Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
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For you? For me? For us!

Summary

The United Nations (UN) aims to promote global peace and reduce inequality. In 1967, most countries in the world signed the United Nations' Outer Space Treaty and made fair international commitments. With the development of science and technology, asteroid mining can enable mankind to bring valuable minerals back to the earth at a relatively safe cost at some time in the future, which can bring huge profits to mankind, but it is bound to have an impact on global equity. The purpose of this report is to establish a quantitative model of global equity to assess global equity. We hope to describe the possible situation of asteroid mining in the future and analyze the impact of different situations on global equity, so as to make policy recommendations for the United Nations to promote the development of asteroid mining industry in a way that promotes global equity. Therefore, we have established three models: model 1: Global Equity Model, model 2: Economy Benefit-Cost Analysis Model and model 3: Economic Growth Model.

For model 1, we use **analytic hierarchy process** to conduct a comprehensive evaluation of countries around the world by analyzing the four factors of **politics**, **economy**, **safe and stable** and **education**. Under each sub factor, we set 3 to 5 indicators respectively. By solving the variance of the comprehensive evaluation of countries all over the world, we get the quantitative index of the differences in development of countries all over the world. We call this quantitative index GIEI. Using the K-means model to cluster the difference quantitative index, we can divide the fairness of the world into four levels. We can judge the level of global equity through the quantitative indicators of differences calculated by model 1.

For model 2, we consider the cost and economic benefits of asteroid mining, so as to obtain the net profit of asteroid mining. At the same time, we also considered whether to participate in asteroid mining, the proportion of profits each country can get from participating in asteroid mining and the taxes paid for asteroid mining. Based on this model, we propose a possible vision for future asteroid mining. By bringing it into model 1 for analysis, we prove that the original scene is beneficial and global equity.

For model 3, by introducing capital, labor factors and the corresponding elastic output elasticity coefficient, we link the income of countries after asteroid mining with national economic growth. By changing parameter ν in model 2, the impact on global equity is analyzed.

After analyzing the impact of asteroid mining on world equity, we put forward some policy proposal for the United Nations to solve the problem of asteroid mining. The sensitivity analysis is carried out at the end of the article. It is found that when the output elasticity coefficient of capital ϕ is changed, the trend of the graph reflecting the change of model parameters tends to be consistent.

Keywords: AHP Model; Global Equity; Economy Benefit-Cost Analysis Model

Contents

1 Introduction

1.1 Problem Background

Fairness is an eternal topic, but people's concept of fairness is often vague. Therefore, it is of great significance to establish a comprehensive quantitative and evaluation model of global equity. However, there is no absolute fairness, and people have different understanding of fairness. How to define and quantify global fairness is a problem worthy of consideration. When an unknown world is discovered by human beings, it is obviously unconvincing to understand fairness with human known concepts. Therefore, we need to reconsider this issue. The exploitation of outer space resources is an unknown world. As early as 1967, most countries in the world signed onto the United Nations' Outer Space Treaty and made fair commitments on the development of extraterrestrial resources. Asteroids are rich in mineral resources. In the future, asteroid mining can bring huge benefits to mankind. However, if it is not distributed and handled properly, it will affect global equity and cause political disputes, Even war. In the face of asteroid mining with many unknown conditions, how can we use the relevant policies of asteroid mining to promote global equity and truly benefit mankind. In this article, we will describe global equity and use this model to propose our team's solution to the unknown asteroid mining problem, which is that the emergence of asteroid mining can better benefit all mankind.

1.2 Restatement of the Problem

Considering the background information and restricted conditions identified in the problem statement, we need to solve the following problems:

- Define global equity, develop a model to measure global equity according to this definition, and then verify the model.
- Facing the unknown conditions, this paper puts forward and proves the possible situation of asteroid mining in the future, and uses the global equity model to analyze the impact of asteroid mining on global equity.
- Explore ways in which changes in asteroid mining conditions affect global equity.
- Put forward reasonable policy suggestions so that the asteroid mining industry can promote global equity.

1.3 Our Work

In Section 1.2, we identified four problems to be solved through problem restatement. In order to solve these problems, we have done the following work:

- After analyzing and considering various factors, we give the definition of Global Equity. Based on the definition of Global Equity proposed by us, we have established a Global Equity Model. We have selected politics, economy, security and stability and education as the four main quantitative indicators, and consider the indicators of each

subsystem. Then we can calculate the current Global Inequality Index according to the Global Equity Model.

- In order to better describe the basic vision of future asteroid mining, we established the Economy Benefit-Cost Analysis Model and put forward the possible vision of future asteroid mining. Then, through parameter analysis, its impact on Global Equity is determined.
- The Economic Growth Model is established, and the Economy Benefit-Cost Analysis Model is brought into the Economic Growth Model to obtain the impact of asteroid mining on Global Equity under different parameters.
- Based on the above analysis of the relationship between asteroid mining and Global Equity, we give a series of policy suggestions according to the actual situation.
- Finally, we carry out the necessary sensitivity analysis, and analyze the advantages and disadvantages of our model.

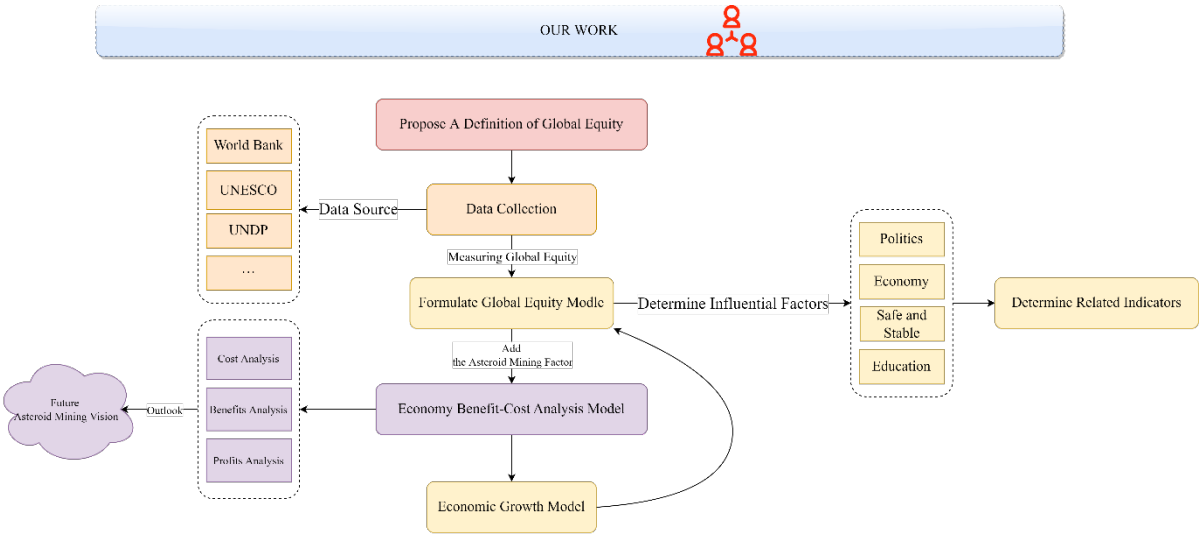

Figure 1 : Our Work

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, each of which is properly justified.

- **Statistics we collect from the website are actual and reliable.**
  Justification: We look up the statistical data on websites such as THE WORLD BANK and UN, so the authenticity and reliability of the data we collect are guaranteed.
- **Global Equity is only related to our evaluation indicators.**
  Justification: Because there are many factors affecting Global Equity, and the established model is very complex and difficult to solve, we only identified the four most important factors for analysis, and other factors will not be considered
- **Within a certain period of time, some indicators can be regarded as constants.**
  Justification: These indicators may fluctuate slightly in the short term, but they are

stable in the long run

- **We will ignore the influence of the extreme events.**
  Justification: We just regard asteroid mining as another way for mankind to obtain energy, and the factor of Force Majeure will not be considered.
- **Asteroid Mining is feasible at some time in the future. Mankind can bring valuable minerals back to earth at a relatively safe cost.**
  Justification: As mentioned in the title, at some time in the future, asteroid mining has become a reality and can be successfully transported back to earth and bring benefits to mankind. Therefore, we make this assumption.

3 Notations

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

Table 1: Notations used in this paper

Symbol	Description	Unit
P_{cor}	Control of Corruption	%
P_{eff}	Government Effectiveness	%
P_{va}	Voice and Accountability	%
P_{law}	Rule of Law	%
P_{reg}	Regulatory Quality	%
E_{Gp}	GDP per capita	$
E_{Gg}	GDP growth rate	%
E_{inf}	Inflation rate	%
E_{mer}	Merchandise trade volume	$
S_{rt}	Refugees and Terrorism	-
S_{coup}	Coup	-
S_{ps}	Political Stability	-
$(ED)_{pt}$	Pupil-teacher ratio	-
$(ED)_{lit}$	Literacy rate	%
$(ED)_{inv}$	Investment in education	%
$(ED)_{years}$	Mean years of schooling	-
ω_i	The ith indicator	-
s^2	Variance	-
$s^2_{(PESE)}$	Variance of PESE score	-
$GIEI$	Global Inequality Index	-

4 Global Equity Model

Considering various factors, we give the definition of global equity as follows:

Global equity means that under the comprehensive consideration of politics, economy, security and stability and education, the comprehensive level difference among countries around the world tends to zero, and people can be in an equal environment and enjoy equal resources and opportunities.

In this part, we evaluate and score each country according to the selected indicators, and then calculate the variance of the evaluation score. The greater the variance, the greater the gap between countries, that is, the more unfair. On the contrary, the smaller the variance, the smaller the gap between countries, that is, the fairer.

We measure the overall situation of a country by using the method of scoring various indicators. Based on the previous assumptions, we determine the corresponding range of each index, and determine the weight of each index through analytic hierarchy process. Through these analyses, the comprehensive situation of a country will be given. In our analysis, we use this method to determine the weight of each main factor and the weight of each index in the factor. Here are the steps.

The main method we use to determine the weight is analytic hierarchy process. **The analytic hierarchy process (AHP)** is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology.

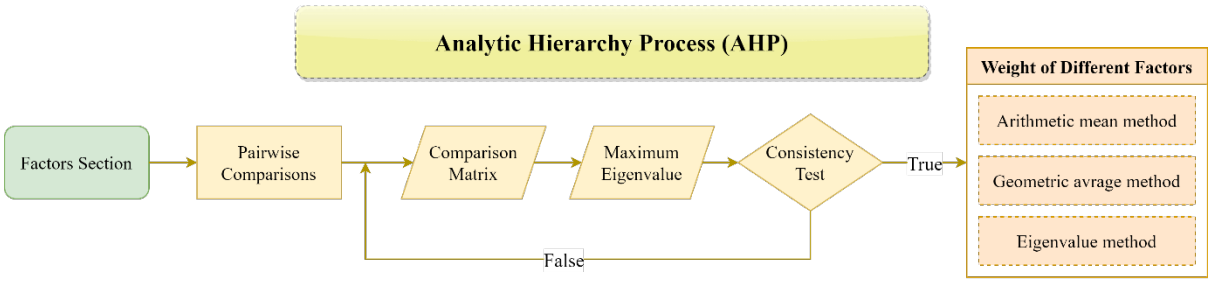

Figure 1 : Analytic Hierarchy Process algorithm diagram

Our Global Equity (GE) model consists of two parts. The first part uses analytic hierarchy process to calculate the value of PESE, so as to reflect the comprehensive scores of countries all over the world. The second part is to find the variance of the comprehensive score to reflect the degree of world unfairness.

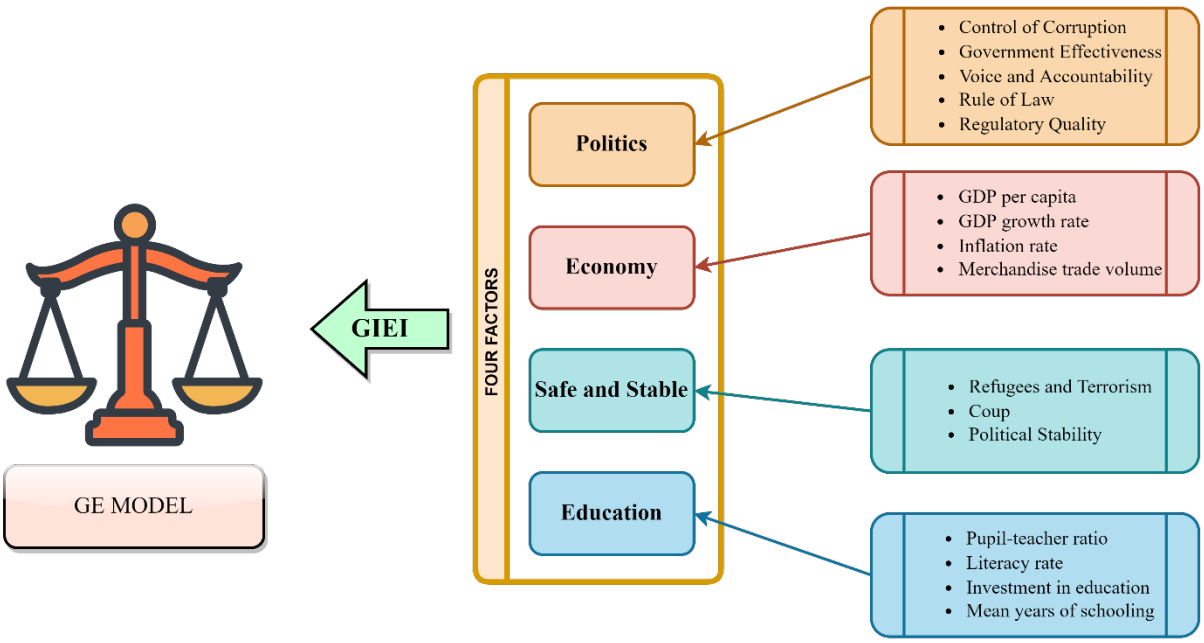

Figure 2 : Tree structure of GE model

4.1 Factors selection

We have selected several main factors previously. They are **Politics, Economy, Safe and Stable and Education**. For each main factor, we have chosen some indicators as well.

- **Politics:**

(1) Control of Corruption

Corruption will reduce the credibility of a government in the eyes of the people, and corruption mostly occurs in the upper class of society, which leads to corruption will inevitably aggravate the social class gap, so as to reduce the fairness of society. Therefore, controlling corruption is an important factor to measure social equity.

(2) Government Effectiveness

The government efficiency of a government determines the efficiency of a government. If the efficiency of a government is very high, the government can provide the necessary help to most people in a limited time, so as to stabilize all sectors of society. On the contrary, if the efficiency of the government is too low, the government will not be able to help most people within a limited time. To a large extent, the government will generally help the upper class first, which will also exacerbate social injustice. Therefore, we use government effectiveness as an indicator to measure world equity.

(3) Voice and Accountability

A government should give citizens the right to speak and make suggestions, which is an important factor to ensure that the government can be in power for a long time. People have the right to put forward their own suggestions to the government, so as to make society more equitable.

(4) Rule of Law

Law is the bottom line. From the community to the United Nations, we should have a code of conduct for fairness, which is another important factor for the long-term normal operation

of our society. For countries and the United Nations, the implementation of the rule of law and the real implementation of the law are the necessary conditions for the existence of justice.

(5) Regulatory Quality

The state should have a strong supervision to crack down on unfair phenomena, which will make the society fairer. Therefore, supervision can be used as an indicator to measure fairness.

The mathematical expression for political indicators in the PESE Model equation has a form of

$$Politics = \alpha_1 P_{cor} + \alpha_2 P_{eff} + \alpha_3 P_{va} + \alpha_4 P_{law} + \alpha_5 P_{reg} \quad (1)$$

where $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ is the weight of each sub index. In Section 1.3, we will discuss its value.

- **Economy:**

(1) GDP per capita

GDP Per capita reflects the overall income level of a country's nationals. If the per capita gross national income gap between countries is too large, it indicates that there is increased inequality among countries. Therefore, per capita GNP can be used as an indicator.

(2) GDP growth rate

The GDP growth rate reflects a country's development potential. The higher the GDP growth rate, the higher the development potential of the country and the better the development prospect.

(3) Inflation rate

Inflation is the devaluation of a country's currency that causes prices to rise. The essential difference between inflation and general price rise: general price rise refers to the temporary, partial and reversible price rise of a certain commodity due to the imbalance between supply and demand, which will not cause currency devaluation; Inflation is a sustained, widespread and irreversible rise in the prices of major domestic commodities that can lead to the devaluation of a country's currency.

(4) Merchandise trade volume

The volume of commodity trade reflects the development level of a country's commodity economy to a certain extent. The higher the volume of commodity trade, the more developed the country's commodity economy can be considered.

The mathematical expression for economy indicators in the PESE Model equation has a form of

$$Economy = \beta_1 E_{Gp} + \beta_2 E_{Gg} + \beta_3 E_{inf} + \beta_4 E_{mer} \quad (2)$$

where $\beta_1, \beta_2, \beta_3, \beta_4$ is the weight of each sub index. In Section 1.3, we will discuss its value.

- **Safe and Stable:**

(1) Refugees and Terrorism

Terrorist attacks are the common enemy of all mankind. In a certain period of time, countries with fewer terrorist incidents can be considered to be safer and more stable to a certain extent.

(2) Coup

Coup is an extremely serious social event. Once a coup occurs, it will have a great impact on people's life and is an important factor affecting social stability.

(3) Political Stability

Similar to the number of terrorist incidents and coups, political stability is conducive to the stable development of society and the further development of social equity.

The mathematical expression for safe and stable indicators in the PESE Model equation has a form of

$$Security = \chi_1 S_{rt} + \chi_2 S_{coup} + \chi_3 S_{ps} \tag{3}$$

where χ_1, χ_2, χ_3 is the weight of each sub index. In Section 1.3, we will discuss its value.

- **Education:**

(1) Pupil-teacher ratio

The larger the Pupil-teacher ratio in a country, to a certain extent, it can be explained that the country pays more attention to education. The proportion of teachers and students is different in different countries, which will lead to different national scientific research reserve forces, and then make the development status of each country different.

(2) Literacy rate

Because some countries are always in war, and children in these countries can not have a good learning environment, the literacy rate of people in these countries is generally low. For other developing countries, some children in these countries cannot go to school because of economic and other pressures, resulting in a low literacy rate, which is unfair to children in these countries. Therefore, literacy can be used as an indicator of world equity.

(3) Investment in education

The comprehensive national strength of developing countries is not strong enough, and they cannot devote more funds to national development in all aspects. The same is true for education. The backwardness of education, coupled with the lack of education funds, makes developing countries lag behind in education, which also exacerbates the inequality of the world. Therefore, we set education investment as an indicator.

(4) Mean years of schooling

Similar to literacy rate and education investment, the mean years of schooling in developing countries is also restricted by economic and other aspects, which will also lead to the shorter average length of education in developing countries, which further exacerbates the inequality in the world. Therefore, we take the average years of education as an indicator of world equity.

The mathematical expression for safe and stable indicators in the PESE Model equation has a form of

$$Education = \delta_1 (ED)_{pt} + \delta_2 (ED)_{lit} + \delta_3 (ED)_{inv} + \delta_4 (ED)_{years} \tag{4}$$

where $\delta_1, \delta_2, \delta_3, \delta_4$ is the weight of each sub index. In Section 1.3, we will discuss its value.

The mathematical expression of the PESE model has a form of

$$PESE = \varepsilon_1 (Politics) + \varepsilon_2 (Economy) + \varepsilon_3 (Security) + \varepsilon_4 (Education) \tag{5}$$

Table 2 : Indicator type table

Factor	Indicator	Symbol	Unit	Impact	D.S.
Politics	Control of Corruption[1]	w_1	%	P	a
	Government Effectiveness[1]	w_2	%	P	a
	Voice and Accountability[1]	w_3	%	P	a
	Rule of Law[1]	w_4	%	P	a
	Regulatory Quality[1]	w_5	%	P	a
Economy	GDP per capita[2]	w_6	$	P	a
	GDP growth rate[3]	w_7	%	P	a
	Inflation rate[4]	w_8	%	B	a
	Merchandise trade volume[5]	w_9	$	P	a
Safe and Stable	Refugees and Terrorism[6]	w_{10}	-	N	b
	Coup[7]	w_{11}	-	N	c
	Political Stability[8]	w_{12}	-	P	a
Education	Pupil-teacher ratio[9]	w_{13}	-	P	a
	Literacy rate[10]	w_{14}	%	P	d
	Investment in education[11]	w_{15}	%	P	a
	Mean years of schooling[12]	w_{16}	-	P	e

Note: D.S. is the abstract of data source. D.S. a is collected from The World Bank. D.S. b is quoted from CHC Global. D.S. c is compiled from Wikipedia. D.S. d and e come from UN, United Nations Educational, Scientific and Cultural Organization (UNESCO) and UNITED NATIONS DEVELOPMENT PROGRAMME (UNDP).

4.2 The value of PESE

4.2.1 Construct comparison matrix

Construct a comparison matrix, pair the selected indicators, and compare the importance of each two groups of indicators. And set the 9 numbers from 1 to 9 to indicate the degree of relative importance. 1 represents equal importance. The larger the number, the more important the former is than the latter. Use the reciprocal of the number to express the importance of the latter to the former, and complete the matrix.

$$A=\begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \tag{6}$$

4.2.2 Consistency Test

After constructing the judgment matrix, the consistency test should be carried out first.

Only after passing the consistency test can the weight be calculated. Otherwise, the elements of the judgment matrix should be changed until they pass the consistency test.

Consistency inspection requires two parameters, namely consistency index (CI) and consistency ratio (CR). The mathematical expression of the two has a form of:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{7}$$

$$CR = \frac{CI}{RI} \tag{8}$$

Where, $\lambda_{\max}$ represents the maximum eigenvalue of the judgment matrix, n is the order of the judgment matrix, RI is the average random consistency index, and its value is related to n, which can be obtained by referring to the table.

If $CR < 0.1$, the consistency of the comparison matrix can be considered acceptable; Otherwise, the comparison matrix needs to be modified.

The results are calculated by MATLAB.

$$(CR)_P = 0.0131 \tag{9}$$

$$(CR)_E = 0.0033 \tag{10}$$

$$(CR)_S = 0.0088 \tag{11}$$

$$(CR)_{(ED)} = 0.0035 \tag{12}$$

$$(CR)_{(PESE)} = 0 \tag{13}$$

All meet $CR < 0.1$. Therefore, the constructed comparison matrix passed the consistency test.

4.2.3 Determine the Weight of Indicators

In this part, we use three methods to calculate the weight of indicators. They are arithmetic average method, geometric average method and eigenvalue method. After obtaining the three groups of weights, we calculate the average weight by solving the arithmetic average value, and regard it as the final weight.

- **Arithmetic mean method**

The comparison matrix is constructed from section 1.2.

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{14}$$

The weight vector obtained by the arithmetic mean method is

$$\omega_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n}a_{kj}}, i = 1, 2, \cdots, n \tag{15}$$

Thus, the weight obtained by the arithmetic mean method is obtained.

- **Geometric mean method**

The comparison matrix is constructed from section 1.2.

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{16}$$

The weight vector obtained by the geometric mean method is

$$w_i = \frac{\left(\prod_{j=1}^{n}a_{ij}\right)^{\frac{1}{n}}}{\sum_{k=1}^{n}\left(\prod_{j=1}^{n}a_{kj}\right)^{\frac{1}{n}}}, \ i = (1, 2, \cdots, n) \tag{17}$$

Thus, the weight obtained by the geometric mean method is obtained.

- **Eigenvalue method[13]**

The comparison matrix is constructed from section 1.2.

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{18}$$

(1) Find the n-th root of each row element of the comparison matrix.

$$\bar{w}_i = \sqrt[n]{\prod_{j=1}^{n}a_{ij}}, i = 1, 2, \cdots, n \tag{19}$$

(2) Normalize $\bar{\omega}_i$

$$w_i = \frac{\bar{w}_i}{\sum_{i=1}^{n}\bar{w}_i} \tag{20}$$

$W = (w_1, w_2, \cdots, w_n)^T$ is not only the approximate eigenvector of the matrix, but also the vector weight assigned to each evaluation index

(3) Find the maximum eigenvalue corresponding to the current matrix

$$\lambda_m = \sum_i \left(\frac{(AW)_i}{w_i} \right) \cdot \frac{1}{n} \tag{21}$$

- **Calculation of mean weight**

Calculate the arithmetic mean of the weights obtained by the above three methods and regard it as the final weight.

- **The results of weight**

Let's first show the weight of politics, economy, safe and stable and education:

For politics:

$$Politics = (0.1746) P_{cor} + (0.1982) P_{eff} + (0.1982) P_{va} + (0.2307) P_{law} + (0.1982) P_{reg} \tag{22}$$

For economy:

$$Economy = (0.3333) E_{Gp} + (0.3333) E_{Gg} + (0.1667) E_{inf} + (0.1667) E_{mer} \tag{23}$$

For safe and stable:

$$Security = (0.1635) S_{rt} + (0.5394) S_{coup} + (0.2971) S_{ps} \tag{24}$$

For education:

$$\begin{aligned} Education = {} & (0.1223) (ED)_{pt} + (0.2272) (ED)_{lit} \\ & + (0.4233) (ED)_{inv} + (0.2272) (ED)_{years} \end{aligned} \tag{25}$$

Table 3 : Indicator weight table

Indicators	Weight (%)
Control of Corruption	17.46
Government Effectiveness	19.82
Voice and Accountability	19.82
Rule of Law	23.07
Regulatory Quality	19.82
GDP per capita	33.33
GDP growth rate	33.33
Inflation rate	16.67
Merchandise trade volume	16.67
Refugees and Terrorism	16.53
Coup	53.94
Political Stability	29.71
Pupil-teacher ratio	12.23
Literacy rate	22.72
Investment in education	42.33
Mean years of schooling	22.72

Finally, through comprehensive analysis, we get the weight of each index:

$$
\begin{aligned}
PESE = {} & (0.0499)P_{cor} + (0.0566)P_{eff} + (0.0566)P_{va} + (0.0659)P_{law} + (0.0566)P_{reg} \\
& + (0.0952)E_{Gp} + (0.0952)E_{Gg} + (0.0476)E_{inf} + (0.0476)E_{mer} \\
& + (0.0467)S_{rt} + (0.1541)S_{coup} + (0.0849)S_{ps} \\
& + (0.0175)(ED)_{pt} + (0.0325)(ED)_{lit} + (0.0605)(ED)_{inv} + (0.0325)(ED)_{years}
\end{aligned} \tag{26}
$$

Figure 3 : Factors and Indicators weight

4.3 Define Global inequality index

After calculating the PESE value of each country, we define the score of global equity by solving the variance of each PESE value.

Variance has a form of $s^2 = \dfrac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n}$

Bring in formula $s^2_{(PESE)} = \dfrac{\sum_{i=1}^{n}\left((GE)_i - \overline{(GE)}\right)^2}{n}$

In the previous step, we have calculated the weight of each index. We can calculate the comprehensive score of each country according to the weight of each index. The larger the comprehensive score gap between countries, the larger the real gap between countries, that is, the more unfair. On the contrary, if the comprehensive score gap between countries is smaller, the smaller the real gap between countries, the fairer it is. Therefore, we use variance to quantify the size of the gap between countries.

Define Global inequality index: $GIEI = s^2_{(PESE)}$

Since the larger the variance, the more unfair the world is, we define this variance as the global inequality index. Therefore, when the global inequality index is smaller, it means that the world is fairer. When the global inequality index is larger, it means that the world is more

unfair. When the global inequality index is 0, we believe that the world is fair.

4.4 Validate the Global Equity Model

In order to verify our global equity model, we collected the data of various indicators of most countries in the world, brought these data into our global equity model and calculated the value of Global inequality index.

We can get $GIEI = 2.839337$

In order to better give the reasonable range of quantifying global equity, we use K-means clustering algorithm to divide the scores of countries around the world into four categories.

We implement the K-means clustering algorithm through SPSS software：

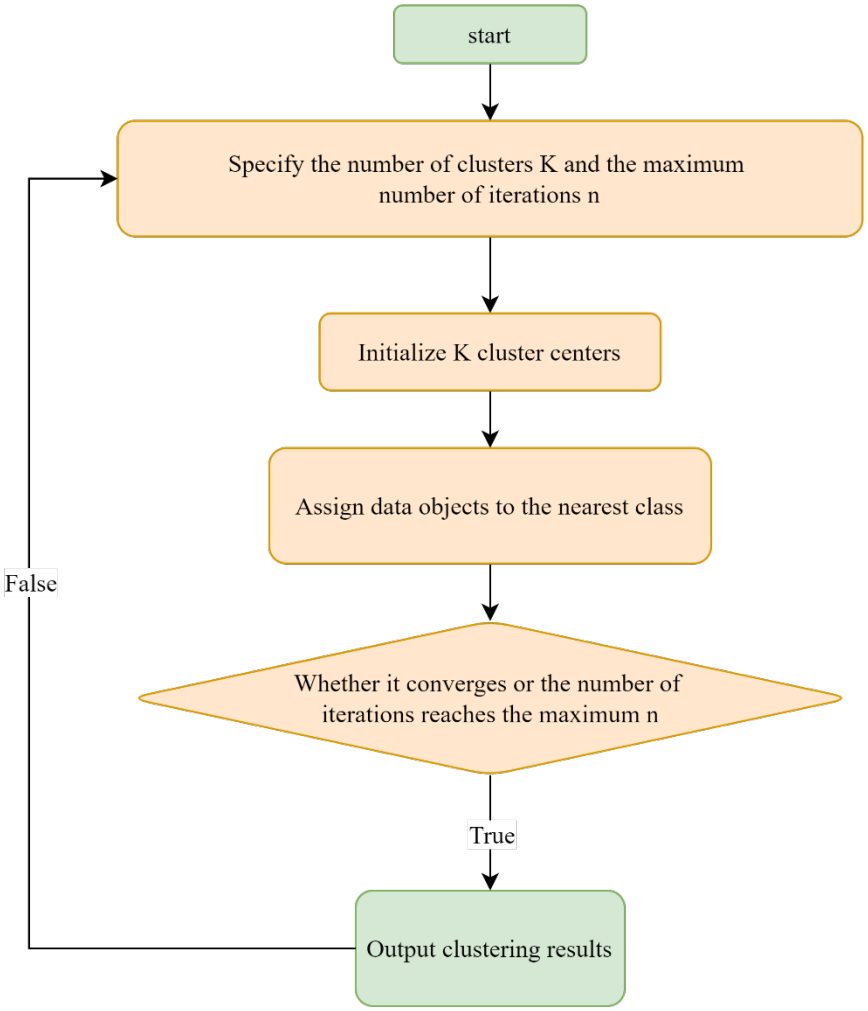

Figure 4 : Flow chart of K-means clustering algorithm

Table 4 : Number of Cases in Each Cluster

Clustering	1	91.000
	2	20.000

	3	30.000
	4	64.000
Effective		205.000
Defect		0.000

Table 5 : Final Clustering Center

	1	2	3	4
Cluster center value	4.193079	8.109675	2.421380	5.995153

By calculating the variance between these four categories of countries, we get the scope of defining the degree of equity.

We have classified the GIEI as follows:

- Fairness: $GIEI = 0$, it means that the comprehensive level of countries in the world is equal, reaching global fairness
- Slight injustice: $0 < GIEI \leqslant 0.811103$, it means that there are differences in the comprehensive level of countries in the world, and there is a slight injustice in the world
- Unfairness: $0.811103 < GIEI \leqslant 2.265912$, it means that the comprehensive level gap between countries in the world is obvious and the world is unfair
- Very unfair: $2.265912 < GIEI \leqslant 7.765608$, it means that there is a big gap in the comprehensive level of countries all over the world, and the world is very unfair
- Extremely unfair: $GIEI > 7.765608$, it means that there is a serious gap in the comprehensive level of countries in the world, and the world is extremely unfair

Because of $GIEI = 2.839337$, according to our model, the world is now in a very unfair state.

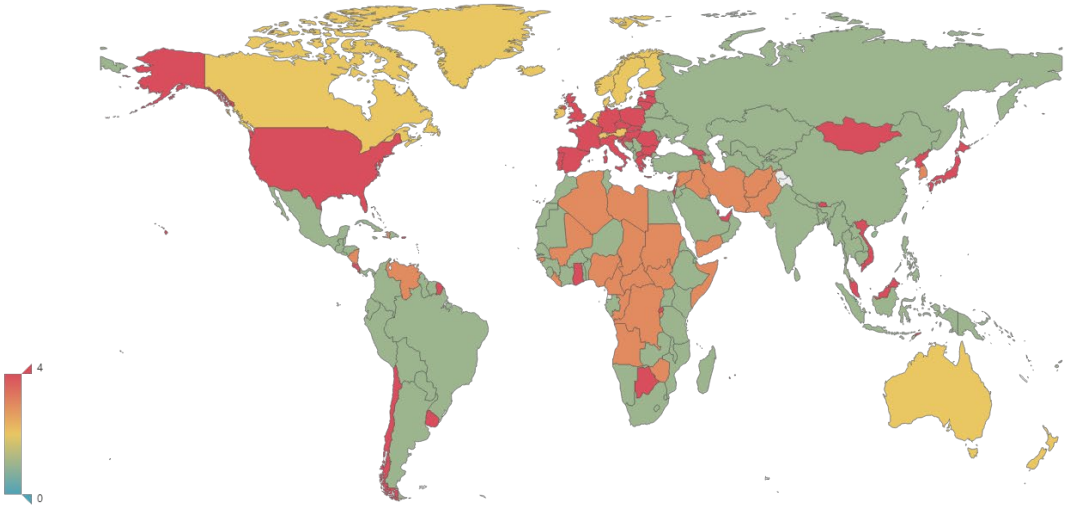

Figure 5 : Visualization of clustering categories around the world

5 Asteroid Mining: Economy Benefit-Cost Analysis Model

5.1 Cost Analysis

According to the hypothesis, asteroid mining can bring valuable minerals back to earth at a safer cost in the future. Therefore, we have established the Economy Benefit-Cost Analysis Model.[14]

We believe that there are three main economic costs of asteroid mining, including energy, equipment and labor. We assume that these three costs have a linear relationship with the mining volume. Therefore, the cost of asteroid mining can be expressed by the product of the mining volume and the unit price P of the three costs, so we can list the following equation:

$$\begin{cases} C_{ene} = \sum_{i=1}^{k} m_{Mining,i} \times P_{ene,i} \\ C_{equip} = \sum_{i=1}^{k} m_{Mining,i} \times P_{equip,i} \\ C_{labor} = \sum_{i=1}^{k} m_{Mining,i} \times P_{labor,i} \end{cases} \tag{27}$$

Where $m_{Mining,i}$ and P_i represent the quantity and price of the ith mineral. Because it may involve the development of a variety of mineral resources, we assume that a total of k mineral resources can be mined. At the same time, we use $\sum_{i=1}^{k}$ to represent it. We calculate the sum of all minerals that can be mined. The meanings of the same symbols in the text are similar.

Therefore, we define mining cost as:

$$Costs = C_{ene} + C_{equip} + C_{labor} \tag{28}$$

5.2 Benefits Analysis

In our asteroid mining system, we assume that whether the mined minerals are sold or used by ourselves, the income generated is the price of the minerals. At the same time, in the assumption conditions, we have assumed that the price is relatively stable. Therefore, no matter who is the subject of selling the minerals, the income per unit of minerals is the same, Therefore, the economic benefits of asteroid mining are:

$$Benefits = \sum_{i=1}^{k} m_{Mining,i} \times P_{\mathrm{mineral},i} \tag{29}$$

where $P_{\mathrm{mineral},i}$ is the price of the ith mineral.

5.3 Profits Analysis

In addition, if we consider that asteroid mining requires certain taxes to be paid to the United Nations:

$$Taxes = \sum_{i=1}^{k} m_{Mining,i} \times P_{tax,i} \tag{30}$$

where $P_{tax,i}$ represents the tax to be paid for the ith mineral resource of the unit

At the same time, we comprehensively consider whether we have participated in mining and the profits we can get from participating in mining. Here we use μ and ν respectively, where μ is 0 or 1, μ is 0 means we have not participated in asteroid mining, and 1 means we have participated in asteroid mining. $\nu\epsilon[0,1]$ which represents the proportion of profits that can be obtained by participating in mining. Moreover, we have calculated the cost and economic benefits of asteroid mining, so we can calculate the profit of asteroid mining:

$$\begin{aligned} Profits &= \mu\nu(Benefits - Costs - Taxes) \\ &= \mu\nu\sum_{i=1}^{k} m_{Mining,i} \times (P_{\mathrm{min}eral} - P_{ene,i} - P_{equip,i} - P_{tax,i}) \\ &= \mu\nu\sum_{i=1}^{k} m_{Mining,i} \times P_{net,i} \end{aligned} \tag{31}$$

5.4 Future Asteroid Mining Vision

Based on the Economic Benefit-Cost Analysis Model, we describe a possible vision for future human asteroid mining as follows:

Countries all over the world work together, mainly with technical support from developed countries. Countries all over the world share the costs of energy, equipment and labor according to their population. Profits from mining are also distributed according to the population of each country.

According to the United Nations Treaty on outer space signed by most countries in 1967, “exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind”. Therefore, the mineral resources on asteroids should be jointly developed by all mankind. The benefits it gains should also be shared by all mankind. However, some developing countries do not have enough technical support, so we believe that developed countries should provide more technical support. So, we think this vision can be realized in the future.

Because the profits from mining are evenly distributed according to the population of all countries, the impact on the GDP per capita of all countries in the world is consistent, so the GDP per capita index will not affect global equity. However, for the GDP growth rate, due to the large per capita GDP base of developed and developing countries, the formula has a form of:

$$\begin{aligned} GDP_{pnew} &= \frac{(POP)\,(GDP_p) + (POP)\,(GDP_+)}{(POP)\,(GDP_p)} \\ &= 1 + \frac{(GDP_+)}{(GDP_p)} \end{aligned} \tag{32}$$

where GPD_{pnew} is the GDP growth rate after distribution, GDP_p is the GDP per capita without profit distribution, and GDP_+ is the per capita profit distribution.

We can get that the average distribution of mining profits according to the population will make the GDP growth rate of developed countries less than that of developing countries. Bring into our GE model：

$$Economy = \beta_1 E_{Gp} + \beta_2 E_{Gg} + \beta_3 E_{inf} + \beta_4 E_{mer} \tag{33}$$

$$GE = \varepsilon_1 (Politics) + \varepsilon_2 (Economics) + \varepsilon_3 (Security) + \varepsilon_4 (Education) \tag{34}$$

$$s^2_{(PESE)} = \frac{\sum_{i=1}^{n} \left((PESE)_i - \overline{(PESE)} \right)^2}{n} \tag{35}$$

$$GIEI = s^2_{(PESE)} \tag{36}$$

We can know that this distribution method can make the comprehensive score of developing countries more improved than that of developed countries, so as to reduce the global inequality index and make countries in the world more equal.

6 Economic Growth Model

6.1 Model Establishment

We define a formula for economic growth. It has a form of:

$$Y = AF(K^{\phi} L^{\varphi}) \tag{37}$$

Where K and L represent capital and labor factors respectively, and A and F represent the role of system, organization, coordination and technology. ϕ is the output elasticity coefficient of capital and φ is the output elasticity coefficient of labor. Y represents the total social output. By adding the profits from mining to K as capital, the new total social output due to asteroid mining can be calculated. Considering the original capital of each country, we update the formula to:

$$Y = AF(K_0 + K_+)^{\phi} L^{\varphi} \tag{38}$$

Where K_0 represents the capital of a country when it did not participate in asteroid mining, and K_+ represents the capital brought to the country by participating in asteroid mining.

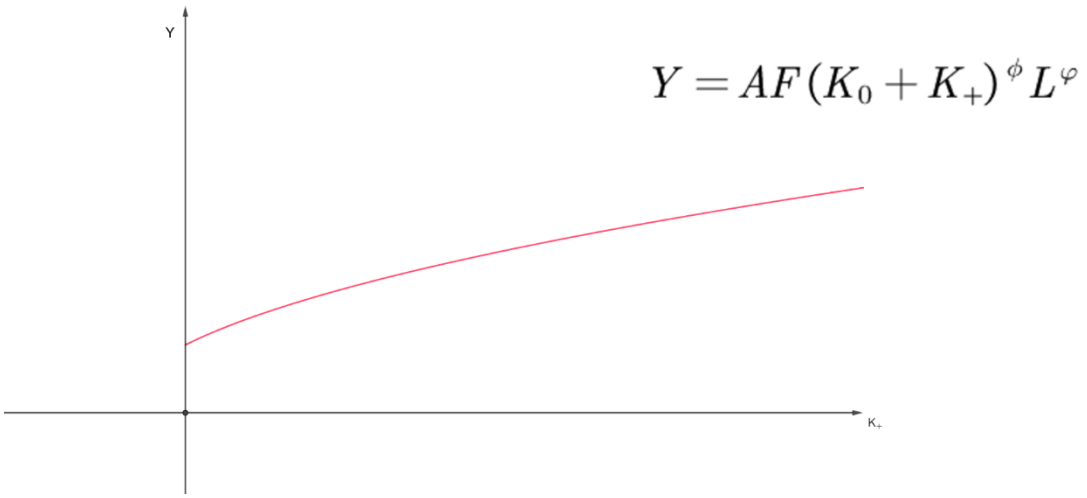

Figure 6 : Improved version of Economic Growth Model

6.2 Influence of parameter change

According to section 5, $Profits$ is taken as the K_+ of Economic Growth Model, that is, the profits obtained from asteroid mining are converted into domestic capital.

$$\begin{aligned} Y &= AF(K_0 + K_+)^{\phi} L^{\varphi} \\ &= AF\left(K_0 + \mu\nu \sum_{i=1}^{k} m_{Mining,i} \times P_{net,i}\right)^{\phi} L^{\varphi} \end{aligned} \tag{39}$$

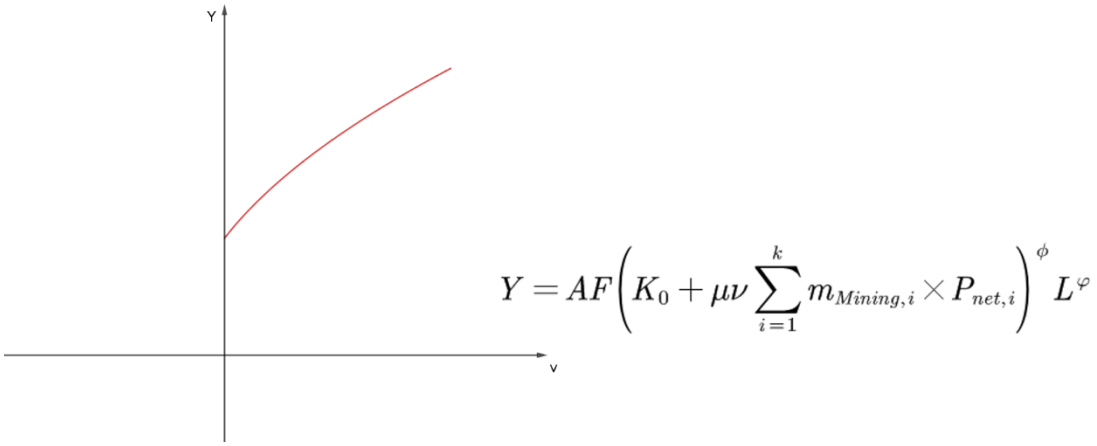

Figure 7 : Economic Growth Model with $Profits$ function

We choose μ and ν as our parameters. When the main body of profit is that the comprehensive score is lower than the global average comprehensive score, if μ = 1 at this time, that is, the country has participated in asteroid mining and the profit it can obtain from it is $\nu \sum_{i=1}^{k} m_{Mining} \times P_{net,i}$, which makes the country's per capita GDP and GDP growth rate increase, so that the country's comprehensive score increases and is closer to the global average comprehensive score, which is conducive to the reduction of the variance of the global comprehensive score, That is, the reduction of $GIEI$ is conducive to global equity. Similarly, when ν increases, the country's profits from participating in asteroid mining will be higher, which can also drive the growth of GDP per capita and GDP growth rate, improve the country's comprehensive score, reduce $GIEI$ and contribute to social equity. Conversely, when ν becomes smaller, the country's profits from participating in asteroid mining will become less, affecting the growth of per capita GDP and GDP growth rate, thus affecting the improvement of the country's comprehensive score, which is not conducive to the reduction of $GIEI$ and social equity.

When the main body of profit is that the comprehensive score is higher than the global average comprehensive score, if μ = 1 at this time, that is, the country participates in asteroid mining and the profit it can obtain from it is $\nu \sum_{i=1}^{k} m_{Mining} \times P_{net,i}$, which increases the GDP per capita and GDP growth rate of the country, which makes the country's comprehensive score

higher and farther away from the global average comprehensive score, which is not conducive to the variance of the global comprehensive score, That is, the reduction of $GIEI$ is not conducive to global equity. Similarly, when ν increases, the country's profits from participating in asteroid mining will be higher, which can also drive the growth of per capita GDP and GDP growth rate, improve the country's comprehensive score, and increase $GIEI$, which is not conducive to global equity. Conversely, when ν becomes smaller, the country's profits from participating in asteroid mining will become less, which will affect the growth of per capita GDP and GDP growth rate, thus affecting the improvement of the country's comprehensive score, which is conducive to the reduction of $GIEI$ and social equity.

We believe that in the short term, the labor factor L, capital and the output elasticity coefficient ϕ, φ of labor and the action factors A and F of system, organization, coordination and technology will not change, and only K will increase due to the profits of asteroid mining. Considering that the economic foundation of developed countries is stronger than that of developing countries, so $K_{0developed} > K_{0developing}$. After obtaining the benefits of asteroid mining, the total social output increased by developing countries is more than that increased by developed countries. Therefore, the gap between the economic strength of developing countries and developed countries will be reduced, according to our GE model:

$$Economy = \beta_1 E_{Gp} + \beta_2 E_{Gg} + \beta_3 E_{inf} + \beta_4 E_{mer} \tag{40}$$

$$GE = \varepsilon_1 (Politics) + \varepsilon_2 (Economics) + \varepsilon_3 (Security) + \varepsilon_4 (Education) \tag{41}$$

$$s^2_{(PESE)} = \frac{\sum_{i=1}^{n} \left((PESE)_i - \overline{(PESE)} \right)^2}{n} \tag{42}$$

$$GIEI = s^2_{(PESE)} \tag{43}$$

7 Policy proposal

In order to promote the development of asteroid mining industry in the direction of promoting global equity, we have put forward a series of policies according to the actual situation.

Legally, the provisions of the United Nations on the property rights of space resources are insufficient. The United Nations' outer space treaty explicitly prohibits the use of all celestial bodies, but the power to extract resources is not so clear. The treaty provides interpretation space for the development and use of some asteroid mineral resources. Treaties are mostly principled provisions, and the conceptual scope is also relatively broad. Therefore, we make the following recommendations on legislation to the United Nations:

1. Formulate sound international laws and establish an orderly international legal system to avoid economic imbalance.
2. Establish a mechanism or principle to balance the interests and needs of all countries. Compared with equal distribution, the competition of interests under competition is more in line with international rules and fully balance the acquisition of rights.
3. Establish an effective international development mechanism and a balanced international framework to manage asteroid mineral resources.

4. To formulate laws to strictly define celestial bodies and asteroids, we need to pay close attention to and restrict some countries from independently acquiring mineral resources on asteroids by implementing asteroid capture plans, so as to avoid the problem of asteroid capture.[14]
5. Countries cannot possess asteroids through sovereignty, and private entities cannot monopolize asteroids.

Economically, because asteroids are rich in mineral resources, once they are privately owned by individuals or individual countries, it will have subversive consequences for the whole human society. Individuals or countries with private asteroid minerals will obtain huge wealth, which will have a great impact on the fairness of human society. Therefore, we put forward the following suggestions for the United Nations in terms of economy:

1. According to the Ge score, the higher the index, the higher the comprehensive level of the country. On the contrary, the lower the index, the lower the comprehensive level of the country. The United Nations and other international organizations should formulate relevant laws to allow countries around the world to pay corresponding taxes to the United Nations every year according to their Ge scores. Using these taxes, the United Nations can improve the infrastructure of the world, so as to promote the common progress of all countries in the world and make the world more equitable.
2. The United Nations should implement a policy of assistance. Countries with high Ge scores need to help countries with low Ge scores in economic, infrastructure and other fields. The following are our suggestions for assistance: countries with the top ten Ge scores help countries with the lowest to the tenth lowest Ge scores, countries with the eleventh to the twentieth lowest Ge scores help countries with the eleventh to the twentieth lowest Ge scores, and so on. The purpose of this is to promote the development of less developed countries and regions in the world faster. For countries that take the initiative to help less developed countries and regions in the world, the United Nations should appropriately reduce their taxes, so as to promote the assistance of developed countries to less developed countries.
3. When distributing or trading asteroid mineral resources, we should prevent them from damaging and hitting the economy of the earth world, including the economy of the earth's natural resources. Otherwise, asteroid minerals will not have any practical value.

In the management of asteroid minerals, we should uphold the concept of mutual benefit and win-win results. Therefore, we put forward the following suggestions to the United Nations on the management of asteroid minerals:

1. Stipulate the international responsibility for international space resource activities and jurisdiction over space resources. Space resource activities need to be authorized in advance and continue to be monitored by appropriate countries or intergovernmental organizations, so that they can be extended to more countries, especially developing countries.[15]
2. Based on international treaties, countries should reach a model of consensus of interests, win-win cooperation and multilateral mutual benefit.

8 Sensitivity Analysis

Our economic growth model has a form of $Y = AF\left(K_0 + \mu\nu\sum_{i=1}^{k} m_{Mining,i} \times P_{net,i}\right)^{\phi} L^{\varphi}$ .We take ϕ as our parameter. ϕ is the output elasticity coefficient of capital. We make the output elasticity coefficient ϕ of capital $\frac{1}{2}$, $\frac{1}{3}$ and $\frac{1}{4}$ respectively, and make $Y-\nu$ images respectively.

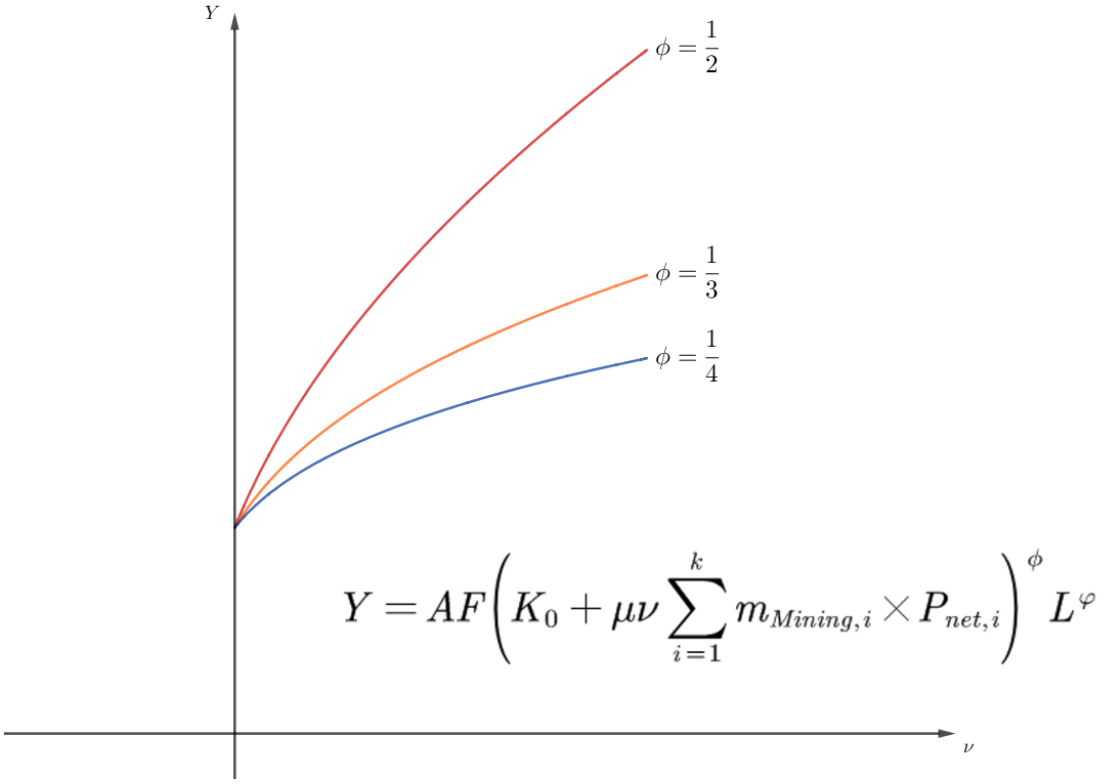

Figure 8 : 1 Sensitivity Analysis

It can be seen from the image that the change of ϕ will not have a great impact on Y, and the general trend of the curve has not changed.

9 Model Evaluation and Further Discussion

9.1 Strengths

- **We have considered enough indicators**

  We selected four main factors and divided them into 16 indicators to establish our model. These factors can fully reflect the scores of each country. At the same time, because we selected enough indicators, we can avoid the accidental impact caused by a certain indicator as much as possible, ensure the reliability and stability of the model, and make the results more complete.

- **We used the latest data**

In order to ensure the reliability of the results, we use the latest database. At the same time, the accuracy of the data in the database we use is guaranteed, which makes our calculation results very close to our life and have high reliability and reference value.

- **We give quantitative criteria**

  In order to measure global equity, we clearly give the quantitative indicators of global equity, and determine the quantitative scope of global equity through data analysis.

- **An Economy Benefit-Cost Analysis Model is established for asteroid mining**

  In order to better describe the situation of asteroid mining, we establish the cost and economic benefit model of future asteroid mining by analyzing the cost and economic benefits of asteroid mining, give the profit of asteroid mining, and bring it into the economic growth model, Thus, the impact of different conditions of asteroid mining on global equity in the future is obtained.

9.2 Weaknesses

- **We ignore changes in data and standards over time**

  When analyzing our model, we give quantitative indicators by bringing the current data of countries around the world into our model. However, in the future, the data of various indicators I use may change, so the quantitative range we give may no longer be applicable.

- **Our model has some subjectivity**

  The selection and determination of some parameters in our model are subjective. When we determine the judgment matrix of analytic hierarchy process, although we refer to the development of many different countries, government reports and other literature, the determination of these parameters is subjective to a certain extent.

- **Some data in the database is missing**

  In the database, the indicator data of some countries are missing. In order to obtain a PESE score, additional weighting of the metrics is required, which means that the GE model can sometimes be complex.

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