Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
F		2212904

Exploit Asteroid Equitably? Join United Minerals!

Summary

At some point in the future, the cost of asteroid mining will be worth the investment, but how to achieve global equity will be a challenge. The challenge mainly includes two aspects. One is to make sure that asteroid mining is beneficial for all countries in the world. The other is to ensure global equity in the development of asteroid mining. Therefore, it is of great realistic significance to establish a system for equitable exploit and use of asteroid mineral resources.

First, we introduce the Global Equity Measurement Model, which estimates every country's global equity index(GEI). The GEI index is proportional to the country's purchasing power for asteroid minerals. To consider the problem more comprehensively, we select 20 representative countries and seven indicators that affect the equitable distribution of mineral resources (e.g., consumption of mineral resources per capita, GDP per capita, extent of invasion in history, carbon dioxide emissions per capita, etc.). Then use the Entropy Weight Method to calculate the weight of each index, and use this weight to calculate each country's GEI value.

Second, We propose the establishment of an asteroid mining company---- United Minerals(UM), which is jointly owned by all member states. The company is set up to raise funds worldwide for asteroid mining and to achieve global equity by using nonlinear programming models in order to find the optimal share of profits. We also design the prediction model after introducing the time dimension.The model is created to reflect the efficiency of asteroid mining and the trend over time of countries investing in United Minerals.Then We apply our model between Russia, a resource-rich country, South Korea, an economically developed country with scarce mineral resources, and India, a relatively backward country. We plot the optimal proportion of the company's profits to be invested in different directions during the year and predicted the trend of the Theil index of GEI between the three countries.The results are as follows: United Minerals sells asteroid Minerals to member countries at a price proportional to GEI; United Minerals spends 13.3% to 18.5% of its annual profits on loans to countries with weak purchasing capacity, 16.5% to 20.9% on mining equipment maintenance and upgrading, and 60.4% to 70.2% on investment and construction of mineral processing industry chain; The presence of United Minerals will reduce the Theil index of GEI between Russia, South Korea and India from 0.231 to 0.1622 in five years, therefore promoting global equity. Furthermore, we analyze the sensitivity of our model and point out our strengths and weaknesses.

Finally, on behalf of United Minerals, we propose to the United Nations and the member states of United Minerals, hoping that member states negotiate appropriate international policies and implement suitable domestic policies. The United Nations should expand the Outer Space Treaty properly in order to develop United Minerals in a sustainable way for the benefit of humanity.

Keywords: Theil index; Nonlinear programming; United Minerals; Global equity; EWM

Contents

1 Introduction

1.1 Problem Background

As the mineral resources on the earth gradually fall short of the growing needs of human beings, people begin to turn their attention to the distant space. But even if the level of science and technology can achieve access to space resources in the future, will it be beneficial to the equitable development of the world? In fact, as early as 1967, most countries in the world signed the Outer Space Treaty, which clearly requires the promotion of global equity in future space exploration.

In the foreseeable future, asteroid mining is highly likely to become a reality and profitable industry, which requires us to further update and improve the Outer Space Treaty to specifically address the problem of asteroid mining, analyze the possible future vision of asteroid mining, and propose a feasible scheme to promote the development of global equity.

1.2 Restatement of the Problem

Considering the background information and restricted conditions identified in the problem statement, in this paper we are required to solve the following problems:

- Problem 1:Lay down a definition of "global equity," and then build and validate a model that measures the level of "global equity" based on the definition.
- Problem 2:Point out one possible future vision of asteroid mining and changes in the selected conditions, and then establish a model to analyze its impact on "global equity".
- Problem 3:According to the results of the analysis, develop appropriate policies to further strengthen the contribution of asteroid mining to "global equity".

1.3 Our Work

First, in the part of Global Equity Measurement Model, we search for some indicators to evaluate global equity, determine the weights by Entropy Weight Method, and obtain the GEI value of each country.

Next, in the part of Operation Model of Asteroid Mining, we establish a globally equitable system for the distribution of asteroid minerals, normalize the model and make predictions based on the changing conditions.

Finally, in the part of Policies Formulation, we propose appropriate international and domestic policies in accordance with the spirit of the Outer Space Treaty. We update the Outer Space Treaty to ensure the healthy and sustainable operation of the asteroid mineral distribution system.

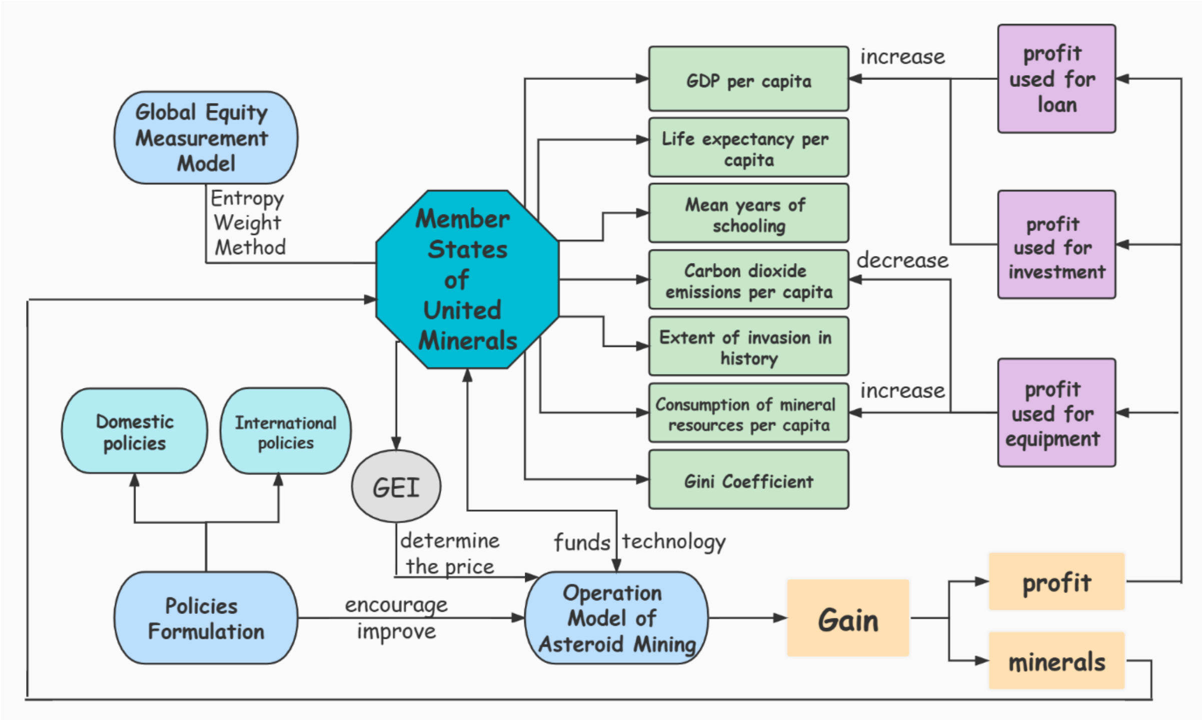

Figure 1: The overall flow diagram

2 Assumptions and Justifications

To simplify the given problems and modify it more appropriate for simulating real-life conditions, we make the following basic hypotheses:

Assumption 1: In the process of asteroid mining, all countries can obtain benefits and volunteer to join the United Minerals.

Assumption 2: The world is in a relatively stable state of politic, economy, and climate, without wars and climate catastrophes on a global scale.

Assumption 3: The demand for asteroid mineral resources will not exceed the supply.

→**Justification:** The title points out that with the development of science and technology, asteroid mining technology has been relatively mature. In other words, we have the abilities to efficiently, continuously and stably exploit the mineral resources contained in asteroids and safely transport them back to earth for all human needs.[1]

Assumption 4: The development of asteroid mining industry can be macro-controlled, i.e. the policies we formulate can have a significant impact on the asteroid mining industry.

3 Notations

Here we list the symbols and their descriptions used in the paper, as shown in Table 1.

Table 1: Notations used in this paper

Symbol	Description
$\widetilde{x}_{ij}$	The value of x_{ij} after normalization
x_{best}	The Optimal value of moderate-type variable
E_j	The information quantity of index j
b_{ij}	The value of a_{ij} after standardization
p_{ij}	The values of elements in probability matrix
w_j	The weight of index j
$\overline{GEI}_i$	The value of GEI after normalization
X	The total capital input
p_l	The portion of profit used for loan expenditure
p_i	The portion of profit used for investment expenditure
$p_{m\&u}$	The portion of profit used for equipment maintenance and upgrading

4 Global Equity Measurement Model

4.1 Definition of global equity

Global equity refers to the dynamic balance of resources and development opportunities allocated among countries around the world and among regions within a country,i.e., while seeking its own development, each country or region should actively promote the common development of other countries or regions, and cannot lay the long-term development of the world on the basis of the increasing prosperity of one group of countries or regions while another group of countries or regions are chronically poor and backward. Moreover, global equity is a concept that is both spatial and temporal. From the perspective of space, if a country or region is limited by many factors such as geography and climate, and has a low level of development, then in order to promote its development, the country or region should be appropriately taken care of by the allocation of resources and development opportunities. From the perspective of time, if a country or region has played a positive role in the development of global equity in a certain period of time, then the country should obtain dividends in the distribution of resources and development opportunities in the next period, thus forming a virtuous circle.

4.2 Establishment of the model

4.2.1 Definition of indicators

According to our definition of global equity, we formulate a series of measurement criteria and form an evaluation model from the perspective of space and time. In this model, we use the Analytic Hierarchy Process and the TOPSIS method based on the Entropy Weight Method. The target hierarchy of this model is the **Global Equity Index(GEI)**. For this problem, this index represents the purchasing power of asteroid mineral resources. The larger the index value is, the more funds need to be paid to obtain the same amount of asteroid mineral resources. The values of the GEI vary from country to country, which is calculated by the Entropy Weight Method. The rule hierarchy of Analytic Hierarchy Process is composed of seven evaluation indicators, namely GDP per capita (reflecting economic equity), life expectancy per capita(reflecting health equity), mean years of schooling (reflecting educational equity), carbon dioxide emissions per capita(reflecting environmental equity), the extent of invasion in history(reflecting historical situation and background), consumption of mineral resources per capita(reflecting energy equity), Gini Coefficient (reflecting the gap between the rich and the poor). And the scheme hierarchy of Analytic Hierarchy Process is composed of 20 universal and representative countries.The specific explanation of the evaluation indicators is as follows:

GDP per capita(GDPPC): a financial metric that breaks down a country's economic output per person and is calculated by dividing the GDP of a nation by its population.

Life expectancy per capita(LEPC): Life expectancy per capita is the key metric for assessing population health. Broader than the narrow metric of the infant and child mortality, which focus solely at mortality at a young age, life expectancy captures the mortality along the entire life course. It tells us the average age of death in a population.[2]

Mean years of schooling(MYS): Average number of completed years of education of a country's population aged 25 years and older, excluding years spent repeating individual grades. It can reflect the educational attainment of the labor force in a country or region.

Carbon dioxide emissions per capita(CDEPC): The ratio of a country's or region’s total carbon dioxide emissions to the country's or region’s total population in the current year.

Extent of invasion in history(EIH): In order to reflect the historical situation and background of a country or region, we create this indicator to measure the degree of being invaded or invading in its history. This value varies from -1 to 1. And if it is greater than 0, it means that the extent of invading other countries is greater than the extent of being invaded by other countries, and less than 0 is vice versa.

Consumption of mineral resources per capita(CMRPC): The ratio of a country's or region’s total consumption of mineral resources to the country's or region’s total population in the current year.

Gini Coefficient(GC): Gini Coefficient is the statistical measure which is used in order to measure the distribution of the income among the population of the country i.e., it helps in measuring the inequality of income of the country’s population. It is a value between 0 and 1. A higher number indicates a greater degree of income inequality.[3]

4.2.2 Data pre-processing

Since negative numbers are included in the data of the indicator "Extent of invasion in history", negative elements are not allowed in the forward matrix in the next step, we utilize the following formula to eliminate negative data:

$$z_{ij}=\frac{x_{ij}-\min\{x_{1j},x_{2j}...x_{nj}\}}{\max\{x_{1j},x_{2j}...x_{nj}\}-\min\{x_{1j},x_{2j}...x_{nj}\}} \tag{1}$$

After the above processing, we have obtained a complete and accurate data set,and then we need to convert different indicators into indicators that can be compared on the same scale. And there are 4 types of indicators as follows：

Benefit-type index: The bigger,the better.

$$\widetilde{x}_{ij}=\frac{x_{ij}-\min\{x_i\}}{\max\{x_i\}-\min\{x_i\}} \tag{2}$$

Cost-type index: The smaller,the better.

$$\widetilde{x}_{ij}=\frac{\max\{x_i\}-x_{ij}}{\max\{x_i\}-\min\{x_i\}} \tag{3}$$

Interval-type index: An interval-type index’s optimal value lies in a certain interval [a,b]. for example, the human body temperature is better in the range of 36 ° ~ 37 °.

$$M=\max\{a-\min\{x_i\},\max\{x_i\}-b\}$$

$$\widetilde{x}_{ij}=\begin{cases}1-\dfrac{a-x_{ij}}{M},x_{ij}<a\\ 1,a\leqslant x_{ij}\leqslant b\\ 1-\dfrac{x_{ij}-b}{M},x_{ij}>b\end{cases} \tag{4}$$

Moderate-type index: The indicator value should be neither too large nor too small, and it is best to take a specific value.(Such as pH value of water quality assessment)

$$M=\max\{|x_i-x_{best}|\},\widetilde{x}_i=1-\frac{|x_i-x_{best}|}{M} \tag{5}$$

In this problem,the seven indicators(GDP per capita, life expectancy per capita,MYS, carbon dioxide emissions per capita, extent of invasion in history, consumption of mineral resources per capita, Gini Coefficient) are all benefit-type indexes.

4.2.3 Weight Calculation by EWM

In order to determine the weight, we introduce the concept of **Global Equity Index (GEI)** . Entropy Weight Method (EWM) is a commonly used weighting method, which can measure the degree of value dispersion in decision-making. It assumes that the greater the degree of dispersion, the greater the degree of differentiation, and more information can be obtained. Therefore, the sample set with larger dispersion should be given higher weight.

Suppose we have a total of m indicators and n countries.A total of n*m elements can form a forward matrix A, and we set the corresponding element in row i and column j in this matrix as a_{ij}. We start by standardizing on a_{ij}. The formula for calculating the standardized value b_{ij} of the i th index of sample country j is:

$$b_{ij}=\frac{a_{ij}}{\sqrt{\sum_{i=1}^{n}{a_{ij}}^{2}}} \tag{6}$$

Next, we calculate the probability matrix p. The element in row i and column j of matrix p is denoted as p_{ij}, and the calculation formula is as follows:

$$p_{ij}=\frac{b_{ij}}{\sum_{i=1}^{n}b_{ij}} \tag{7}$$

In EWM, the entropy value of the j th column E_j is calculated:

$$E_j=-\frac{1}{\ln n}\sum_{i=1}^{n}p_{ij}\ln\left(p_{ij}\right)\ ,\ j=1,2...,m \tag{8}$$

The larger the E_j, the greater the degree of differentiation of the indicator j and the greater the weight. Therefore, the weight w_j of item j is calculated as follows:

$$w_j=\frac{1-E_j}{\sum_{j=1}^{m}(1-E_j)} \tag{9}$$

In summary, after the above processing of all the data found, the comprehensive weights of the 7 indicators can be obtained as follows:

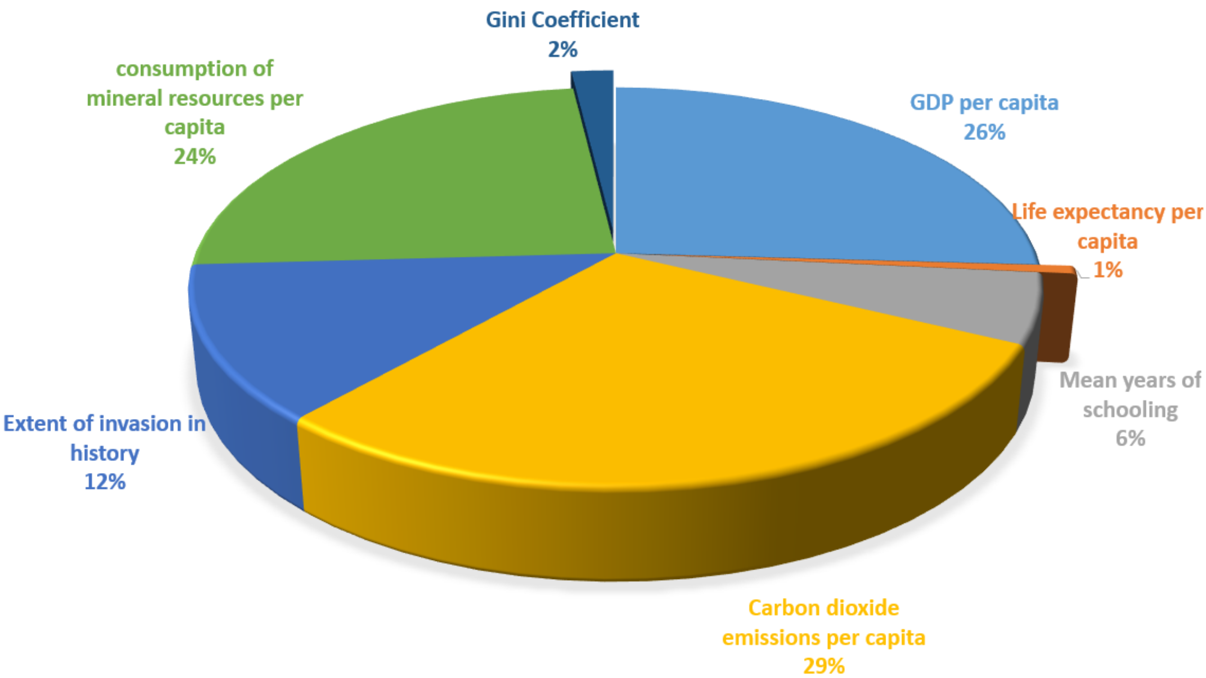

Figure 2: Weights of the seven indicators

4.2.4 Calculation of GEI

The calculation formula of Global Equity Index (GEI) for 20 countries is as follows:

$$GEI_i = \sum_{j=1}^{m} w_j \times z_{ij} \tag{10}$$

On this basis, we normalize the GEI, and the normalization formula is as follows:

$$\overline{GEI_i} = \frac{GEI_i}{\sum_{i=1}^{n} GEI_i} \tag{11}$$

The result of normalization is shown as follows:

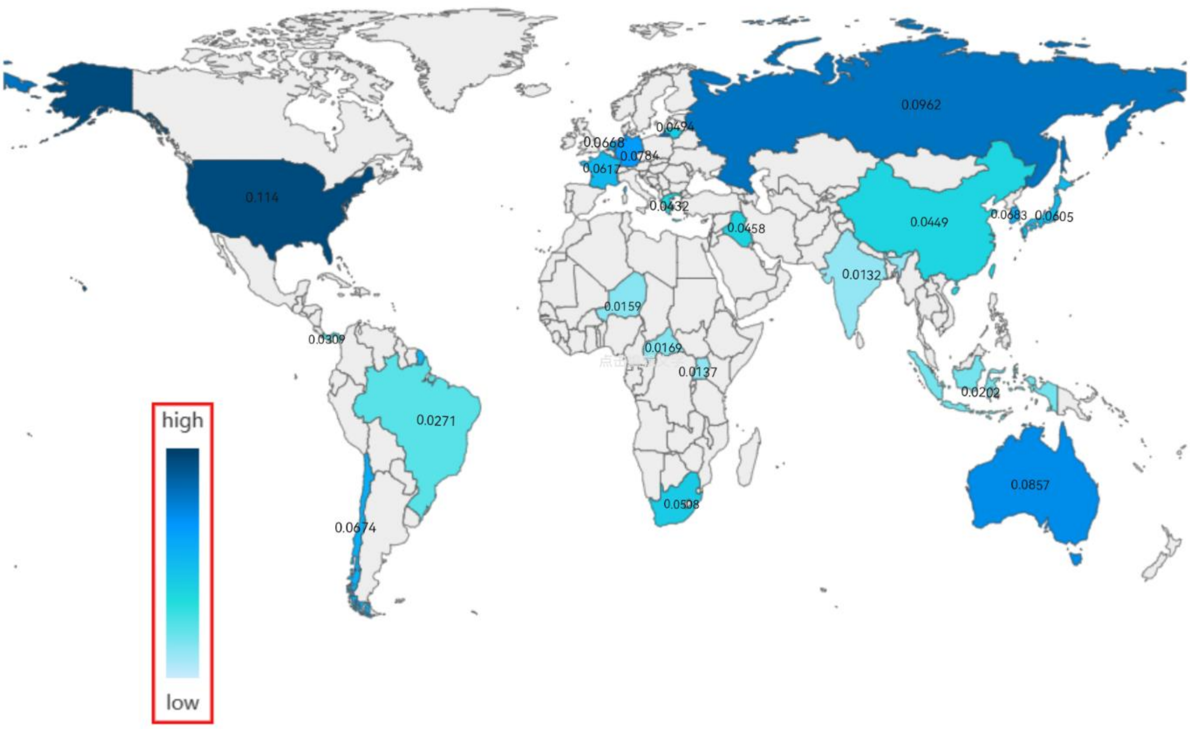

Figure 3: GEI of the twenty countries

According to the calculation results, we can perceive that:the GEI of the United States, Russia, Germany is relatively high, so we set a relatively high price for asteroid minerals in these countries; The GEI of India and Uganda is relatively low, so we set the purchase price of asteroid minerals in these countries relatively low.

4.3 Validation of the model

In order to verify the correctness of the model in terms of space, we selected three representative countries: Australia, Congo and Greece, and put them into the model. According to our general understanding of the comprehensive situation of the three countries, we perceive that the GEI ranking of the three countries should be Australia > Greece > Congo; and Australia's GEI should be at the forefront of the world, Greece's GEI should be in the middle of the world, and the Congo's GEI should be low in the rank.

Then, we search the data of the above seven indicators of three countries, combined with the data of the first 20 countries, and substitute them into the evaluation model, and calculate the GEI (after normalization) of the three countries as below：

Table 2: GEI of the three countries

COUNRTRY	GEI
AUSTRALIA	0.0857
GREECE	0.0432
CONGO	0.0156

In a total of 23 countries, Australia ranks third, Greece ranks 15th and Congo ranks 21st, which is consistent with our general cognition and can verify the correctness of our model.

In order to verify the correctness of the model in terms of time, we select China, which has developed rapidly in recent years, to calculate the GEI value of China. After data collection and calculation, the GEI value of China in 1990 is 0.0263, ranking 16th among all countries; In 2020, China's GEI value is 0.0459, ranking 12th among all countries, which is consistent with our expected results and can verify the correctness of our model.

To sum up, our model has high accuracy both in terms of time and space, and can correctly reflect the level and changes of GEI in the country.

5 Operation Model of Asteroid Mining

5.1 Future vision of asteroid mining

Our future vision of asteroid mining is as follows: first, hundreds of tons of asteroids are conveyed to the Earth-Moon gravity system or near-Earth space, and astronauts can reach the asteroid for exploration through a few weeks of voyages, thus significantly reducing the mining cost. Then, the asteroid is segmented by a solar heating device and the mineral resources are brought back to the surface. In addition, asteroids can also be used as transit stations which can build space facilities for humans and provide a large number of basic materials for interstellar navigation transfer systems, including extracting propellants, developing protective materials, building interstellar navigation radiation protection structures, and even materials needed by the entire interstellar exploration industry. At the same time, in order to avoid unlimited plundering of asteroid mineral resources and abuse of market position by some private entities or national governments with abundant funds and advanced technology in the future, thus forming a monopoly and eventually undermining global equity. Therefore, in the future asteroid mining, in order to enable the equitable distribution of resources, we need global alliances for macro-control, to promote the development of global equity.

We assume that a large company—**United Minerals(UM)** jointly controlled by all Member States has been established in the world. UM mines mineral resources of asteroids in accordance with the principle of advancing global equitable development while promoting mutual benefit and win-win of all Member States. The company's operating model is as follows:

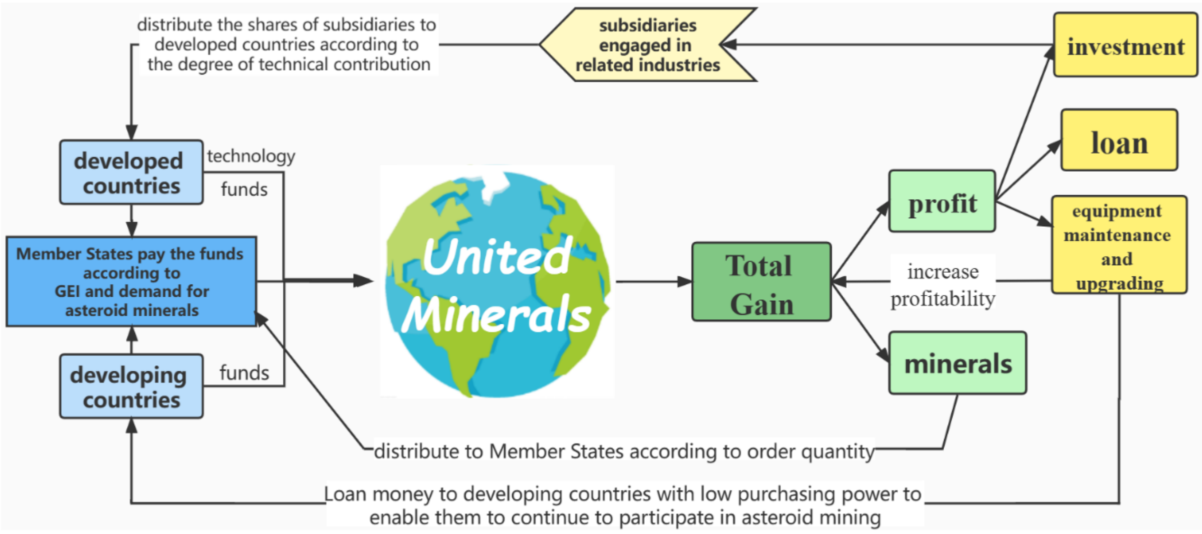

Figure 4: UM operation model

5.2 Impact of UM on global equity

UM's annual profit can be calculated using the following formula:

$$\begin{gathered} Gain = K \cdot X \\ Gain = minerals + profit \end{gathered} \tag{12}$$

where K is the profit coefficient and the initial value of it is 1.08.

To explore whether the company's operations uphold the principle of global equity, we mainly consider the following two dimensions:

1) Whether the establishment of UM will benefit all Member States.

For the first dimension, when designing the company's operation mode, we introduce several positive feedback mechanisms to reasonably distribute the remaining profits.

- Although it is a company which is jointly held by Member States and carries out macro-control over capital distribution and production process. But in order to maintain the vitality of the company's development, we still decide to allow free capital to set up a series of subsidiaries, including mineral resources smelting, mineral product manufacturing and large-scale equipment manufacturing through UM investment. The shares of the subsidiaries shall be distributed to the member states in proportion to the technical costs paid by the member states at the beginning of UM's establishment. Because developed countries pay a large technical cost at the beginning of UM's establishment, this feedback path is mainly beneficial to developed countries.

- The company will also set up an international banking institution to lend part of its annual profits as international loans to Member States with low purchasing power, so that they can have sufficient funds to meet the demand for asteroid mining next year. This feedback path fully embodies the principle of global equity and protects the interests of developing countries.
- In addition, it is difficult to ensure the sustainable development of the company only by relying on the accumulated technical resources at the beginning of the establishment of the company. Therefore, we should take part of the profits as technology development and equipment maintenance and upgrading, such as developing more energy-efficient electric engines to reduce the cost of interstellar journeys, and developing more efficient asteroid mining equipment and so forth. This part of R&D funds has improved UM's future production efficiency, developed its production potential and safeguarded the common interests of all Member States.[4]

These parts of the expenditure are derived from the acquisition of UM funds, and we can get the following relationships:

$$profit = p_l + p_i + p_{m\&u} \tag{13}$$

2) Whether UM will narrow the gap between member states for GEI

From the second dimension, UM should also shoulder the mission of establishing global equity in the distribution of mineral resources.

By the calculation of GEI indicators and their weights in Global Equity Measurement Model, we can know that some countries are in a weak position in the global resource allocation system because they have historically suffered resource plunder and lost the opportunity to keep up with the development trend of the world;Also,there are other countries which lack of resources and motivation for development because of unfavorable geographical location. According to the principle of global equity, these countries should receive preferential treatment in resource allocation, so as to obtain equal opportunities for development. Therefore, according to GEI, we have formulated a new price system conducive to global equitable development, that is, the price of mineral resources purchased by different countries in UM is directly proportional to the GEI value of that country, which can not only restrict some large countries from plundering mineral resources in outer space, but also ensure that some backward developing countries have the ability to buy mineral resources needed for development at a relatively low price,which truly achieves global coordinated development. And our new price system is as follows:

$$\frac{Price_a}{GEI_a} = \frac{Price_b}{GEI_b} \tag{14}$$

where the formula represents the relationship between the price and GEI when two countries a and b purchase the same mineral resource.

$$\frac{\sum_{k=1}^{n}\sum_{i=1}^{m} Price_{k,i}\cdot T_{k,i}}{T_i}=\frac{C_i}{T_i'} \tag{15}$$

where $Price_{k,i}$ is the purchase price of the i th mineral in the k th country;$T_{k,i}$ is the total demand for the i th mineral in the k th country;T_i is the total amount of the i th mineral resources mined from the asteroid that year;n is the total number of Member States;m is the total number of types of mineable asteroid mineral resources;C_i is the total value of the ith mineral resource mined from the earth in that year;T_i' is the total amount of the i th mineral resources mined from the earth in that year.

5.3 Planning Model

In order to verify whether our UM model can promote global equitable resource allocation, our idea is to establish a planning model to change the indicators affecting GEI through the rational allocation of UM's profit, so as to achieve the goal of global equity.

When establishing the planning model, we must first determine the objective function. Therefore, we introduce Theil index:

$$\sum_{i=1}^{n}\frac{x_i}{\sum_{j=1}^{n}x_j}\cdot\ln\frac{x_i}{\overline{x}} \tag{16}$$

The Theil index is an indicator,which measures the income gap (or inequality) between individuals or regions. The greater the value, the greater the degree of difference.[5]

For the subject of n members, if all members have the same indicator, then the Thiel index of the whole for this indicator is 0; if an indicator is concentrated in one member and the indicator values of other members are all 0, that is, when the resource distribution is extremely unbalanced, the Theil index of the whole indicator is ln (n).

In order to measure the imbalance of GEI in the world, we created a new calculation method of GEI in a country after one year of operation of UM company:

$$\begin{aligned} GEI_{new}=S_{GDPPC}\cdot\left(1+\ln\left(\frac{x+x_2}{2}\right)\right)+S_{CMR}\cdot(1-\ln k)+S_{LEPC}\\ +S_{MYS}+S_{CDEPC}+S_{EIH}+S_{CMRRPC}+S_{GC}\end{aligned} \tag{17}$$

When calculating the Thiel Index, if all member states are taken as a whole, the amount of calculation is too large. Therefore, only 3 representative countries are selected to form a small whole, and the Thiel index of this small whole GEI is calculated, so as to simulate the Theil index of GEI all over the world.

The countries we choose are Russia, South Korea and India. Russia is a large country with rich mineral resources and a strong industrial foundation. Therefore, it has a very high GEI index, which represents a large country with rich mineral resources and high CO2mission in the world; South Korea has a high level of economic development, but it is lack of mineral resources. It represents a country with narrow land, short minerals resource and high level of economic development in the world; and for India, its per capita resources are scarce, industrial base is relatively weak, and GEI index is very low, which represents developing countries with backward economy and insufficient resources.

Our image analysis of the changes of the three main indicators of the three selected countries with years is as follows:

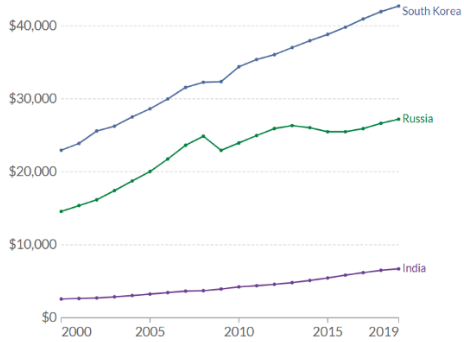

Figure 6: Per capita GDP changes

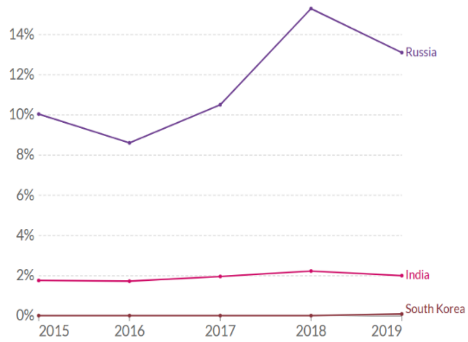

Figure 7: Changes in the ratio of mineral resources in the world

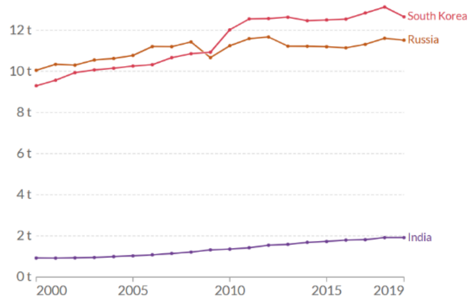

Figure 8: Changes in CO2 emissions per capita

According to Global Equity Measurement model, we calculate that the GEI Theil index of the three countries as a whole is 0.231, which indicates that there is indeed an imbalance in GEI in the world.

Next, we need to determine the constraints of the planning model:

- UM's annual operating profit is used in three aspects: investment, loan, and equipment maintenance and upgrading.So the first constraint is:

$$Gain = K \cdot X \tag{18}$$

- In order to balance the benefits obtained by developed countries (mainly gain from investment) and developing countries (mainly gain from loan and minerals)which join um, we introduce the second constraint:

$$-\frac{1}{20}X \leqslant Gain_{MEDC} - Gain_{LOC} \leqslant \frac{1}{20}X \tag{19}$$

where $Gain_{MEDC}$ is the estimated gain of developed countries;$Gain_{LDC}$ is the estimated gain of developing countries

$$Gain_{MEDC} = (1 + 25.12\%) \cdot x_2 + \frac{1}{3} \times minerals$$
$$Gain_{LOC} = x_3 + \frac{2}{3} \times minerals \tag{20}$$

where 25.12% is the average annual growth rate of market value of international stock market; $\frac{1}{3}, \frac{2}{3}$ is the reasonable ratio of profits in minerals between developed and developing countries.

- Since developed countries provided technical support for the initial development of UM, and their voice in international affairs is still relatively high, we have to listen to the opinions of developed countries when formulating the company's development plan. In order to protect their own interests, the developed countries will certainly not lend most of the profit to developing countries, and we introduce a third constraint on this basis:

$$P_i + P_{m\&n} \geqslant 0.8Y \tag{21}$$

We use the above three conditions as constraints, take Theil index as the objective function, and use matlab to perform nonlinear programming operations on the objective function. One year after the company is founded and operated according to our optimal plan for profit, the Theil index among Russia, South Korea and India decreased to 0.2061, indicating that the company we established can indeed promote the development of global equity under the condition of operating according to our vision.

5.4 Prediction Model

With the development of the company, the investment expenditure and profit coefficient involved in the planning model will change, which will lead to changes in the optimal solution for the profile distribution in order to obtain a smaller Thiel coefficient.

- UM's annual expenditure on equipment maintenance and operation accounts for about 15% of the invested capital. Therefore, UM's funds for equipment research and development are:

$$P_u = P_{m\&u} - 0.15X \tag{22}$$

Obviously, the larger this value is,the more advanced the technology is, the greater the profit coefficient of the next year will be. And when this value is 0, the profit coefficient of the next year will be the same as that of the current year. However, with the continuous increase of equipment research and development funds, the impact on the profit coefficient of the next year will gradually decline. That is, more research and development investment is required to achieve a certain breakthrough of the more high-end technology. From the above inference, we can get:

$$K_{n+1} = \left(1 + \ln \frac{P_{m\&n}}{0.15X}\right) \cdot K_n \tag{23}$$

- The impact of UM's operating results in the current year on the next year's capital investment will be much simpler. Because UM will lend to countries with low purchasing power every year for the purchase of asteroid mineral resources in the next year, the investment funds in the second year can be roughly regarded as the sum of the investment funds and loan funds in the current year:

$$X_{n+1} = X_n + P_l \tag{24}$$

We first use the operating data of the first year to calculate the investment capital and profit coefficient of the second year, and then re-plan the objective function under the condition that the constraints are unchanged. By analogy, the predicted value of the Thiel coefficient is calculated year by year.

And the optimal proportion of profit investment over a five-year period is as follows:

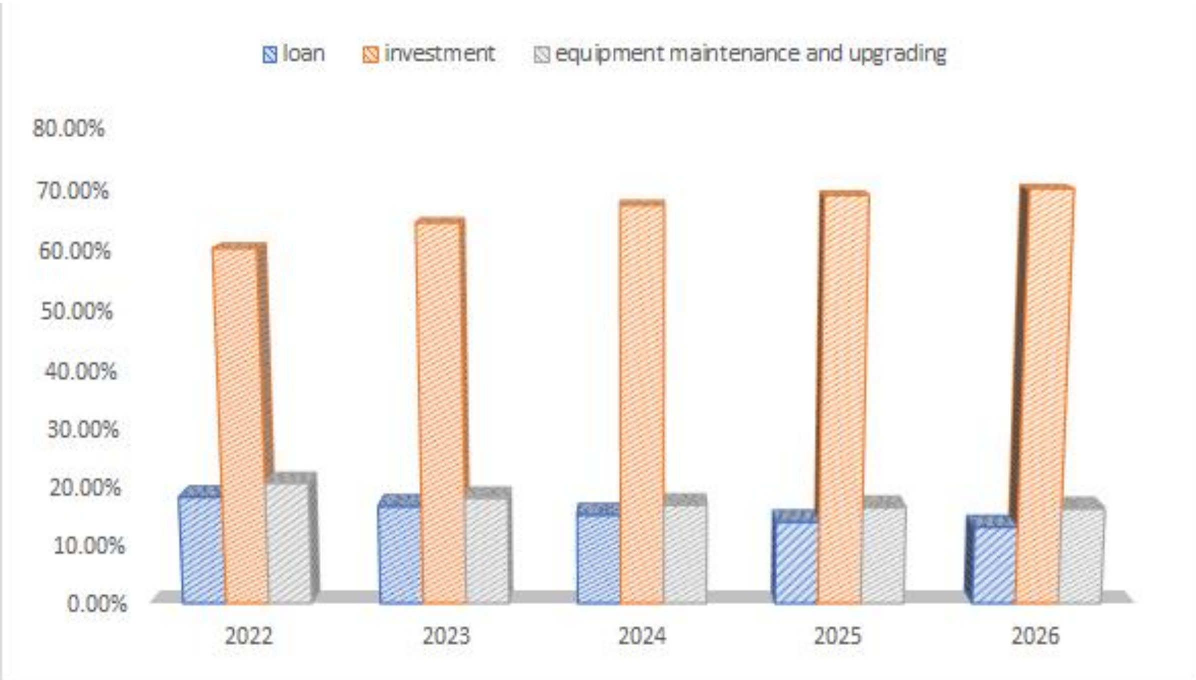

Figure 9:The predicted trend of allocation ratio

According to this figure, we can see that in the first year, the proportion of loan, investment, equipment maintenance and upgrading is 18.52%, 60.46% and 20.93% respectively. With the change of years, in order to promote the development of global equity, the investment should be increased year by year, and the investment in loan, equipment maintenance and upgrading should be reduced year by year and tend to be stable gradually.

The predicted values of changes of Theil index with years are as follows:

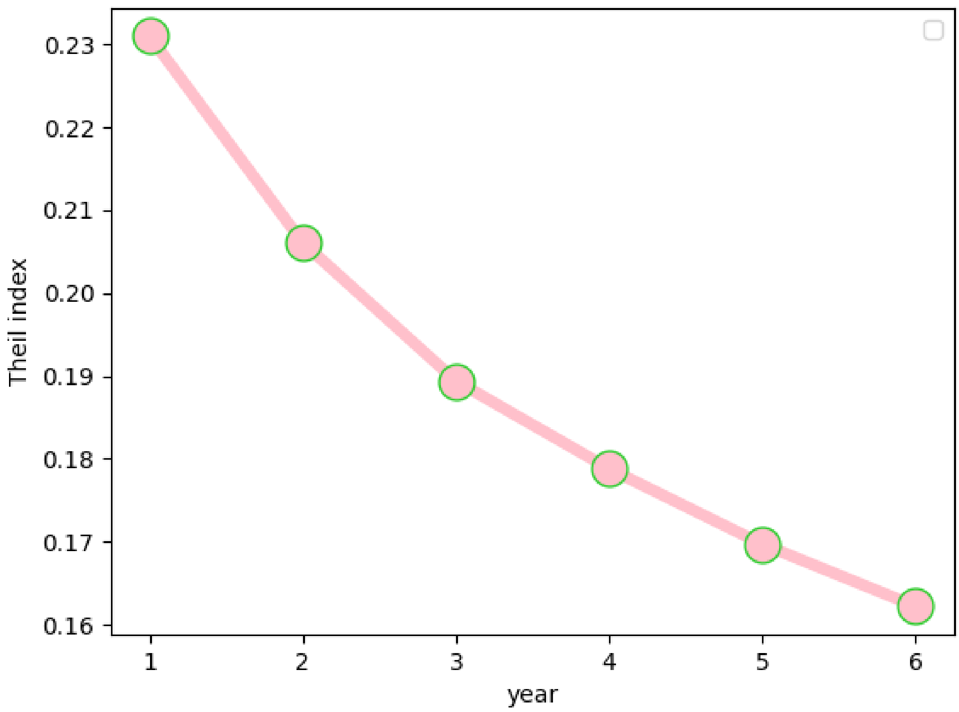

Figure 10: The predicted trend of Theil index

According to our prediction, in five years, the Theil index of GEI among Russia, South Korea and India will drop to 0.1622, which indicates that the global equity of resource allocation has increased significantly, and our company has played a positive role in the construction of global equity while mining asteroid mineral resources.

6 Policies Formulation

In order to further enhance the role of asteroid mining in global equity, in accordance with the spirit of the first article("the exploration and use of outer space shall be carried out for the benefit and in interests of all countries and shall be the province of all mankind")and the tenth article("countries should cooperate and assist each other in outer space activities")of the Outer Space Treaty, we recommend that the relevant departments of UM develop appropriate international and domestic policies as follows.[6]

6.1 International Policies

1. UM Member States enjoy equal voting rights within the UM shareholders' meeting, so as to avoid the situation that some countries have a too strong or too weak voice in UM policy-making.[7]
2. UM proposes to add the following articles on the basis of the Outer Space Treaty signed by all countries in 1967 to safeguard the interests of all countries in the asteroid mining industry: the mineral resources contained in asteroids belong to the common resources of all mankind; If a country finds a new asteroid which is suitable for mining, it should report the finding to UM for macro-control. Any concealment, false report or private mining is regarded as illegal.

3. UM Member States should participate in and improve the property rights protection system for asteroid mineral resources as soon as possible, that is, respect and guarantee the ownership of various mineral resources by market subject, and further promote the development of exploration and utilization of outer space, which will ultimately benefit all mankind.
4. UM should enhance technical assistance to developing countries. In Operation Model of Asteroid Mining, we introduce a way to provide loans to developing countries through UM, but these loans may not meet the needs of developing countries. So for extremely backward developing countries, UM should also provide technical assistance from the perspective of global equity.
5. UM should formulate corresponding policies to encourage the construction of a series of matching subsidiaries including mineral resource smelting and mineral product processing,etc.,and encourage free capital to invest in these subsidiaries, which not only ensures the vitality of UM's sustainable development, but also ensures the interests of some developed countries with strong purchasing power and investment capabilities, so as to enable these developed countries to continuously invest technology and funds in UM.
6. In addition to the global equitable distribution of profits, environmental protection is also a concern that we should pay attention to. Therefore, UM should formulate corresponding policies to reduce the accumulation of space garbage outside the atmosphere caused by the asteroid mining industry, and avoid damaging the earth's environment in the process of transporting mineral resources back to the earth.

6.2 Domestic Policies

6.2.1 Policies of developed countries

1. Because there are many monopoly interest groups with advanced technology in developed countries, the cheap mineral resources mined by asteroids are very easy to be monopolized by domestic interest groups in developed countries. So the developed countries should formulate corresponding domestic policies to break the monopoly of large domestic companies and distribute the benefits of asteroid mining to most people, so as to avoid the rapid rise of Gini coefficient, leading to the rise of GEI and then affecting their future position in UM price system.
2. Since there are some companies in developed countries that master the core technology of asteroid mining, developed countries should formulate corresponding policies to limit the scope of technology use of these companies. And the role of these policies is to supervise these companies' implementation of the outer space treaty.
3. Developed countries should increase their investment in asteroid mining technology, so as to promote the continuous upgrading of asteroid mining technology. Because the improvement of mining technology in developed countries means that the improvement of global mining technology and more profits for all UM members states.[8]

6.2.2 Policies of developing countries

1. Developing countries should build an industrial chain for processing mineral resources at home, which produces asteroid mineral resources purchased cheaply from UM into high value-added commodities, so as to make these mineral resources truly play a role in driving the growth of national economy.
2. Developing countries should invest in domestic mineral companies in the form of national capital to achieve the purpose of macro-control of domestic mineral resources, so that the distribution of mineral resources can truly conform to the national conditions and the interests of the people.

7 Sensitivity Analysis

After the optimal solution is obtained from certain data, what impact will it have on the optimal solution when one or several of these data change. In other words, if the optimal solution remains unchanged, how widely can the individual data vary. This method of exploring the stability of planning model is called sensitivity analysis of planning model.

In this problem, we need to verify whether Operation Model of Asteroid Mining is stable. The value of the Thiel index of the objective function in Operation Model of Asteroid Mining depends on the proportion of UM's funds for the maintenance and research and development of mining equipment, investment in subsidiaries, and loans to developing countries, which are record as x1, x2, and x3 respectively.

In the above article, by planning the operation results of UM in the first year, we determined that the initial values of the capital proportion in these three directions were 20.93%, 60.46% and 18.52% respectively. Since the total proportion of x1, x2 and x3 is 100%, under the condition that the proportion of x3 is unchanged, the proportion of x1 increases by a%, which means that the proportion of x2 decreases a%.On this basis, we test the stability of the model from two angles:

1. **Greatly change the proportion of x1 and x2 and observe the change of Theil coefficient:**Let the proportion of x1 increase by 5 percent, and the proportion of x2 decrease by 5 percent, and we find that the Thiel index changed from 0.2061 to 0.2068, the change rate is about 0.34%.Compared to 5% smaller, the stability of the model was better.

2. **Under the condition that the change of the Thiel index is less than 0.001,obtain the maximum value of the change of the proportion of x1 and x2:** Based on the original data, we use matlab to change the proportion of x1 and x2 in steps of 0.1% and observe the change of Theil index:

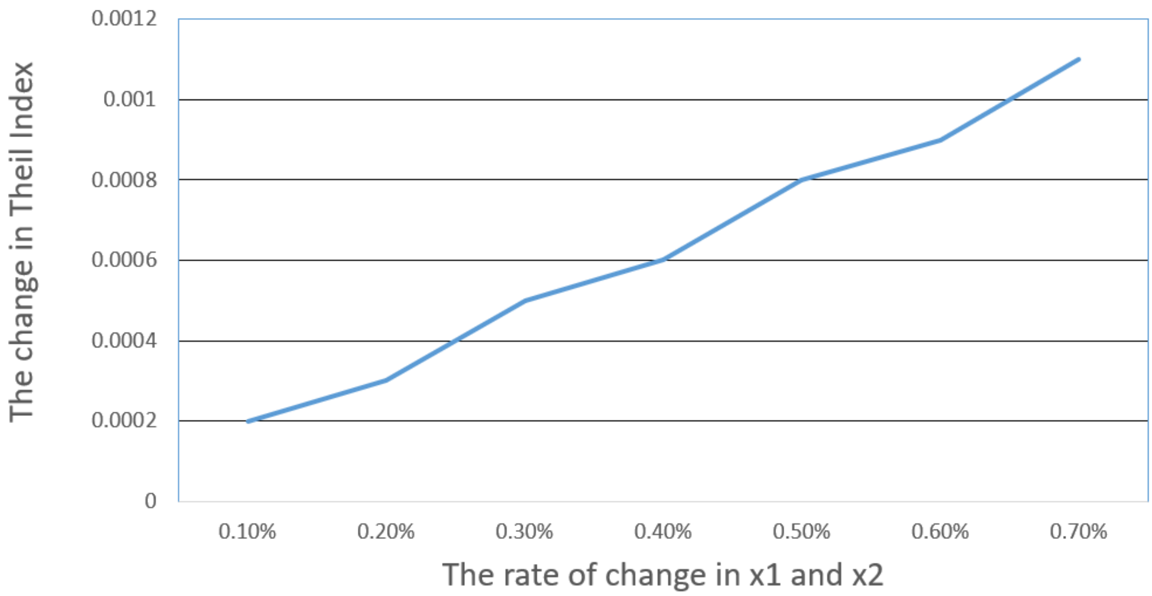

Figure 11: The change in Theil Index

We find that when the proportion of x1 and x2 is changed by 0.7%, the change of the Thiel index exceeds 0.001 for the first time. Therefore, the sensitivity of the dependent variable of the Operation Model of Asteroid Mining is low and the its stability is good.

In conclusion, the stability of the model is good whether the independent variables are changed in a large range or in a small range.

8 Model Evaluation

8.1 Strengths

1. We have introduced social, economic, environmental, historical and other evaluation indicators, which can correctly and comprehensively evaluate the country's general strength and its role in the process of global equitable development. The proportion of index weight calculated by Entropy Weight Method is reasonable,which is in line with our psychological expectations.
2. We use a variety of modeling methods to enrich the structure of the model. We first introduce the weights of UM company's capital investment in three directions, then find the initial value of the weights that meet the constraints by Monte Carlo method, and then find the optimal solution of the investment proport on by nonlinear programming. Finally, we use the prediction model to re-plan the objective function according to the proportion of the previous year, and calculate the prediction value of Theil index for the next year.
3. Our model fully embodies the principle of international cooperation, and the member states in UM have achieved mutual benefit and win-win results within our asteroid mining system. Our model also embodies the principle of global equity. After using our model, the Theil index of GEI in the world gradually decreases, representing the gradual realization of global equity.

4. We conduct sensitivity analysis on the weight Operation Model of Asteroid Mining. We use the variable-controlling method: make the weight of the two indicators fluctuate within a certain range on the premise of meeting the constraints, and observe the change of the predicted Theil index. We find that there is no significant change in the Thiel index between the three countries in the list, indicating that our evaluation model has high stability.

8.2 Weaknesses

1. For objective reasons, we cannot obtain all the data for the required indicators, which inevitably have missing values. Although we have already processed missing values, the accuracy of the model will still be affected. In defining the extent of invasion in history, although we looked up a large amount of historical information, the accuracy of the data is affected by subjectivity.

2. For the prediction model, one round of prediction can only use the existing data of this year to predict the data of the next year, but can not predict the data of the following years at one round. That is, if it is necessary to predict the data of the following years, multiple rounds of prediction are required. At the same time, when multiple countries are introduced, the calculation amount of Theil index will increase significantly.

9 Conclusion

We first propose the concept of global equity, and build an evaluation model for global equity indicators(GEI) to evaluate 20 countries. Next, we calculate the GEI value of each country, which can accurately reflect the overall situation of a country. Then, we verify the correctness of the evaluation model from the perspective of time and space. In the evaluation model, life expectancy and Gini coefficient have little influence on the weight of GEI score, which are 0.6% and 1.9% respectively. We can choose more appropriate indicators,i.e. indicators with greater weight, to replace these two indicators to ensure that the weight of each indicator is not too small.

In order to achieve a global equitable distribution of mineral resources, we establish a model to solve the problem of UM's allocation of mining profit. We introduce the concept of Theil index, optimize the proportion of profit allocation with the Theil index among Russia, South Korea and India as the objective function and obtain that the proportion of profit allocation to equipment maintenance and upgrading, investment in subsidiaries and loan in developing countries in the first year of asteroid mining is 20.93%, 60.55% and 18.52%. Meanwhile, we calculate that the Theil index among the three countries decreases from 0.231 to 0.2061. On this basis, we establish a prediction model to predict the optimal proportion of profit distribution and Theil index of Russia, South Korea and India in the next five years. The results show that the optimal distribution proportion of profit in the next five years will change to 16.54%, 70.16% and 13.3%, and gradually stabilize. The Theil index will decrease to 0.1622 and continue to decline, which indicates that the degree of global equity has been significantly improved, and the rationality of Operation Model of Asteroid Mining has been verified. However, it will be a long process to achieve global equity,so in order to accelerate the realization of global equity, we encourage Member States to increase capital investment in UM to increase the benefits of UM and accelerate the rate of the decline of Theil index.

In Policies Formulation, we have developed a series of international and domestic policies with reference to the Outer Space Treaty. The policies points out that all countries participating in asteroid mining should cooperate and mutually assist to realize the rational development and utilization of resources. On this basis, our policies should also keep pace with the times and continue to improve over time,so as to achieve the purpose of promoting global equitable development.

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Appendices

Appendix 1
Introduce:This code is written in matlab, and it calculates the optimal ratio of investment in profit and the Theil index through nonlinear programming.

```
%Monte Carlo Model:
n=100000; %the number of random numbers generated
fmin=+inf; % set minimum value
syms x1;syms x2;syms x3;
for i=1:n
    x1=unifrnd(0,800,1,1);
    x2=unifrnd(0,800,1,1);
    x3=unifrnd(0,200,1,1);    % Generate random numbers x1 x2 x3
    if (x1+x_2>=880) & (x1+x2+x3<=1080) &
        (7*x1+16*x3-8*x2<=450) & (7*x1+16*x3-8*x2>=-450)%set constraints
        result = (objective function of Theil index)
        if    (result    < fmin) %Update result
            fmin = result;    %Update value to the new minimum value
            x1 = x1_new; x2 = x2_new; x3 = x3_new; %Update x1 x2 x3
        end
    end
end
%Programming Model:
A = [1 1 1; -1 -1 0; 7 -8 16; -7 8 -16];
b = [1080 -880 450 450];%set constraints
x0 = [x1 x2 x3];
lb = [50 50 50];    ub = [800 800 200]; %set upper limit and lower limit
[x,fval] = fmincon(@fun1,x0,A,b,[],[],lb,ub,[]);%Nonlinear programming
disp(x0);
disp(fval);%output results
```