Journal of Research in Social Science and Humanities
ISSN 2709-1910
www.pioneerpublisher.com/jrssh
Volume 2 Number 4 April 2023

An Asteroid Mining Model Based on Input and Output Equity

Zimu Peng[1]

[1] School of Transportation Engineering, Tongji University, China
Correspondence: Zimu Peng, School of Transportation Engineering, Tongji University, China.

doi:10.56397/JRSSH.2023.04.02

Abstract

With the progress of science and technology and the rapid consumption of earth resources, the exploitation of outer space resources such as planetary mining has become an international hot issue. The power gap between countries in today's world is so wide that how to realize the so-called fairness has become a problem worth thinking.

Firstly, we establish an Input Output Equity Model (IOEM) to measure global equity. We define global equity as the balance between the input of human and material resources in the management and construction of a country and the overall strength of the country. Ten sets of data from many countries are divided into four categories: Science and technology, Traffic, Workforce and Energy consumption. We used the Entropy Weight method (EWM) based on TOPSIS comprehensive evaluation to determine the weight of each part and index, comprehensively evaluated 12 countries covering six continents and calculated their input equity index. Then we compared the index with the GDP of each country and found that the overall trend was consistent. This shows that there is a balance between input and output, which verifies the rationality of the model.

We then establish the Asteroid Mining Model (AMM) to evaluate and predict the Asteroid Mining capabilities of various countries. In combination with the whole process of asteroid mining and the analysis of main components, we choose these three indicators: Scientific Research (SR), Exploitation of Mineral (EM) and Aeronautics and Astronautics (AA) to measure. We use the analytic hierarchy process (AHP) to determine the weights of the three factors and calculate Asteroid Mining Model (AMI) for each country. Then, the model is applied to two representative countries, China and Colombia, and the future is predicted by fitting. According to the results, it is concluded that the asteroid mining industry has a good development prospect.

Next, we use correlation analysis to discuss the impact of the asteroid mining industry on global equity and conclude that there is a correlation between the decision index of asteroid mining and equity index, among which the correlation coefficient between aircraft and equity index reaches 0.9290. It can be concluded that the development of asteroid mining in the future will inevitably affect global equity. Furthermore, in order to explore how changes in asteroid mining will affect global equity in different ways, we carry out multiple linear regression analysis of variables from macro and micro perspectives respectively and find that the development of asteroid mining industry will indirectly affect global equity through its impact on computers and researchers.

Finally, based on our findings, we propose policy recommendations for the development of asteroid mining to the United Nations from the perspective of global equity. Our advice can be summed up as

"Inspire, Share and Collaborate". We hope that while promoting scientific and technological development and exploration of outer space, all countries will enjoy friendly cooperation and common development so as to realize a fair and beautiful vision of the universe.

Keywords: Asteroid mining, TOPSIS, correlation, proposal

1. Introduction

1.1 Problem Background

The United Nations' Outer Space Treaty of 1967 has provided the legal underpinnings for projects that have promoted multinational access to space. It is an international commitment aimed at promoting global equity. In recent years, asteroid detection has gradually become possible with the maturity of various technologies. At the same time, the rich mineral resources of asteroids have also received extensive attention from various countries. The exploration and utilization of space resources is a new area in the game of great powers as well as the commanding point of competition in science and technology, bearing the hope of the sustainable development of human civilization in the future. Therefore, asteroid mining is a general trend of development, and it will impact global equity to a certain extent. How to use the Outer Space Treaty to regulate the asteroid mining industry and safeguard global equity requires the United Nations to perform its functions.

1.2 Problem Restatement

Given the background information and constraints of asteroid mining, we need to address the following problems:

- Establish a mathematical model to define and measure global equity.
- Assuming that asteroid mining is viable and worthwhile for investment in the future, propose, describe and justify a possible vision for the asteroid mining industry, and identify its impact on global equity.
- Analyze the different impacts of different conditions selected on global equity in asteroid mining.
- Based on the results analyzed above, put forward justified policy recommendations to help the United Nations update the Outer Space Treaty, so that asteroid mining might help promote global equity.

1.3 Overview of Our Work

Since asteroid mining industry is still at the basic stage, we should study this problem further. Firstly, after considering many factors and processing the data, we establish a new evaluation model IOEM. The main body of the model is to verify global equity with TOPSIS comprehensive analysis based on entropy weight method. Then, taking China and Colombia as examples, we predict the future vision of asteroid mining by using analytic hierarchy process and curve fitting. At the same time, we use correlation analysis to combine asteroid mining with the model of problem one, and summarize the impact of asteroid mining on global equity. Then, through multiple linear regression, we identify the biggest factors affecting global equity in asteroid mining. Finally, combining the results of all the above models, we provide some recommendations for the United Nations to update the Outer Space Treaty.

The entire modeling process is shown as follows in detail.

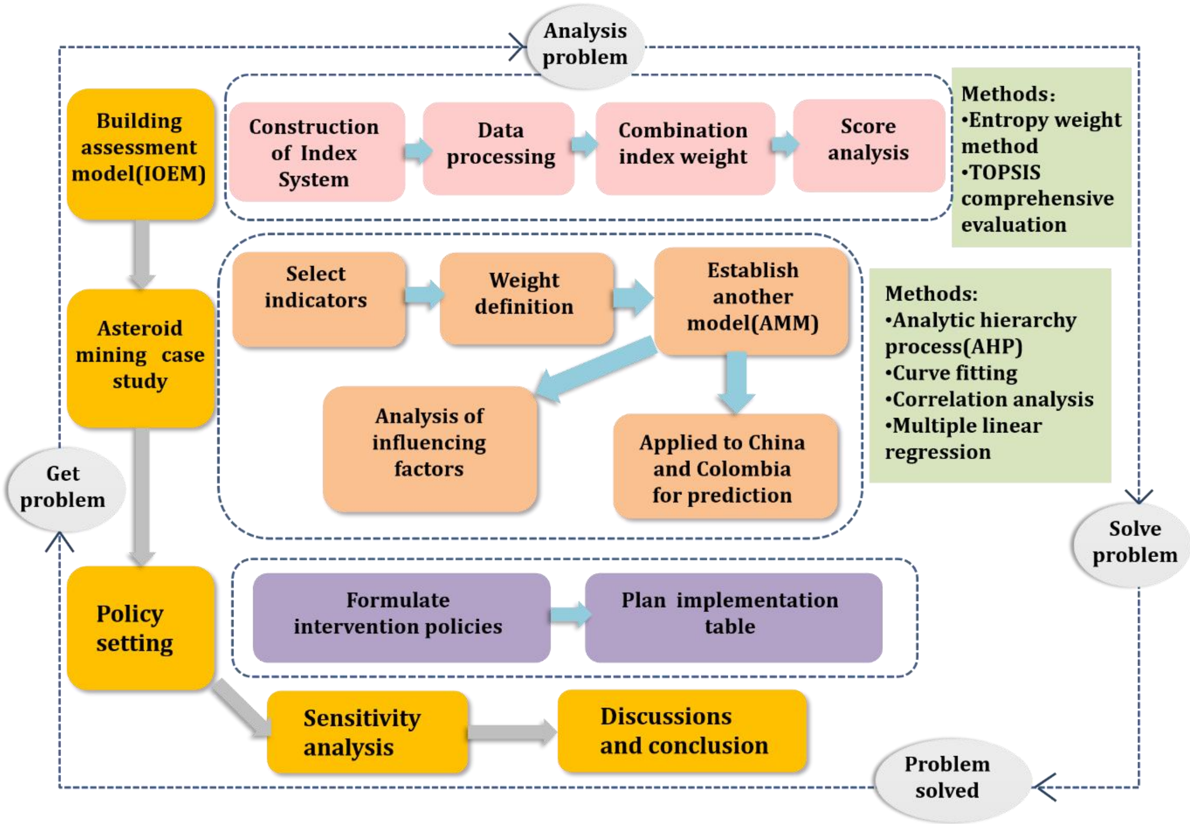

Figure 1. The flow chart of our work

2. Assumptions and Justifications

Global equity is a complex issue that concerns all humankind. As an emerging industry, asteroid mining has infinite possibilities in the future. It is impossible for us to model every possible factor. To simplify the given problems and modify them to be more suitable for simulating real-life conditions, we made the following basic assumptions, which are properly justified.

- Assumption: The data we collect from online databases is accurate, extensive and reliable.

Justification: Our data is collected from the websites of international organizations, so we can reasonably assume that the data is of high quality.

- Assumption: Factors affecting global equity can be considered in terms of energy, science and technology, traffic and workforce, and asteroid mining is mainly determined by aeronautics and astronautics factors, exploitation of mineral factors, and scientific research factors. Those we ignore have little impact on the overall model.

Justification: By looking at large amounts of data, we summarize several inferior indicators into these superior indicators. They basically cover all aspects of the problem to be considered.

- Assumption: We ignore the impact of some extreme conditions on the asteroid mining.

Justification: The future trend of the asteroid mining will not necessarily evolve as we predict, and there may be many contingencies. So we will disregard force majeure and assume that the asteroid mining industry is normal and stable.

- Assumption: Some specific countries are representative and can be regarded as a macro-strategic development unit.

Justification: Different countries are relatively independent, and each country's investment and decision-making in various fields, such as economy, science and technology, are related to the future development of the country. Overall, although there are differences in the degree of development among countries, a country is representative in a specific region and level interval, and its development planning can represent countries near the level to some extent.

3. Notations

The key mathematical notations and abbreviations used in this paper are listed in Table 1.

Table 1. Notations used in this paper

Symbol	Description	Unit
IOEM	Input-output Equity Model	-
IOEI	Input-output Equity Index	-
AMM	Asteroid Mining Model	-
AMI	Asteroid Mining Index	-
SR	Scientific Research	-
EM	Exploitation of Mineral	-
AA	Aeronautics and Astronautics	-

4. Measurement Model of IOE

4.1 The Establishment of IOEM

Input Output Analysis was first proposed in 1963 by Wassily W. Leontief, an American economist, which represents a balanced relationship between production input and product distribution across sectors of the national economy. Therefore, we take examples from this concept and establish our global equity model: Input-Output Equity Model. We shall call it IOEM in the following paper for short.

We define global equity as a balanced relationship between the input of human and material resources in the management and construction of a country and the overall national strength (Rodrik D., 2017). Different countries have different investment capacities in different industries, and the returns are the same. In order to fully consider this problem, in our model, we select 12 countries that are distributed on different continents and have different comprehensive national strengths. Roughly speaking, total GDP can approximately represent their comprehensive national strength.

Input is measured by four secondary indicators: science and technology, traffic, workforce and energy consumption. Each secondary indicator is divided into two or three inferior indicators. We consider a total of 10 inferior indicators and the framework of specific indicators identified by us is shown in Figure 2.

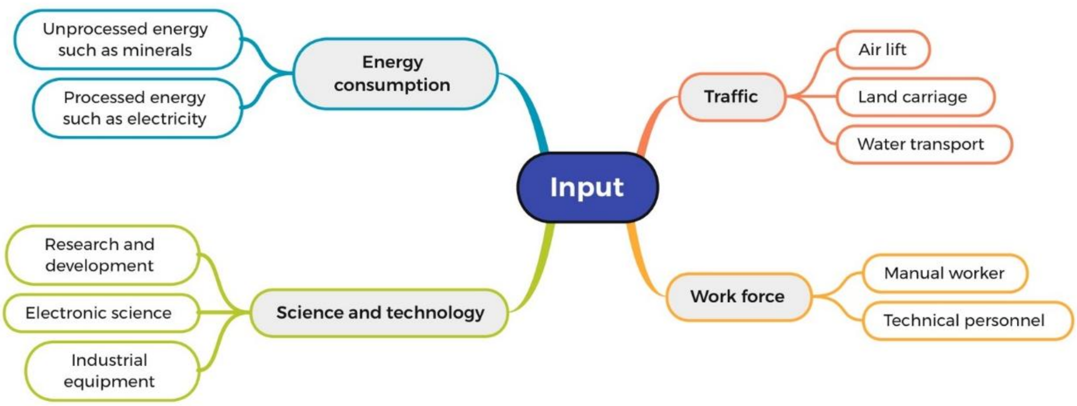

Figure 2. Overview of IOE model indicators

4.2 The Calculation of IOEI

In our basic model, we adopt TOPSIS based on entropy weight method to solve the IOE model. Entropy weight method is an objective weighting method, which obtains the weight according to the data itself and avoids the deviation caused by human factors. TOPSIS is a commonly used comprehensive evaluation method, which can make full use of the information of original data to obtain the relative closeness between the evaluation object and the optimal scheme. The weights of ten inferior indicators are obtained by the entropy weight method, and then the relative scores of twelve countries are calculated according to TOPSIS. We use IOEI to describe the final results. The specific solving steps are as follows:

Step 1: According to the data of twelve countries and ten evaluation indexes, we establish a matrix X for these indexes.

$$X=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nm} \end{bmatrix}(n=1,2,\cdots,12;m=1,2,\cdots 10) \tag{1}$$

Where $x_{ij}(i=1,2,\cdots,12;j=1,2,\cdots,10)$ represents the initial value of the i-th country's j-th index. The measurement units of each index are different. In order to eliminate the influence of different units, we standardize the matrix. The standardized formula is as follows.

$$z_{ij}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{n}{x_{ij}}^2}} \tag{2}$$

Through the above calculation we can get a standardized matrix Z.

$$Z=\begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1j} & \cdots & z_{1m} \\ z_{21} & z_{22} & \cdots & z_{2j} & \cdots & z_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ z_{i1} & z_{i2} & \cdots & z_{ij} & \cdots & z_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ z_{n1} & z_{n2} & \cdots & z_{nj} & \cdots & z_{nm} \end{bmatrix}(n=1,2,\cdots,12;m=1,2,\cdots,10) \tag{3}$$

Step 2: Calculate the proportion of the country i under the index j.

$$p_{ij}=\frac{z_{ij}}{\sum_{i=1}^{n}z_{ij}} \tag{4}$$

Then the information entropy and information utility value of the index j is obtained. Information entropy is a measure of uncertainty, and its essence is the expected value of information. The information utility value is also called information entropy redundancy, which is simply the repetition rate of information. The calculation formulas of the two are as follows:

$$e_j=-\frac{1}{\ln n}\sum_{i=1}^{n}p_{ij}\ln(p_{ij})\,(n=12;j=1,2,\cdots,10) \tag{5}$$

$$d_j=1-e_j \tag{6}$$

After the normalization of the utility value, we can get the weight of each index W_j.

$$W_j=\frac{d_j}{\sum_{j=1}^{m}d_j}(j=1,2,\cdots,10) \tag{7}$$

The specific weight results are shown in the following table. The weights calculated here will be used to calculate the score in TOPSIS comprehensive evaluation.

Table 2. Weights of indicators at all levels in IOE model

Indicator(Ⅰ)	Indicators(Ⅱ)	Weights	Indicators(Ⅲ)	Weights
Input	Science and technology	0.0520	Research and development	0.5083
			Industrial equipment	0.1560
			Electronic science	0.3357
	Traffic	0.7326	Airlift	0.2391
			Land carriage	0.3772
			Water transport	0.3837
	Workforce	0.0555	Manual worker	0.0329
			Technical personnel	0.9671
	Energy consumption	0.1598	Unprocessed energy	0.3283
			Processed energy	0.6717

Step 3: Define the best and worst solution for each indicator. The optimal value consists of the maximum value in each column.

$$Z^{+}=(Z_1^{+},Z_2^{+},\cdots,Z_m^{+})=(\max\{z_{11},z_{21},\cdots,z_{n1}\},\max\{z_{12},z_{22},\cdots,z_{n2}\},\cdots,\max\{z_{1m},z_{2m},\cdots,z_{nm}\})$$
$$(n=1,2,\cdots,12;m=1,2,\cdots,10) \tag{8}$$

The worst value consists of the minimum in each column.

$$Z^{-}=(Z_1^{-},Z_2^{-},\cdots,Z_m^{-})=(\min\{z_{11},z_{21},\cdots,z_{n1}\},\min\{z_{12},z_{22},\cdots,z_{n2}\},\cdots,\min\{z_{1m},z_{2m},\cdots,z_{nm}\})$$
$$(n=1,2,\cdots,12;m=1,2,\cdots,10) \tag{9}$$

Then on the basis of W_j, the distance between each country and the optimal value and the worst value is calculated respectively.

$$D_i^{+}=\sqrt{\sum_{j=1}^{m}W_j\left(Z_j^{+}-z_{ij}\right)^2} \tag{10}$$

$$D_i^{+}=\sqrt{\sum_{j=1}^{m}W_j\left(Z_j^{+}-z_{ij}\right)^2} \tag{11}$$

Eventually, we can get the proximity between each country and the optimal solution.

$$S_i=\frac{D_i^{-}}{D_i^{+}+D_i^{-}}\,(0\leqslant S_i\leqslant 1) \tag{12}$$

IOEI for each country is obtained after normalization.

4.3 Results of IOEM

We construct the IOEM, and by designing the corresponding algorithm, we obtain the closeness between countries and the optimal value of comprehensive national strength. After sorting, the specific results are shown in the figure below.

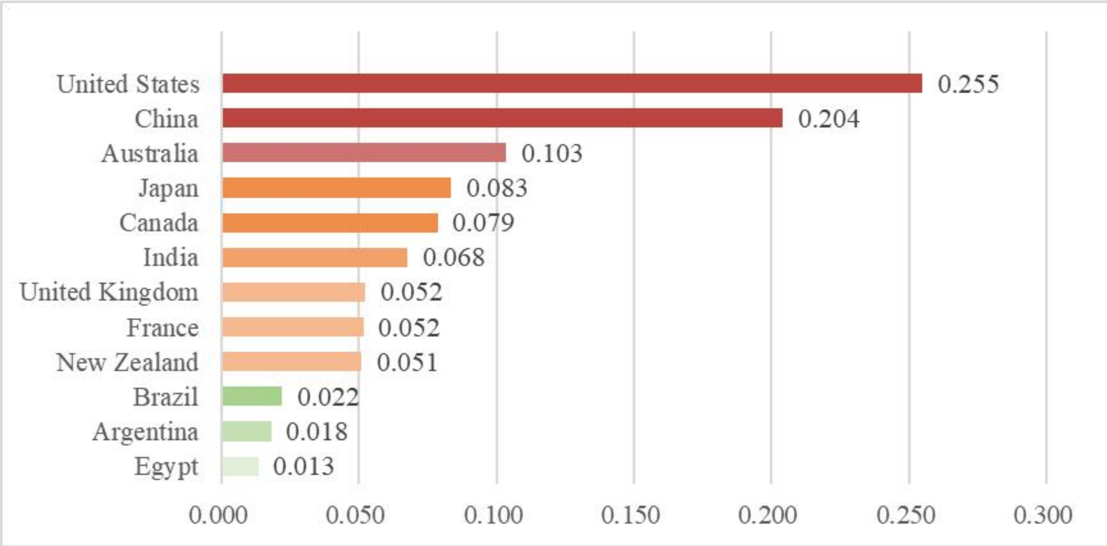

Figure 3. Countries sorted by IOEI values

From the above figure, we can see that two countries are closer to the optimal value, which is more than 0.2, and 10 countries are less than 0.2. The country with the highest approximation to the optimal value is the United States, with a value of 0.255. The country with the lowest approximation value is Egypt, with a value of 0.013. Finally, we compare the total GDP of twelve countries with the ranking results, and draw the following line chart.

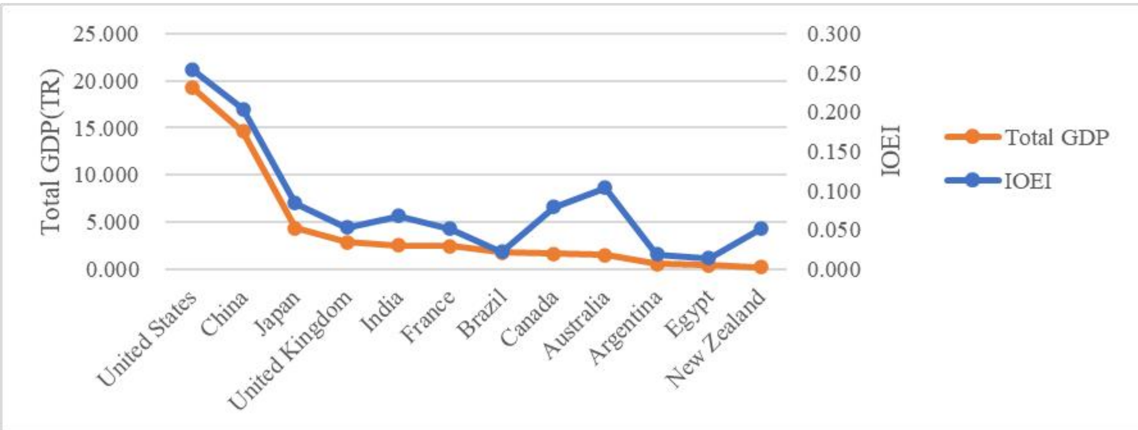

Figure 4. The fitting diagram of IOEM results

From the line chart, we can see that the ranking results are consistent with the overall trend of GDP, so we can approximately believe that a country' s construction investment in all aspects will eventually be in the form of national strength. The more input is, the stronger the national strength is. There is a balanced relationship between the two, and the global equity is skillfully maintained.

5. Asteroid Mining Model

5.1 The Establishment of Asteroid Mining Model

Firstly, we need to understand the whole process of asteroid mining. Compared with the current mining process of coal, iron ore and other minerals on the earth, the whole process includes three parts: Scientific Research (SR), Exploitation of Mineral (EM) and Aeronautics and Astronautics (AA). Therefore, we selected data from science and technology research, mining industry and aviation industry to analyze the future vision of asteroid mining and its impact on global equity.

In our model, we define an Asteroid Mining

Index to characterize the development of the Asteroid Mining industry in the country. The index is composed of the above three factors. The formula is as follows:

$$AMI = \varepsilon_1 SC + \varepsilon_2 EM + \varepsilon_3 AA \tag{13}$$

Where ε_1, ε_2, ε_3 are the coefficients of the variables.

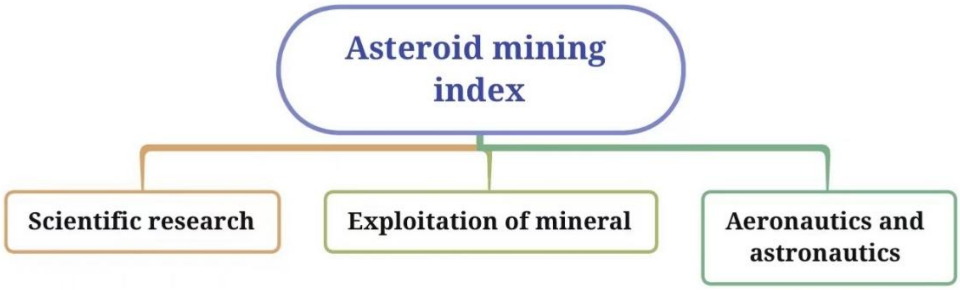

Figure 5. The components of AMI

- Scientific Research

In the context of a new round of scientific and technological revolution and industrial transformation, the mining industry has shown an accelerating trend towards remote operations: the high speed, reliability and connectivity brought by advanced communication technologies such as 5G enable mining enterprises to better leverage massive amounts of data from equipment, assets and applications. Advances in artificial intelligence and other cutting-edge technologies promote mineral exploration and discovery. Industrial Internet of Things technology will revolutionize mine operations (Hein A M, Matheson R & Fries D., 2020). The future of "space commerce" is based on scientific innovation, which determines the upper limit of human exploration. For this data, we choose the proportion of national expenditure on scientific research in GDP as the representative data of scientific research.

- Exploitation of Mineral

Mining expenditures include direct materials, direct wages, other direct expenditures and manufacturing costs actually consumed in the process of extracting the raw ore. The administrative expenses incurred by the administrative department of an enterprise in managing and organizing business activities, the financial expenses incurred in raising funds, and the sales expenses incurred in selling products are all period expenses. As an intermediate part of the asteroid mining process, this part will have a significant influence on the entire mining process. We collect the economic expenditure on mining in each country on the website as an indicator.

- Aeronautics and Astronautics

Unlike cargo transport on earth, asteroid mining involves space transportation. This requires technical support from the aviation industry. In the future, it may be necessary to assemble spacecraft, build bases and build cables in space. Therefore, the development of aerospace cannot be ignored. In the future, the roadmap of space transportation systems will be formulated to realize innovative future space transportation systems and produce more achievements in space transportation system development. We collect the aeronautics and astronautics expenditure of each country on the website as an indicator.

5.2 The Calculation of Weights

Analytic Hierarchy Process (AHP) is a systematic and hierarchical multi-objective comprehensive evaluation method. According to the nature of the problem and the goal to be achieved, the problem is decomposed into different constituent factors, and assembles the factors at different levers according to the correlation between factors and the membership relationship, forming a multi-level analysis structure model, so as to ultimately attribute the problem to the determination of the relative importance weights of the lower level relative to the higher level or the arrangement of the relative order of advantages and disadvantages. In our model, we use analytic hierarchy process to determine the weight of AMI. The process is as follows:

Step 1: After extensive access to information, we determined our judgment matrix $(X_{ij})_{3\times 3}$

$$X = \begin{bmatrix} 1 & 3 & \frac{1}{4} \\ \frac{1}{3} & 1 & \frac{1}{8} \\ 4 & 8 & 1 \end{bmatrix} \tag{14}$$

Where X_i for $i = 1, 2, 3$ represents AA, EM, SR respectively.

Step 2: Consistency Test

We use the maximum eigenvalue $\lambda_{\max}$ to get CI (coincidence indicator) and CR (inconsistency ratio) to conduct consistency test. By using MATLAB, we can obtain $CI = 0.0153$, $CR = 0.0294$. Because $CR < 0.10$,the consistency of the judgment matrix X is acceptable.

Step 3: Using arithmetic average method, geometric average method, eigenvalue method to calculate the weight as follows:

$$W(SC, EM, AA) = (0.7158, 0.0792, 0.2051) \tag{15}$$

So AMI can be expressed as:

$$AMI = 0.7158SC + 0.0792EM + 0.2051AA \tag{16}$$

5.3 Applying AMM to Forecast

Fitting is to use a model (or equation) to fit a series of data into a line in order to observe the internal relationship between the two groups of data and understand the changing trend between the data. In data analysis, we sometimes need to predict future data through existing data, and then we can use simple fitting to predict future data.

We choose China and Colombia to forecast. As one of the countries with development potential in the world, China has made great achievements in economy, scientific and technological innovation, and aerospace in recent years. Colombia has a medium level of development in Latin America, and its economy has maintained continuous growth for nearly ten years. The international community is generally optimistic about the long-term development prospects of Colombia. We refer to the expenditure of the two countries on scientific research, mining and aviation from 2016 to 2020, and put these data into the formula to calculate AMI.

Table 3. Data of the two countries

AMI	2016	2017	2018	2019	2020
China	0.396	0.431	0.444	0.447	0.491
Colombia	0.335	0.371	0.439	0.505	0.548

The specific solving steps are as follows:

Step 1: make the scatter diagram of the index, the results are as follows:

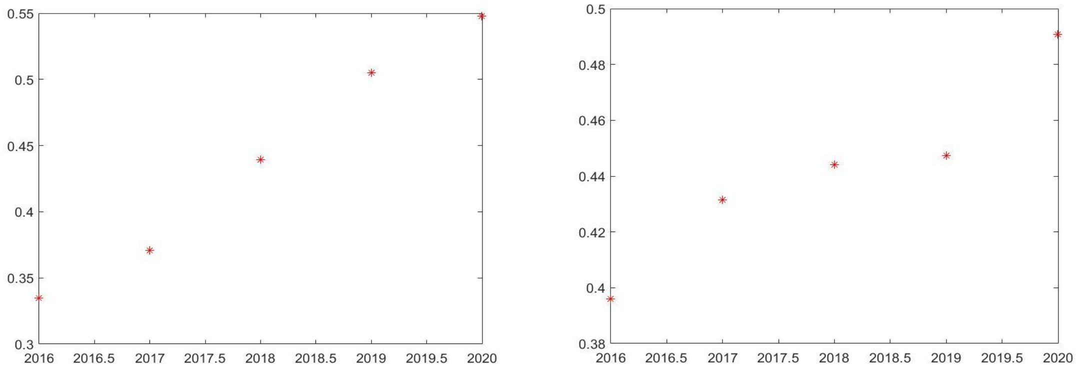

Figure 6. The scatter plot obtained according to the known AMI

Step 2: Using the least square method, according to its definition:

$$\hat{y}_i = kx_i + b$$

$$\hat{k}, \hat{b} = \underset{k,b}{arg\min}\left(\sum_{i=1}^{n}(y_i - \hat{y}_i)^2\right) \tag{17}$$

Then we use MATLAB to get $k_1 = 0.05599, b_1 = -112, k_2 = 0.02057, b_2 = -41.06$ The fitting results are as follows:

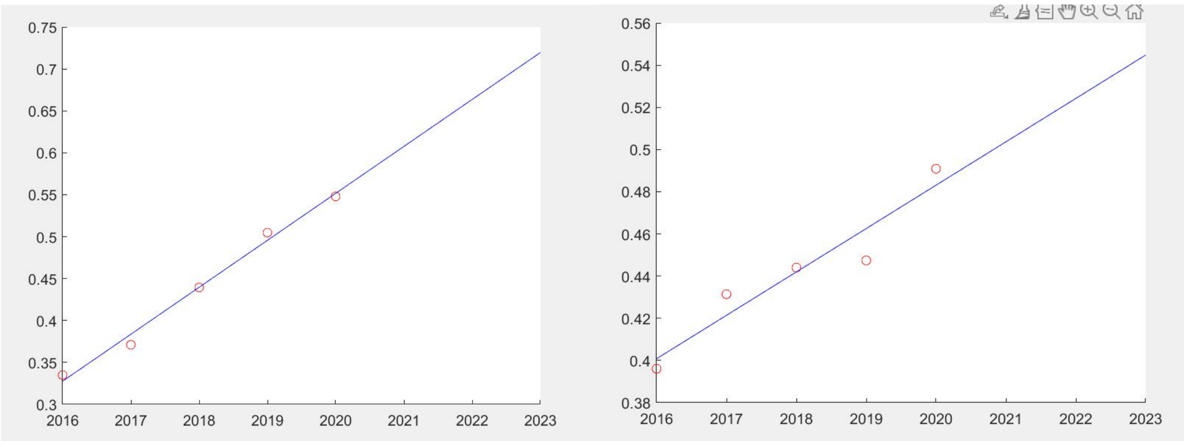

Figure 7. MATLAB fitting results

According to the fitted curve equation, the predicted values for the next three years are summarized as follows:

Table 4. Summary of forecast values

AMI	2016	2017	2018	2019	2020	2021	2022	2023
China	0.396	0.431	0.444	0.447	0.491	0.503	0.524	0.545
Colombia	0.335	0.371	0.439	0.505	0.548	0.608	0.664	0.720

Through data and prediction, we can find that the development index of asteroid mining industry in China and Colombia, two more representative countries, shows an upward trend from 2021 to 2023 and has good prospects for development. With China as the representative of a relatively strong power, the AMI index will grow steadily in the future. In emerging countries like Colombia, the AMI index will rise faster. If the investment in this area can be maintained, it may bring more economic value to the country.

5.4 Impacts of Asteroid Mining on Global Equity

For the issue of how asteroid mining affects global equity, we select three main variables, AA, EM and SR. Because exploitation of mineral is the driving force for countries to travel to asteroid mining, aeronautics and astronautics is the necessary hardware requirement for landing on the planet, and scientific research is strong support. These three are more persuasive in predicting and explaining the area of asteroid mining in three different ways.

We use the cluster analysis method to select five representative countries, so that they are almost all over every continent with population living in the world, which can more generally explain the relationship between asteroid mining and global equity.

Next, we will combine the two models of asteroid mining and global equity for analysis. Recalling the previous IOEM, we use ten indicators to evaluate global equity, and AMM is divided into exploitation of minerals, aeronautics and astronautics and scientific research.

Step 1: Data analysis is conducted on the exploitation of minerals, aeronautics and astronautics, scientific research and the equity index. The results are as follows:

Table 5. Data analysis

	AA	EM	SR	IOEI
Average	8.11E+10	1.69E+11	1.8474889	0.136433
Standard error	4.3E+10	1.19E+11	0.3348741	0.039646
Median	2.22E+10	5.9E+10	1.9955556	0.103483
Standard deviation	9.62E+10	2.65E+11	0.7488013	0.088652
Variance	9.26E+21	7.04E+22	0.5607034	0.007859
Peak	-3.22435	4.001373	1.3739389	-2.12932
Deviation	0.598917	1.982278	-0.718013	0.602699
Region	1.9E+11	6.28E+11	2.0427778	0.202337
Min	3.69E+09	3.86E+09	0.7083333	0.05239
Max	1.93E+11	6.32E+11	2.7511111	0.254727
Sum	4.05E+11	8.46E+11	9.2374444	0.682167
Observations	5	5	5	5

Then in order to obtain the relationship between asteroid mining and fair model, we use the method of correlation analysis to analyze whether there is a linear relationship between the three factors of AMM and IOEM.

Step 2: Using Pearson correlation coefficient method, the principle is as follows:

Assuming two sets of data $X\colon\{X_1, X_2, \cdots, X_n\}$ and $Y\colon\{Y_1, Y_2, \cdots, Y_n\}$

Sample average:

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \qquad \bar{Y} = \frac{\sum_{i=1}^{n} Y_i}{n} \tag{18}$$

Sample covariance:

$$Cov(X,Y) = \frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)\left(Y_i - \bar{Y}\right)}{n-1} \tag{19}$$

Sample $Pearson$ correlation coefficient:

$$r_{XY} = \frac{Cov(X,Y)}{S_X S_Y} \tag{20}$$

Where: S_X is the sample standard deviation of X, the formula is as follows, the same as S_Y.

$$S_X = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}{n-1}} \tag{21}$$

We use MATLAB for correlation analysis and summarize the data to obtain the results.

Table 6. Results of correlation analysis

	AA	EM	SR	IOEI
AA	1.0000	0.6408	0.6197	0.9290
EM	0.6408	1.0000	-0.0252	0.4155
SR	0.6197	-0.0252	1.0000	0.7598
IOEI	0.9290	0.4155	0.7598	1.0000

From the correlation coefficient table, we can intuitively see that many indicators of asteroid mining have a large correlation coefficient with the equity index, which means that the asteroid mining field has a great influence on the global equity model.

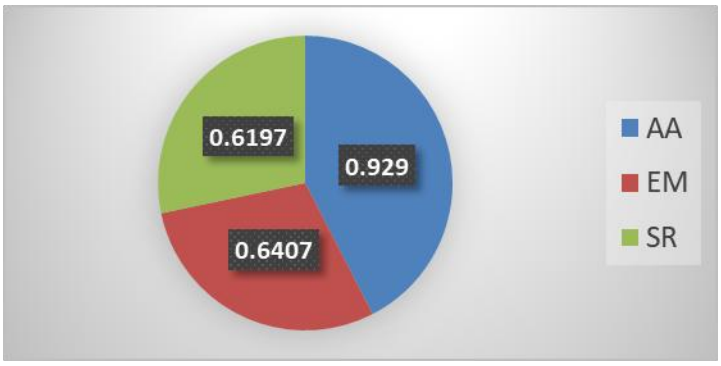

Figure 8. Pearson Correlations pie chart

It can be seen that although asteroid mining is a new field and there are many unknown conditions at present, such as which countries will be engaged in mining in the future, how the United Nations will finance the operation of these projects, and which countries will gain profits from it. These will not be known until asteroid mining becomes a reality, but what we can determine is that its development will inevitably affect the global equity model in the future.

In the table, we can see that the correlation coefficient between AA, EM, SR, especially the correlation coefficient between AA and IOEM index is 0.9290. Therefore, we can reasonably predict that spacecraft and aviation levels as important hardware facilities and foundations for asteroid mining will have a significant impact on the global equity index and will be an important basis for future resource allocation and equity. Other conditions in EM and SR will also have a certain impact on the equity index.

6. Solution of Problem Three

As for how the asteroid mining sector will affect global equity in the future, we choose the three indicators SC, EM and AA in the second question as conditions and conduct multiple linear regression analysis with the indicators in the IOE model to find the internal relationship between them, in order to explore how asteroid mining specifically affects global equity.

6.1 Multiple Linear Regression Analysis

Suppose the independent variables x_1, x_2, x_3 and dependent variables y meet the formula:

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \mu \tag{22}$$

In this formula, $\beta_1, \beta_2, \beta_3$ are the coefficients of the variables.

We are going to build two regression models. The first is to establish a regression model with IOEI as the dependent variable and SR, EM, AA as independent variables to observe the impact of changes in the mining sector on the equity index from the overall macro perspective. The second one uses ten indicators in IOE model as dependent variable, SR, EM, AA as independent variables to establish a regression model, to explore how the mining sector changes affect the equity index in different ways. In the two models, the variables are quantitative indicators.

6.1.1 Regression Model 1

First of all, we take AA, EM, SR as independent variables, IOEI as the dependent variable to carry out the regression analysis from the macro aspect.

Step 1 Based on the above analysis, we draw bubble diagrams to see the correlation. It is found that there is a strong linear relationship between AA, SC and IOEI. Just as the following figure shows:

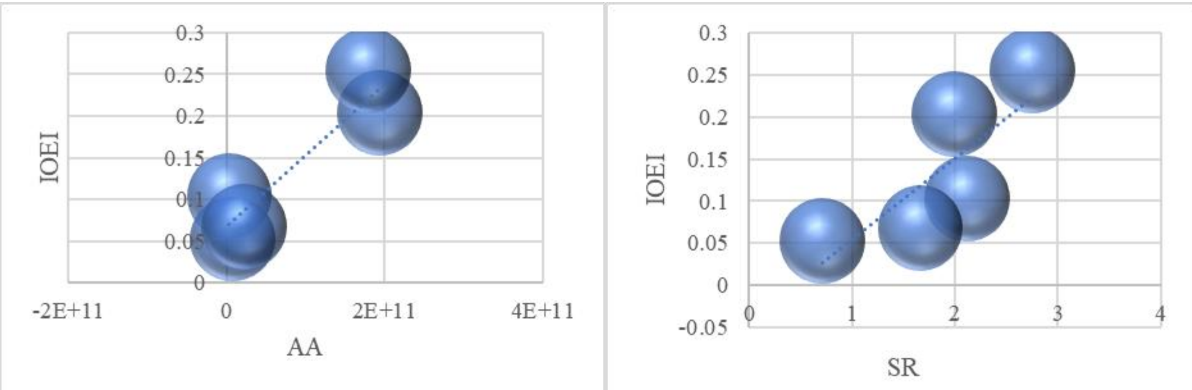

Figure 9. Correlation bubble diagram

Step 2 Due to the two indicators AA, EM data derive from the country's economic investment in aerospace and mining, so we take the data logarithmically. The adjusted regression equation is:

$$y = \beta_1 \ln x_1 + \beta_2 \ln x_2 + \beta_3 x_3 + \mu \tag{23}$$

Step 3 Next, we analyze the variance of this model.

Suppose the original assumption: $H_0: \beta_1 = \beta_2 = \beta_3 = 0$

Table 7. Analysis of variance data

Source	SS	df	MS	F(3,1)=26.77

Model	0.03105	3	0.01035	Prob>F=0.0409
Residual	0.000387	1	0.000387	R-squared=0.9877
Total	0.031437	4	0.007859	Adj R-squared=0.9508

We can find the joint test of visibility Prob > F = 0.0409 < 0.05, so at the 95 % confidence level we reject the original assumption and believe that the coefficient is not zero. And at the same time R^2 = 0.9877, $R^2{}_{adjusted}$ = 0.9508, which are close to 1, so the regression effect is good.

According to the results of the hypothesis test, we can see that the prob value is less than 0.05, and the hypothesis does not pass. Therefore, we can think at the 95 % confidence level that we can reject the original hypothesis $H_0:\beta_1=\beta_2=\beta_3=0$, so we conclude that the regression coefficient is significantly not zero.

Step 4 Regression analysis of data with the linear regression function of Stata.

Table 8. Regression results table

IOEI	Coef.	Std.Err.	t	P>t	[95%Conf.Interval]
EM	0.004462	0.010768	0.41	0.75	[-0.13236, 0.1412824]
AA	0.020164	0.007316	2.76	0.122	[-0.07279, 0.1131211]
SR	0.09877	0.021296	4.64	0.035	[-0.17182, 0.3693607]
_cons	-0.64501	0.142957	-4.51	0.139	[-2.46146,1.17143]

So we got the formula:

$$y=0.004462\ln x_1+0.020164\ln x_2+0.09877x_3-0.64501 \tag{24}$$

6.1.2 Regression Model 2

Then, we use the AA, EM, SR as independent variables, industrial equipment, electronic science, airlift and other indicators that have an impact on the IOEI as dependent variables to carry out the regression analysis from the micro aspect.

Step 1: Similarly, we take logarithms of the two variables of AA and EM.

Step 2: We use the hypothesis testing to test whether these dependent variables and independent variables fit the regression model. After testing, the p value of electronic science and technical personnel is less than 0.05, the hypothesis does not pass. Therefore, we can believe that we can reject the original hypothesis at the 95 % confidence level, so we conclude that the regression coefficient is not zero.

Step 3: Regression analysis of data with the linear regression function of Stata.

Table 9. Regression result of electronic science

IOEI	Coef.	Std.Err.	t	P>t
AA	18.95229	2.277092	8.32	0.076
EM	8.926153	1.547084	-5.77	0.409
SR	33.73383	4.503433	-7.49	0.084
	127.056	30.23097	-4.2	0.149

So we can get formulas for electronic science, AA and SR:

$$y=8.926153\ln x_1+18.95229\ln x_2+33.73383x_3+127.056 \tag{25}$$

Table 10. Regression result of technical personnel

IOEI	Coef.	Std.Err.	t	P>t
AA	174.249	1325.044	-1.34	0.408
EM	94.7138	900.2508	1.06	0.181
SR	25.409	2620.555	1.1	0.071
	170.37	17591.45	0.97	0.511

So we can get formulas for technical personnel, AA and SR:

$$y = 94.7138 \ln x_1 + 174.249 \ln x_2 + 25.409 x_3 + 170.37 \quad (26)$$

To summarize, combined with the macro and micro analysis, the impact of asteroid mining on the IOEI is mainly reflected in the two indicators of aeronautics and astronautics and scientific research, and the impact on the IOEI is realized through the impact of electronic science and technical personnel. We can conclude that the development of asteroid mining industry will indirectly affect our fairness research model through the impact on electronic science and technical personnel. It is not difficult to find that computer technology and scientific research have great impacts on the global equity.

7. Policy Recommendations

The Outer Space Treaty of 1967 has been the subject of international law governing outer space since the space era. It is a constitutional document regulating outer space activities and establishes the basic principles applicable to all outer space activities. However, there are no direct laws and regulations on the exploitation of asteroid resources in current international law, so it is necessary to update the Outer Space Treaty.

In order to solve the asteroid mining problem and ensure its benefits to all humankind, we put forward the following policy recommendations:

- Establishing an excitation mechanism

Space is often called 'the last frontier', and further exploration of space is regarded as the next step of human development. Rare precious metal resources on asteroids are much richer than on earth. Therefore, from the perspective of the community of shared future for humankind, the development and exploration of space resources are undoubtedly more conducive to human survival and development.

Therefore, the United Nations should put forward corresponding incentive policies to promote the development of asteroid mining. According to our analysis of the second and third questions above, in order to promote the development of asteroid mining and truly achieve global equity, the most important driving force is the development of advanced electronic technology and the cultivation of scientific research talents. The United Nations must take certain measures to stimulate the development of both.

- Establishing a sharing mechanism

The provisions of 'everyone benefits' in Outer Space Treaty are based on the principle of fairness. In this case, the principle of fairness means reciprocity and sharing. Such sharing is not the involvement of certain countries with aviation capabilities in the financing and development of natural resources in outer space and celestial bodies, while other countries simply await equal resource allocation. Developing countries should not only be willing to benefit from space activities in developed countries, but should also make relevant contributions to space activities, such as the provision of natural laboratories, food research and production, which in turn would make sharing particularly equitable. We particularly agree with the view that each country, especially developed countries are responsible for another country (Giuseppe Reibaldi, September 8, 2020). In this mode, the global countries are connected into a community, and each country should not only pay attention to the exploration and utilization of space by individuals but also pay attention to how the global human society benefits from space.

- Establishing a cooperation mechanism

Nowadays, international cooperation in space missions is quite common, but cooperation usually occurs among developed space countries. This leads to other countries, especially developing countries, being dissatisfied with their lack of participation in international space cooperation. In updating the Outer Space Treaty, the United Nations should consider joining a cooperative mechanism between developed space countries and non-space and less developed countries. After all, there is a close relationship between prosperity in developed countries and growth and development in developing countries. Developed space countries can provide funds and technologies for the development of space resources, while developing countries with insufficient capacity in space or science and technology can provide mining labor and later processing (Okezie P., 2021). According to the first IOE model, both countries have invested in this aspect, which in turn is a kind of capacity building for both countries and the whole mankind.

- Adhering to the concept of sustainable development

Resources from space play an important role in complementing supply on earth, but the use and allocation of space resources must be undertaken in a responsible and sustainable manner. When updating the Outer Space Treaty, the United Nations must consider the impact of mining activities on the external environment, prevent excessive exploitation and premature depletion of resources, so that asteroid mining can be truly sustainable / ensure the sustainability of development. Similar to many production activities on the earth that require producers to obtain licenses, the United Nations can introduce this way, the licenses will be managed by a specific agency, and a certain royalty fee. This can, to a certain extent, limit exploitation, while the fees charged can be used to help low-income countries develop.

Finally, by consulting a large amount of information, we have preliminarily estimated the timeline for the development of asteroid mining based on the degree of difficulty achieved at each stage and mapped the following timeline, hoping to provide some reference for the United Nations to update the Treaty.

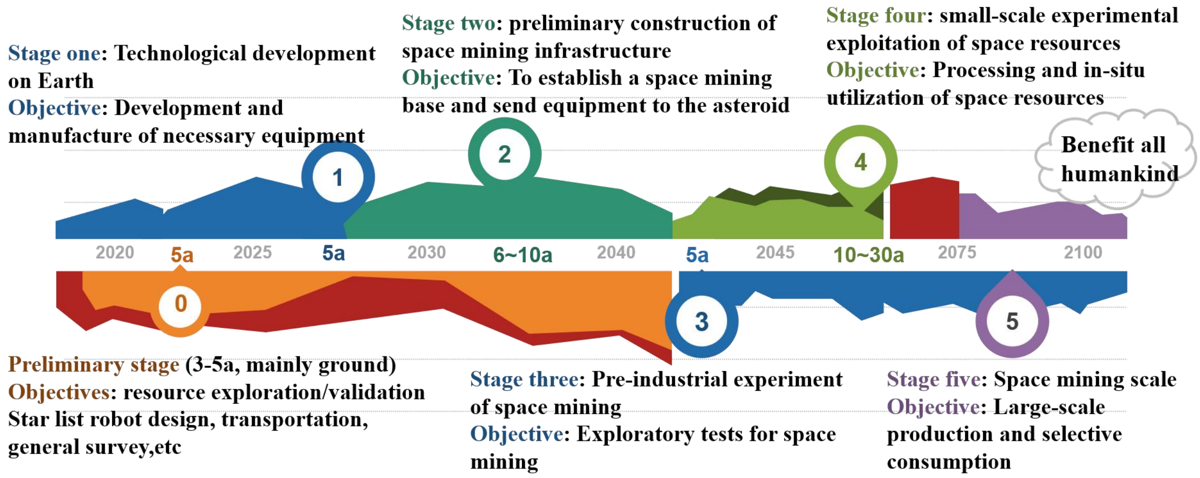

Figure 10. Schedule of asteroid mining development

8. Sensitivity Analysis and Error Analysis

8.1 Sensitivity Analysis

In problem two, we use TOPSIS comprehensive evaluation based on entropy weight method to obtain the closeness of twelve countries to the optimal solution. Now we do sensitivity analysis for IOEM. The specific methods are as follows: Canada is selected as the research object, the weight of each index is fixed, and the value of each index is gradually increased to observe the change of its proximity to the optimal solution (fairness index). The faster the index changes, the higher the sensitivity of the model. On the contrary, the slower the evaluation score changes with the index value, the lower the sensitivity of the model. The following figures represent the sensitivity of the index in Industrial equipment and technical personnel.

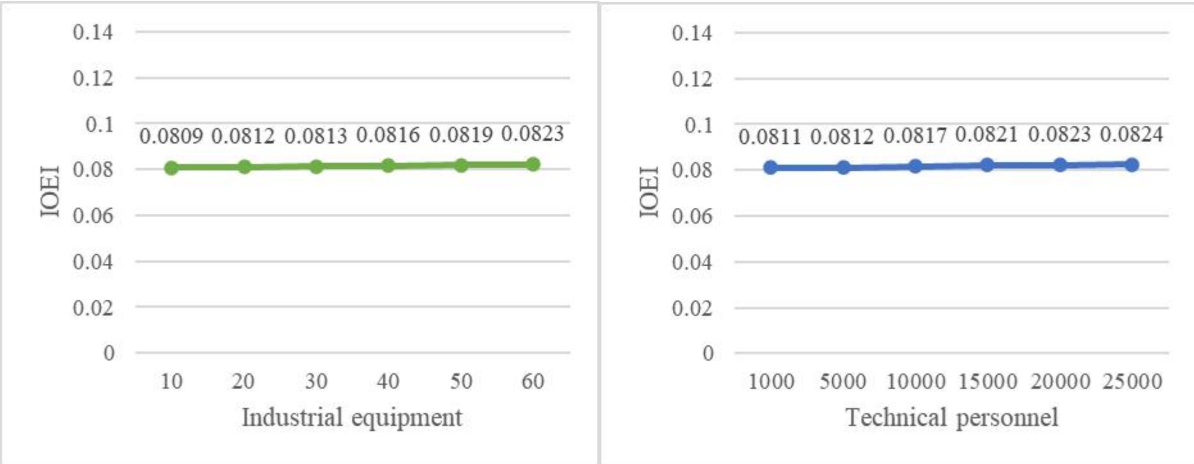

Figure 11. Sensitivity plot of two indicators

As can be seen from the above chart, the score results are not very sensitive to the change of a single index. If you want to significantly improve the evaluation score, you need to improve a number of indicators at the same time, which corresponds to the country's need to develop policies in all aspects to promote the progress and development of various industries to improve the equity index.

8.2 Error Analysis

In problem two, we selected two countries, China and Colombia, to make projections using data for proposed merger. The fitting accuracy is shown in the following table:

Table 11. Fitting accuracy of two countries

Countries	SSE	R-square
Colombia	0.0003107	0.9902
China	0.0004162	0.9104

The closer SSE is to zero, the smaller the error is, the better the fitting effect is. The closer R^2 is to 1, the closer the sum of squares of error is to 0, the better the fitting effect is. It can be seen that using linear regression, the fitting curve fitting effect of Colombia is better, and the fitting curve R^2 of China is smaller, and the fitting effect is general. Considering the poor fitting effect of prediction curve in China, the fitting curve in China can be optimized by MATLAB CFTOOL to obtain better optimization results.

9. Model Evaluation and Further Discussion

9.1 Strengths

- We model global equity in terms of workforce, science and technology, traffic and energy consumption, fully identifying and basically covering key aspects of national construction inputs.
- We quantify indicators such as national comprehensive strength and fairness, and show them in the form of charts after sorting, which can reflect the results of the model more intuitively and vividly.
- TOPSIS comprehensive evaluation based on entropy weight method avoids the subjectivity of data and ensures the objectivity and applicability of the evaluation system.
- In predicting the future vision of asteroids, we selected China and Colombia as our analysis objects, but our model also applies to any other country and is of universal significance.

9.2 Weaknesses

- Due to the lack of the latest data, we use the data from 2020 and before to predict the future development of asteroids. The predicted results of 2021 may deviate from the reality.
- Some parameters used in the model are obtained subjectively. Although we have taken many government reports and development of other countries into account, the parameters seem subjective to some degree.
- We set several assumptions, so the whole model is a bit idealized.

9.3 Further Discussion

- If we can search for more comprehensive data, the future vision of asteroids we predict will be better and more accurate.
- In the future, we hope to consult relevant research and policy experts and add more evaluation indicators to our model to help us put forward more practical and constructive suggestions.

10. Conclusion

This paper establishes a model to validate global equity and a model to comprehensively evaluate the asteroid mining sector and specifically describes the future vision of asteroid mining. Using IOEM, we confirm that in today's international environment, a country's input in all aspects of construction and output represented by comprehensive national strength is basically balanced. So we have reason to conclude that the world today is basically in a state of global equity. At the same time, according to the prediction results, we can believe that the asteroid mining industry has ushered in unprecedented development opportunities. Finally, based on the above two models, we link asteroid mining with global equity. Asteroid mining will affect several key factors in the global equity model, thereby affecting global equity. We write this article and put forward relevant policy suggestions, hoping to help the United Nations better deal with global issues and benefit all mankind.

References

Gapminder. (n.d.). The data of ten indicators. Retrieved from https://www.gapminder.org/data/.

Giuseppe Reibaldi. (September 8, 2020). (President of the moon association) on MVA webinar Series: Governance of Global Moon Exploration and Settlement, Episode 3—Sharing Benefit of Lunar Activities.

Hein A M, Matheson R, Fries D. (2020). A techno-economic analysis of asteroid mining. *Acta Astronautica*, 168, 104-115.

Okezie P. (2021). Addressing Proprietary Rights Issues in Outerspace. *New Space*, *9*(4), 257-265.

Rodrik D. (2017). Is global equality the enemy of national equality? *HKS Working Paper.*

United Nations. (n.d.). The data of SR, AA and EM. Retrieved from https://data.un.org/.