercial institutions into the market. When the mining industry enters a mature stage, this mode of operation can help the government recover costs and obtain high fiscal revenue. At the same time, it is also conducive to the marketization of the mining industry and enhance the vitality of the industry through the role of market regulation. In order to make the asteroid mining industry more market-oriented, the secondary market will also be introduced in the near future, so that the asteroid mining right will become a financial product circulating in the secondary market, realize the risk management of mining value, and help investors provide funds for the mining industry through equity investment.

In other words, during this period, the most important change was the introduction of commercial institutions into the asteroid mineral development market.

4.2 Condition change analysis

Let's think about which indicators of the global equity model will change after the introduction of business institutions?

The degree of economic development in the Opportunity Equity index is an indirect reflection of the strength of a country's commercial institutions, and can also reflect the number of commercial institutions in the field of science and technology. We assume that this index will not change. Similarly, for the indicator of asteroid mining technology, the development degree of the country will also be presented in the main body of commercial institutions, and we assume that it will not change. The geographical location will not change in the short term, so we assume that the index will not change. At the same time, we also assume that the degree of feedback of business institutions on procedural fairness is similar to that of the countries they rely on and will not change.

Therefore, we believe that the following indicators will change after the introduction of commercial institutions:

Social system and socio-cultural indicators. Due to the profit seeking and expansionary nature of commercial institutions themselves, they are bound to believe in more radical cultural concepts in order to pursue capital. For the social system and social culture of various commercial institutions in the mature period, we choose to combine two main factors to score. The first is based on the individual trend of profit seeking of various commercial institutions, and the second is based on the common trend of developing culture in their countries. Finally, we can get the real-time score of each sample commercial institution at the maturity stage.

Historical pollution index. Compared with the main body of the state, commercial institutions will bear much less pressure on social and ecological responsibility, or they are more reluctant to bear the corresponding social and ecological responsibility, and will suffer much less pressure from public opinion after damage, so their damage to the natural environment may increase. Based on this reality, we can multiply the historical pollution index in the mature period by 1.4 times as the predicted value of the historical pollution index of each sample commercial institution in the mature period.

Redistribution indicators. Business organization is different from collective organization. It is a private profit seeking organization. It rarely makes more contributions to the harmonious development of mankind. Similarly, we can't make high humanitarian requirements for it like the main body of the state, so as to formulate a strict redistribution plan. Therefore, when commercial institutions are introduced into the asteroid mining market and the asteroid mining rights are financial products, it is bound to weaken the degree of redistribution.

Next, we assume that one of the seven sample countries is the leading or typical enterprise that best reflects the characteristics of the sample country, and analyze the indicators that change one by one. When analyzing each indicator, we will control other indicator variables.

4.3 Multidimensional sensitivity analysis through control variable method

Based on the changes of various conditions after the asteroid mining maturity discussed in 4.2, we use the control variable method according to the secondary indicators or the parameters involved in the secondary distribution β After the change, the new value of the primary index is further obtained and substituted into the global equity model. For every change in conditions, we will get a new degree of global equity. The specific correspondence is as follows.

	Change ratio of output	Change ratio of input	Model sentivity
SC	-0.001133144	0.94	0.001205473
HP	-0.016713881	0.78	0.021428053
β	-0.07223796	0.42	0.171995144

Figure21 Sensitivity analysis

By comparing the sensitivity of the model to each dimension index, we conclude that when the conditions of different dimensions of the asteroid mining industry change, it will reduce the current degree of global equity. According to the sensitivity, the different dimensions are: redistribution degree, ecological environment damage degree and cultural radicalization degree.

5. Optimize the design of treaty scheme

Based on the different weights of the three change indicators in question 3, we believe that the United Nations can update the outer space treaty according to the following policies:

5.1 For social system and socio-cultural indicators

Due to the radical exploitation of resources caused by the profit seeking nature of commercial institutions, we cannot change this fact, but at the same time, it has the least impact on global equity, so we will not discuss it.

5.2 Indicators of historical pollution degree

Asteroid mineral resources are the common wealth of all mankind. Commercial institutions should not only pay attention to their own economic benefits, but should pay more attention to ecological and social benefits. We believe that the United Nations Treaty on outer space should clarify the environmental protection supervision and restraint capacity of commercial institutions in various countries in the field of asteroid mining, and implement a joint seat system for their countries. The United Nations should monitor the air and geological dimensions of each country and the mining area of commercial institutions and give corresponding scores. For those commercial institutions that pay less attention to environmental protection during asteroid development, a punishment system should be adopted immediately to reduce their development opportunities. More serious business institutions should punish their countries.

At the same time, countries must also be required to establish their own environmental protection policies and regulations for commercial institutions in the field of asteroid mining, and take strict environmental protection punishment measures for commercial institutions at the international and national levels, so as to alert commercial institutions to pay attention to ecological and social responsibility.

We firmly believe that every subject in the world should make efforts for the environmental protection of the whole outer space.

5.3 For redistribution indicators

[11]Referring to the model of Central South University and the payment model of ecological resources development on the outer continental shelf, we believe that the main body of asteroid resources development should be diversified, at least including commercial institutions and countries.

As mentioned earlier, we can't make high humanitarian requirements for commercial institutions as we treat national subjects, so as to formulate strict redistribution plans for them. Therefore, we should allow the existence of national subjects in the asteroid development market to reconcile the unequal redistribution results.

For the common development of all mankind, developed countries within their capabilities in the field of asteroid mining or countries that play an important role in the international order should assume the responsibility of a big country to the less developed countries.

- It can provide talents or technical assistance for technologically backward technologies to help them overcome technical barriers and build infrastructure.
- Countries with insufficient funds can be provided with low interest or interest free loans to help them have the opportunity to develop asteroid mining and even promote the development of other industries.
- We can directly provide resource matching assistance to less developed countries or regions when we meet our own resources.
- International organizations can also provide all kinds of knowledge assistance to less developed countries.

Asteroid mining is the main equity issue we study in this article, but when all mankind faces the common practical problems, it is not only this aspect, including politics, economy, culture and so on. Asteroid mining is a cut-off point. It tells people today from the perspective of the future that mankind should return to become a real community with a shared future. People all over the world can put aside their contradictions of interests, jointly participate in global governance, share development opportunities, and work together to create a bright prospect for everyone to avoid poverty, achieve development and enjoy dignity[12].

6. Advantages and disadvantages of the model

6.1 Advantages

- **Comprehensive elements:** Our model contains three primary indicators and 11 secondary indicators. These indicators can basically fully reflect the main factors affecting global equity, make it very reliable, and lay a good foundation for our model.
- **Widely used:** Our model can analyze the fair value in different periods and countries, and can start from both horizontal and vertical aspects, which has high applicability.
- **Interdisciplinary:** Our model introduces the principle of economics, which can well explain the redistribution index and is scientific.
- **Intuitive and effective:** Our model can carry out similarity analysis and present the changes of fairness degree of different subjects or in different periods by means of comparative visualization.

6.2 Disadvantages

- **It has certain subjectivity:** When introducing some indicators, because their data cannot be collected through objective channels, they can only be scored by human subjectivity, so there is a certain degree of subjectivity.
- **High dependence on data:** Our model has high requirements for the comprehensiveness and fineness of data, which makes it impossible to apply the model accurately in the case of some missing data.

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