Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
F		2214476

Profound Cosmic Innovations: Will Asteroid Mining Be a Game Changer to Global Equity?

Summary

Asteroids contain a rich diversity of minerals, which will open a vast new source to benefit humanity. Most countries in the world have signed agreements for fairness and peace in the space. So, will asteroid mining effect the process of global equity? To provide the appropriate solution for the problem, our investigation will look across the definition and measurement of global equity. Our emphasis will be upon the usage of various models to analyze the impact of asteroid mining on relative equity among countries around the world.

For part 1, in order to measure global equity, we choose to use our own indicators to describe the development of countries around the world. Therefore, we consider the two general directions of national strength development and residents' living conditions. We use **Entropy Weight Method** analytic hierarchy process to obtain a score to represent a country's score in development, and then we use the standard deviation of the score to represent the degree of global equity, because this shows the differences in development between different countries.

In part 2, in order to find out the impact of asteroid mining on world equity, we choose to reasonably distribute the ore acquired from small planets first, because a reasonable distribution will make the world more equitable. Therefore, we have considered social development, economic development, local energy, environment, scientific and technological development. The 'score' of each country in the distribution is obtained by using the entropy weight method analytic hierarchy process in the six directions of energy trade. After the overall normalization, the distribution weight of each country in the asteroid mineral resources is obtained, which is added to the regression of global equity as a variable. The **Breakpoint Regression Method** is applied to analyze and obtain the results. Finally, it is found that if asteroid mining can be reasonably distributed on the earth, the fairness of the world will be improved.

In terms of part 3, we choose to establish an index system including six parameters to generate the proportion that each country can benefit in new mineral energy generated from asteroid mining. Then we apply **ARIMA Model** to predict the future tendency of six parameters until 2050, and we screen out the six most representative countries through the entropy weight method. We utilize **AHP** to propose a judging matrix of six distributional factors and predict the future tendency of the six countries' proportion of extraterrestrial mineral energy. Finally, we acquire the impact of changing conditions on global equity by adjusting the importance of environmental pollution and technology in the judging matrix. We believe that changes in the Gini index due to adjusting importance reflect changes in global equity. The results shows that the increase in the importance of technological factors will promote global equity, while the increase in pollution will have the opposite effect.

With regard to part 4, we put forward suggestions on the formulation of UN policies from the perspective of resource allocation, scientific and technological development and environmental protection.

Keywords: Asteroid Mining, Global Equity, Breakpoint Regression, Analytic Hierarchy Process

Contents

1 Introduction

Asteroid mining has been more and more mentioned in recent years. The limited resources lead to fierce competition on the earth. If we can explore outer space and mine the minerals from other planets back to the earth, it can be expected to achieve sustainable development and global equity.

Firstly, based on several academic papers, we determine the method and index system to describe the global equity, and find the data to make a comprehensive analysis of the development of countries and the global equity.

Then, we consider the distribution of asteroid mining, that is, according to the needs and contributions of each country, and add asteroid mining as a variable to the analysis of causality, and make a causal judgment of asteroid mining on the fairness of the world.

Finally, we consider the impact of different policies on the asteroid mining industry and make a judgment on the impact of different policies on global equity.

2 Assumption

To simplify our model and eliminate the complexity, we make the following main assumptions in the literature. All assumptions will be re-emphasized once they are used in the construction of our model.

Asm.1 By 2030, humans will have enough capacity for asteroid mining, and will not be able to mine minerals from other planets until 2050.

Asm.2 The ore transported back from space by technologically developed countries will be sold to countries in need of it at a low price (we assume that the cost of mining ore in space after 2030 is close to that of mining ore on earth)

Asm.3 Ignore the cost of allocating ore resources recovered from the asteroids (negotiation cost, transportation cost, etc.)

Asm.4 There is no other epoch-making technology to improve the efficiency of the earth's ore use or energy application (including use efficiency, environmental efficiency and distribution efficiency) by leaps and bounds.

Asm.5 Countries with sufficient data account for most of the world's total volume (total economic output, total scientific and technological power, etc.).

Asm.6 All countries will implement the policies announced by the United Nations, and will pay attention to the well-being of their people, to cooperate. Such cooperation will bring Pareto improvement.

Asm.7 The amount of data is large enough to meet the law of large numbers required by the prediction of the time series model.

Asm.8 Attribute conditional independence assumption: for known classes, we assume that all the metrics are independent of each other.

3 Abbreviations and Symbols

Before we begin analyzing the problems, it is necessary to clarify the abbreviations and symbols that we will be using in our discussion. These are shown below in **Table 1**:

Table 1: Abbreviations and Symbols

Abbreviations/Symbols	Description
p	the order of the AR model
q	the order of the MA model
ϕ	the fitting parameter of AR model
θ	the fitting parameters for MA model
d	the differential order(used in ARIMA)
Y_t	Differential sequences(used in ARIMA)
ε_t	the noise sequence(used in ARIMA)
A	the judging matrix(used in AHP)
w_i/w_j	How important factor i is to factor j(used in AHP)
λ_{max}	Largest characteristic root(used in AHP)
n	Order of the matrix(used in AHP)
AHP	Analytic Hierarchy Process
EWM	Entropy Weight Method
edu	Gap in national investment in Education
$forest$	Gaps in national forest cover
gov	Gap in government expenditure
$life$	The gap in life expectancy of the country's population
$power$	Gap between countries in power coverage
gni	The gap between countries in per capita national income
$mine$	0-1 variable, when equal to 1, asteroid mining exists
Inf	Impact of space mining on the country
rd	National gap in scientific research personnel
$urban$	National gap in urban population ratio
$newgni$	=gni+mine$\times$Inf

4 Global Equity

4.1 Definition

In order to abstract and concretize global equity, we choose to describe global equity with the development gap of different countries. We choose to concretize the development of different countries with a large index system. Eventually, each country will get a development score, and the difference between development scores is described by standard deviation, that is, the standard deviation is used to represent global equity, The higher the standard deviation, the more unfair the world is.

Next, we first build an index system to describe national development in **Figure 1**, measuring global equity from two categories. The first category is population happiness, including education expenditure as a percentage of GDP, life expectancy, electrification rate, and the proportion of urban residents. According to relevant studies, these four factors have a significant impact on population well-being [1]. The second category is strength development, including forest area, government expenditure as a percentage of GDP, PPP adjusted per capita national income, and R&D expenditure as a percentage of GDP. According to the results of the literature review, we believe that these four factors are enough to summarize the development degree of a region[2]. We will calculate the weight of these factors in the following parts, and finally get a region-based global common balance index system. Using this index system, we can calculate the comprehensive strength of each region. Finally, we use the root mean square obtained from this set of values as an indicator of global equity.

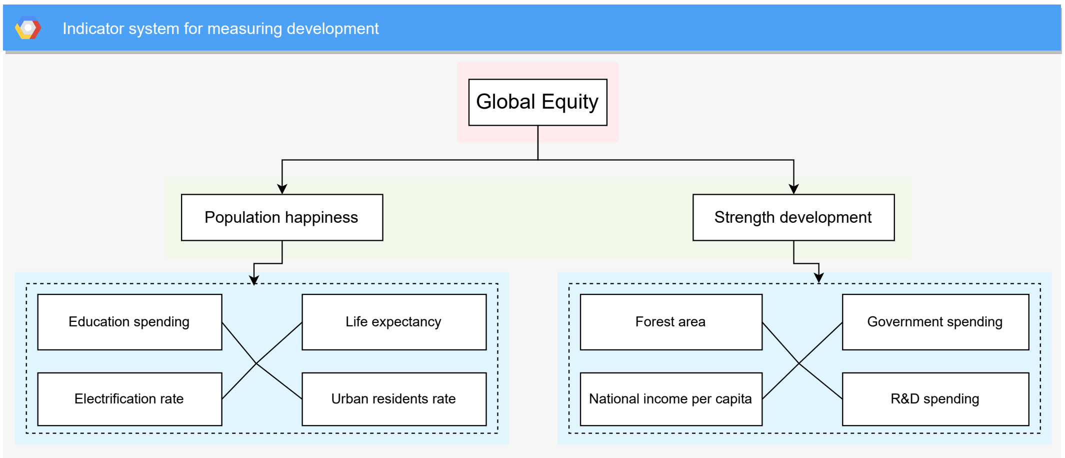


Figure 1: Indicator system for depicting National Development

4.2 Data Process

In this step, we process the obtained data, including prediction and screening. Because asteroid mining at present is obviously impossible, we need more data in next years to match and analyze the subsequent planetary mining data. Then we need to filter the data, because not all countries have complete and appropriate data.

4.2.1 Prediction via ARIMA Model

First of all, we cannot mine in space today, but we assume that the mining industry on the asteroids will be fully exploited by 2050. Mining on the asteroids will be fully exploited by 2050, so in the following, we will use a **Time Series Model** to make reasonable predictions for our selected variables and then proceed to the next step of the analysis. So we will use a time series model to make reasonable predictions for our selected variables and then proceed to the next step of the analysis.

ARIMA model, ARIMA model, that is, the differential autoregressive moving average model is one of the methods of time-domain analysis of time series. The model can stabilize non-stationary time series by different methods and overcome the disadvantage that the AR model and MA model can only deal with stationary time series. Therefore, it is one of the most widely used methods for univariate time series data prediction.

ARIMA model is recorded as $ARIMA(p,d,q)$, where p is the order of the AR model, q is the order of the MA model, and d is the different order. The general expression of the model is as follows:

$$Y_t = c + \phi_1 y_{t-1} + \ldots + \phi_p y_{t-p} + \theta_1 \varepsilon_{t-1} + \theta_q + \ldots + \varepsilon_t \tag{1}$$

Where Y_t are differential sequences, ε_t is the noise sequence, ϕ_t is the fitting parameter of AR model, θ_t is the fitting parameter for MA model.

Generally speaking, the establishment of the ARIMA model has three stages: model identification and order determination, parameter estimation, and model test. Model identification and order determination mainly determine the model parameters p, q, and d according to the truncation and tailing properties of autocorrelation diagram (ACF diagram) and partial autocorrelation diagram (PACF diagram). As shown in the **Figure 2** below, we only show the prediction of eight indicators in Russia:

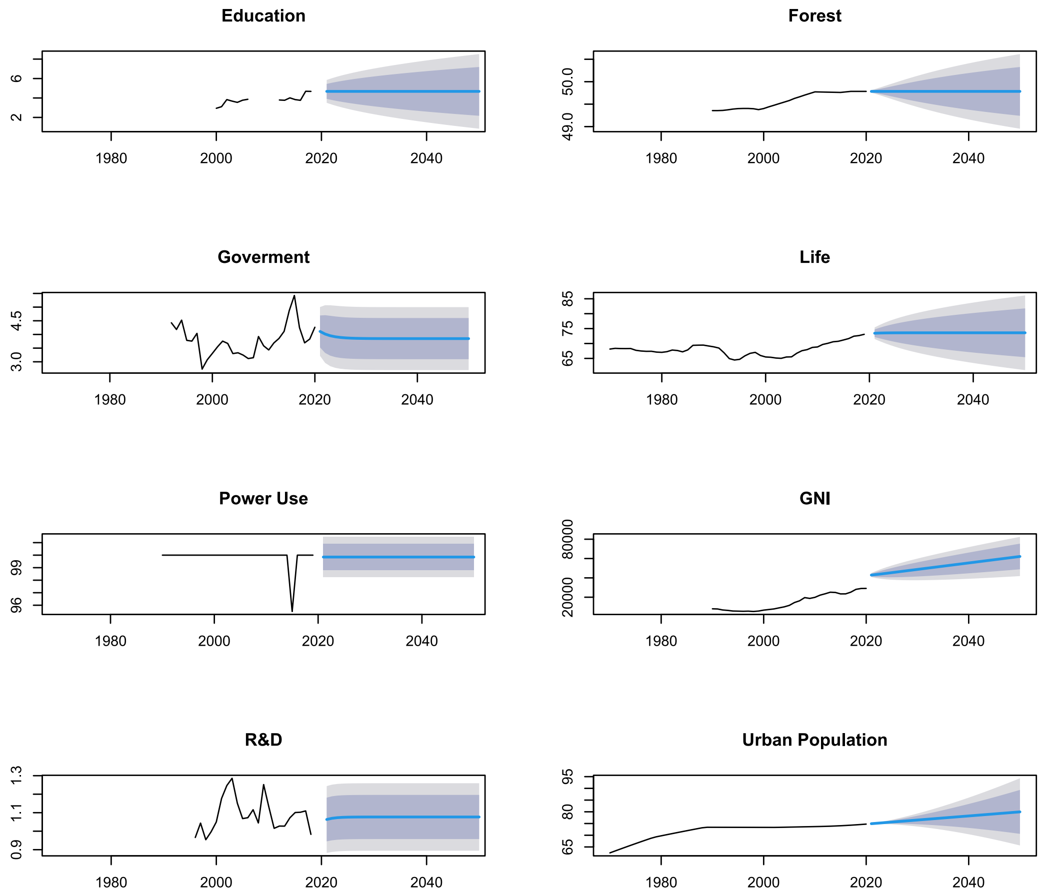


Figure 2: Prediction of various indicators of Russia to 2050

4.2.2 Get Importance by EWM

First of all, we first define the previously selected indicators Education spending as a percentage of GDP, Life expectancy, Electrification rate, Proportion of urban residents as A_1, A_2, A_3, and A_4 respectively and select Forest area, Government spending as a percentage of GDP, PPP-adjusted national income per capita and R&D spending as a percentage of GDP as A_5, A_6, A_7, and A_8 respectively. These indicators are normalized by their respective components and weighted by experts. At the same time, we put the categories in **Table 2**.

Table 2: Categories of population happiness and Strength development

Index	**Symbols**
Education spending as a percentage of GDP	A_1
Life expectancy	A_2
Electrification rate	A_3
Proportion of urban residents	A_4

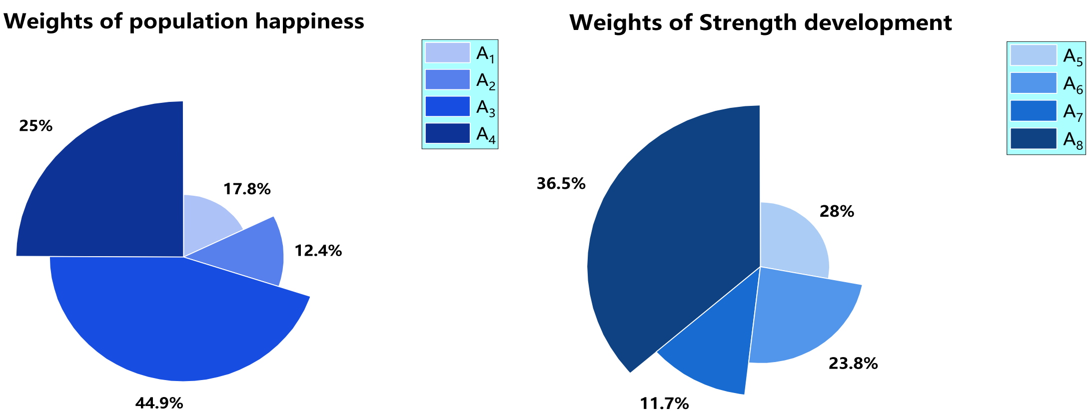
Index	**Symbols**
Forest area	A_5
Government spending as a percentage of GDP	A_6
PPP-adjusted national income per capita	A_7
R&D spending as a percentage of GDP	A_8

In this section, we use the **Entropy Weight Method** to estimate the weight of each indicator in its category. In the entropy weight method, information entropy is the most commonly used indicator to measure the purity of a sample set. Assuming that the proportion of the k-th sample in the current sample set D is $p_k(k = 1,2,...,|y|)$, the information entropy of D is defined as:

$$Ent(D) = -\sum_{k=1}^{|y|} p_k log_2 p_k. \tag{2}$$

The smaller the value of $Ent(D)$, the higher the purity of D.

In the evaluation index system, since each evaluation index has different roles, status, and inuence compared with other indicators in the same category, different weights must be assigned according to the importance of each index. The weight reects the importance of each indicator in the indicator set, and the weight of an indicator is directly related to the contribution of this indicator to the overall. Therefore, determining the weight of the indicator system is the basis of system evaluation[2]. We calculate the information entropy scores for all regions and place the weight of eight indicators via the entropy weight method in **Figure 3**.



(a) Population happiness (b) Strength development

Figure 3: Weights of each category

4.2.3 Equality score calculation

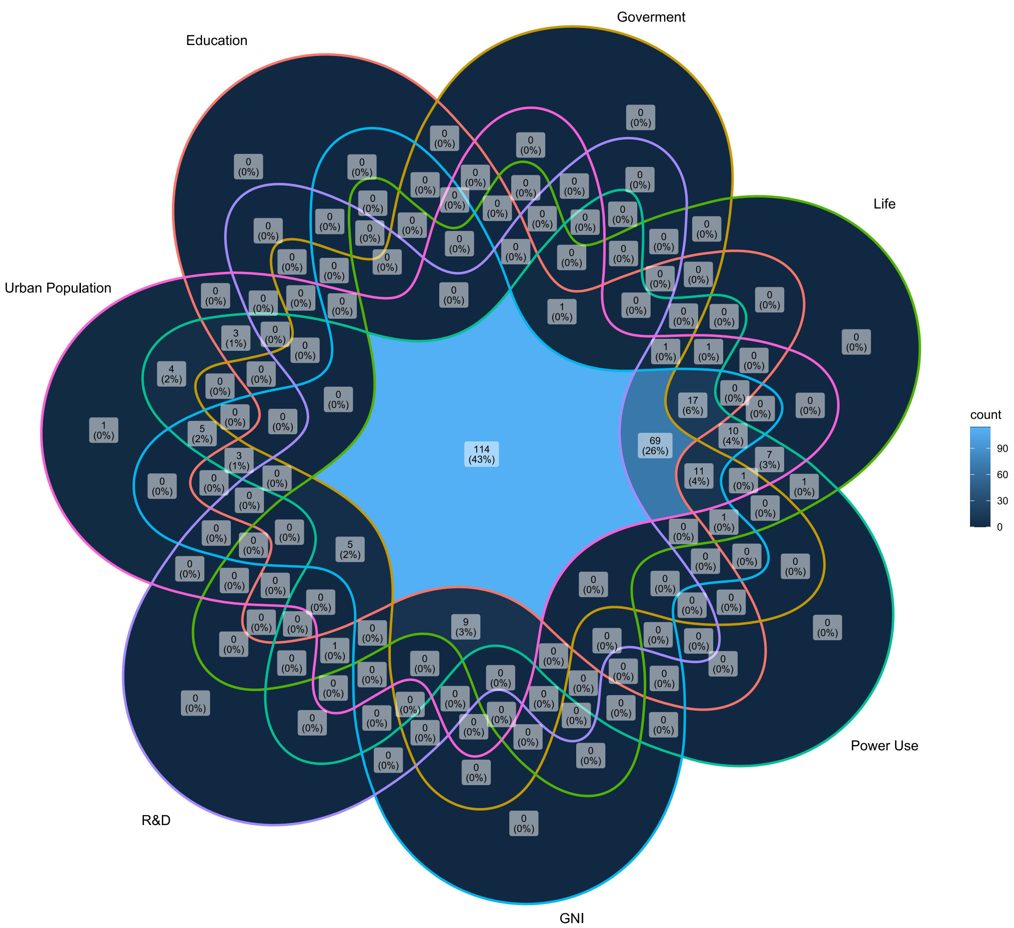


Figure 4: Wayne chart of development indicators

We will get the annual development score data of all countries. However, only some countries have relatively complete data, as shown in **Figure 4**. The data of only 114 countries are relatively complete, so we can only display the data of less than 114 countries. The score results of these countries are visualized in **Figure 5**:

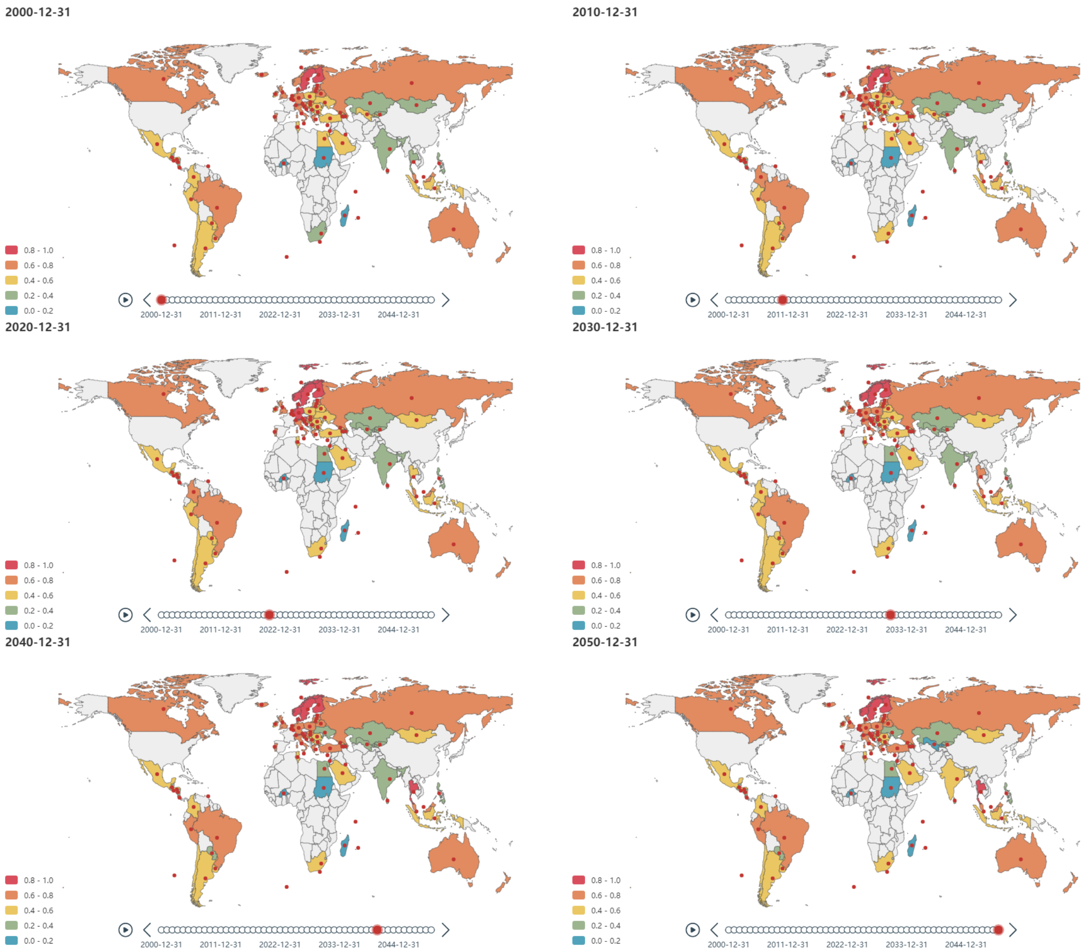


Figure 5: National development scores per decade

Next, we calculate the standard deviation after normalizing the obtained score data for all countries every year, and the formula is as follows:

$$ES_t = \sqrt{\frac{\sum_{i=1}^{n}(score_{ti} - sc\bar{o}re)^2}{n-1}} \tag{3}$$

Where ES_t is the annual Global equity score, $score_{ti}$ represents the score of each country's annual development every year, and n is the number of countries. The results are in **Figure 6**:

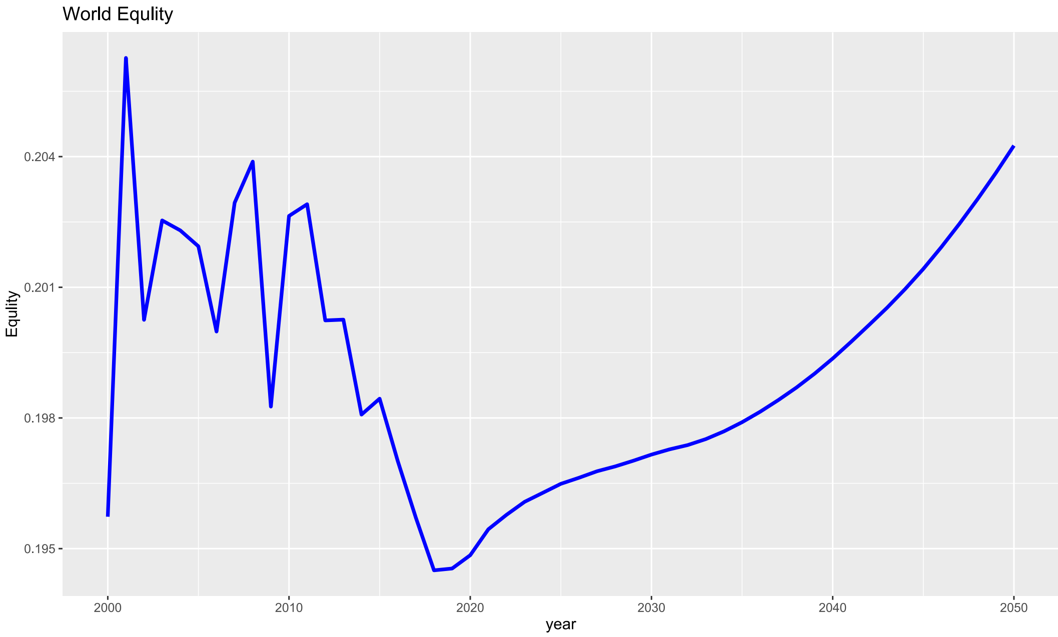


Figure 6: Global equity index 2000-2050

From the figure, we can see that the global equity index before 2010 has only periodic items but no trend items. After 2010, the global equity index has decreased significantly before 2020. We may think that the development of the world over the past decade has gradually made all countries fair, and there is a rebound after 2020 (that is, the year in which our data first came from the forecast), This may be caused by the imprecision of the prediction model, but it does not affect our analysis of the impact of asteroid mining on global equity.

4.3 Asteroid Mining and Global Equity

4.3.1 Causal judgment

We want to study the impact of planetary mining on global equity. Therefore, we need to make causal judgment.

In the empirical method of causality analysis, the best choice should be random experiment, but the time cost and economic cost of random experiment are relatively high. When random experiment is not available, other methods should be considered. Breakpoint regression, second only to random experiment, is an empirical method that can effectively use realistic constraints to analyze the causal relationship between variables.

To this end, we apply two regression, using the data with and without the impact of space mining to regress the fairness index, the variables and equations are as follows:

$$equity_t = edu_t + forest_t + gov_t + life_t + pover_t + gni_t + rd_t + urban_t + mine_t \times \mathrm{Inf}_t \quad (4)$$

Note: when the time is 2030 and later, $mine_t = 1$, otherwise $mine_t = 0$.

Table 3: regression of data without planetary mining

Variables:	Estimate	Std.Error	t-value	Pr(>ltl)	
(Intercept)	0.2945	0.0851	3.461	0.00125	**
edu	-1.59125	0.27308	-5.827	0.000000704	***
forest	-0.86895	1.20884	-0.719	0.476228	
gov	0.03727	0.05732	0.65	0.519089	
life	0.8133	0.24725	3.289	0.002038	**
power	0.07957	0.02114	3.763	0.000515	***
gni	-1.74457	0.32002	-5.451	0.000002433	***
rd	-0.23806	0.09486	-2.51	0.016027	*
urban	0.3341	0.2631	1.27	0.211129	

Signif. codes: 0 *** 0.001 ** 0.01 * 0.05 . 0.1 1
Multiple R-squared: 0.8568, Adjusted R-squared: 0.8295
F-statistic: 31.41 on 8 and 42 DF, p-value: 0.000000000000002453

Here, we assume that there are cross-era technologies in the world in 2030, so that we can mine on the outer planet. At the same time, the minerals of the outer planet are not endless. We assume that we can only mine the minerals of the moon by 2050 (compared with the number of minerals of the earth).

Whether there is a breakpoint in the worlds fair score in 2030 is the premise of R&D estimation. We use this dividing line as a benchmark to examine whether there are discontinuous changes in the worlds fair score at this dividing line in 2030. As shown in **Figure 7**, the fair score jumps significantly downward at the breakpoint, indicating that sudden new resources (suddenly fully realize asteroid mining) are an important reason for the world to become fairer.

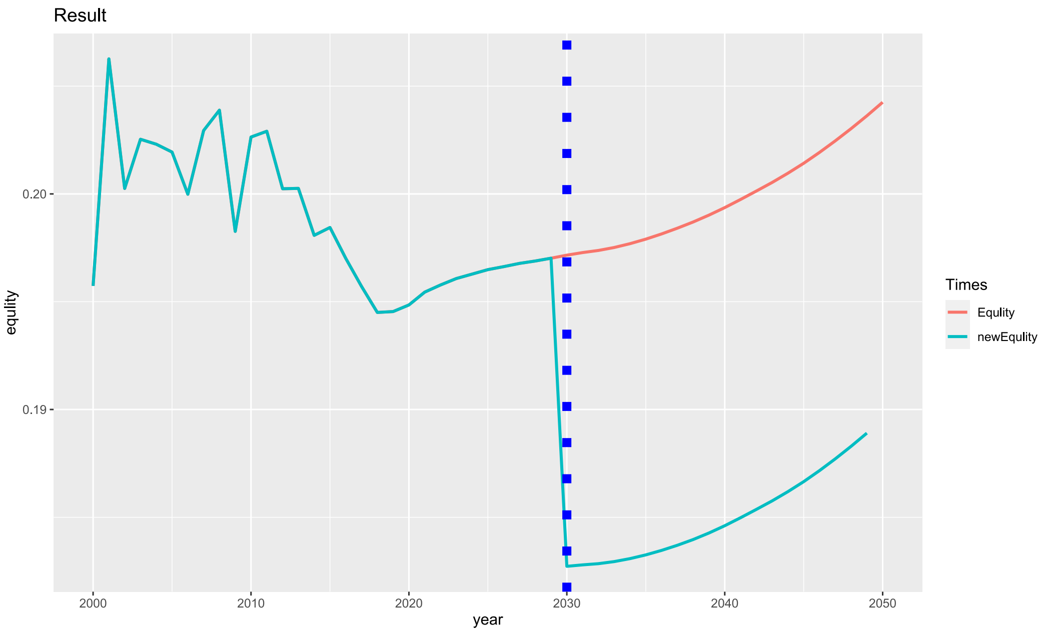


Figure 7: Global equity index after asteroid mining and reasonable distribution

5 AHP Hybrid Entropy Weight Method Model

5.1 Method Overview

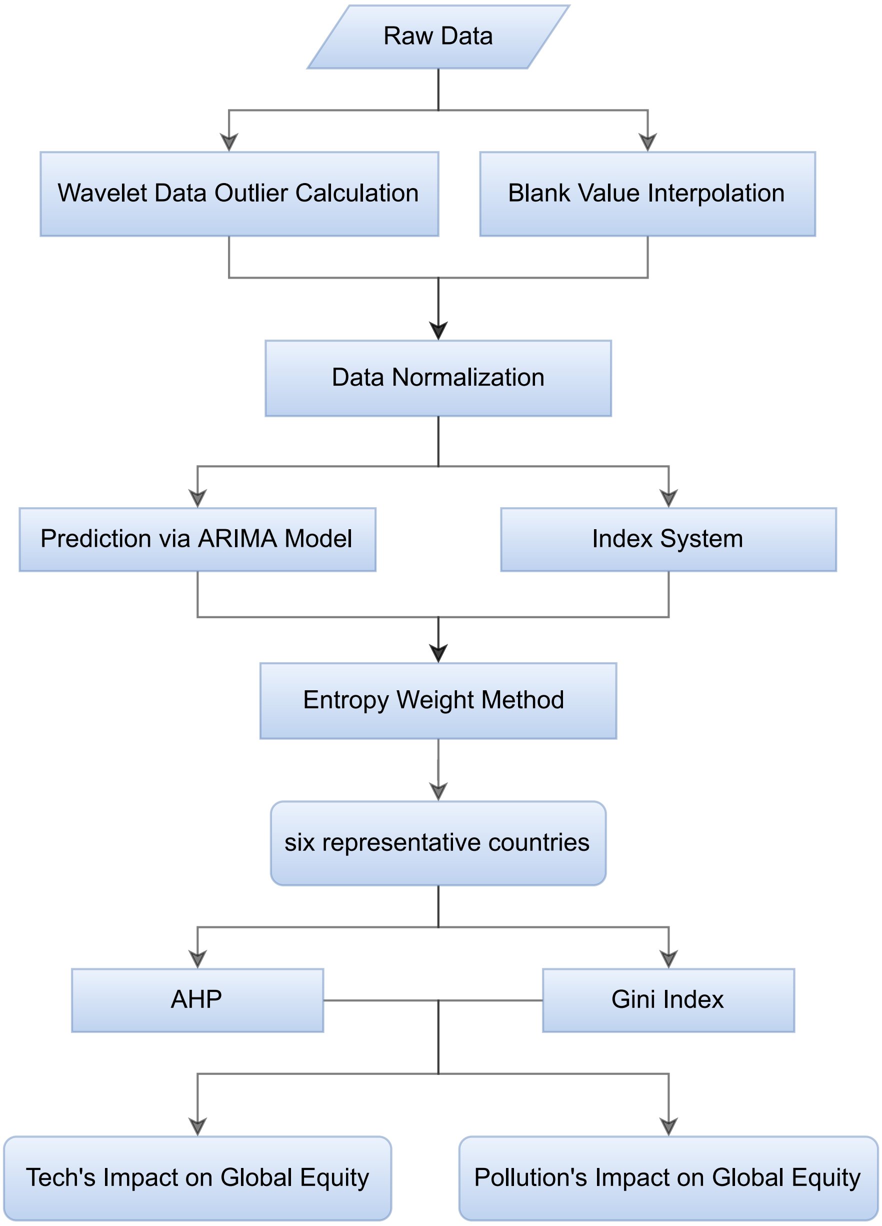


Figure 8: The workflow of AHP Hybrid Entropy Weight Method Model

In this section, we argue that once asteroid mining is feasible, the gaps in technological strength and environmental conditions between regions will have an impact on global equity. Obviously, for the sake of global equity, we cannot allocate all extraterrestrial mineral resources to developed countries that can accomplish space mining, so we choose to establish an index system to generate the proportion that each country can benefit in new mineral energy generated from asteroid mining. First we used **ARIMA**

Model to predict the future changes of these parameters until 2050, and then we screened out the six most representative countries through the **Entropy Weight Method**. We apply **AHP** to build a judging matrix of these distributional factors and predict the future direction of the six countries' proportion of extraterrestrial mineral energy's allocation. Finally, we acquire the impact of changing conditions on global equity by changing the importance of environmental pollution and science and technology in the judging matrix. We believe that changes in the Gini index due to adjusting importance reflect changes in global equity. The workflow of this section is in **Figure 8**.

5.2 Establishment of the Index System

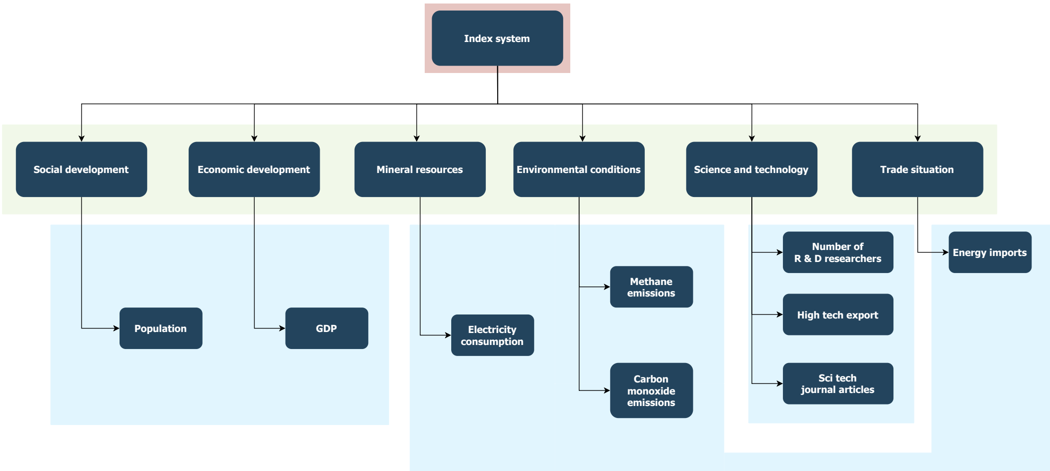


Figure 9: Index system of global equity

First, in order to give the definition of global equity, we construct the indicator system as shown in **Figure 9**. We select seven major categories of indicators, namely, Social development, Economic development, Mineral resources, Environmental conditions, Science and technology and Trade situation. At the social level, we select population as our measurement, and at the economic level, We choose GDP as the standard. Considering that the current power generation is basically fueled by fossil energy, we choose the electricity consumption of each region as the standard. We all know that the mining of minerals will bring serious pollution and emit a lot of harmful gases [3], so we choose carbon monoxide and methane emissions to measure the environmental status of a region. In principle, the resources in space do not belong to any country, but in the process of space mining in the future, human beings will definitely encounter the problem of distribution of the benefits brought by space mining. Usually, a country contributes more to space mining with technology, they deserve more in return. Therefore, technology is a factor that cannot be ignored. We select three factors: Number of R&D researchers, High tech export and Sci tech journal articles to measure a country's technological strength. Finally, a country's energy import and export situation should also be taken into account. The higher a country's dependence on energy imports, the more the country should be favored by the policy of the space energy program. In particular, all our raw data are downloaded from the website `https://data.worldbank.org.cn/`.

5.3 Data Process

As in the previous subsections, we use the ARIMA model to predict how our six selected indicators will change from 2020 to 2050.

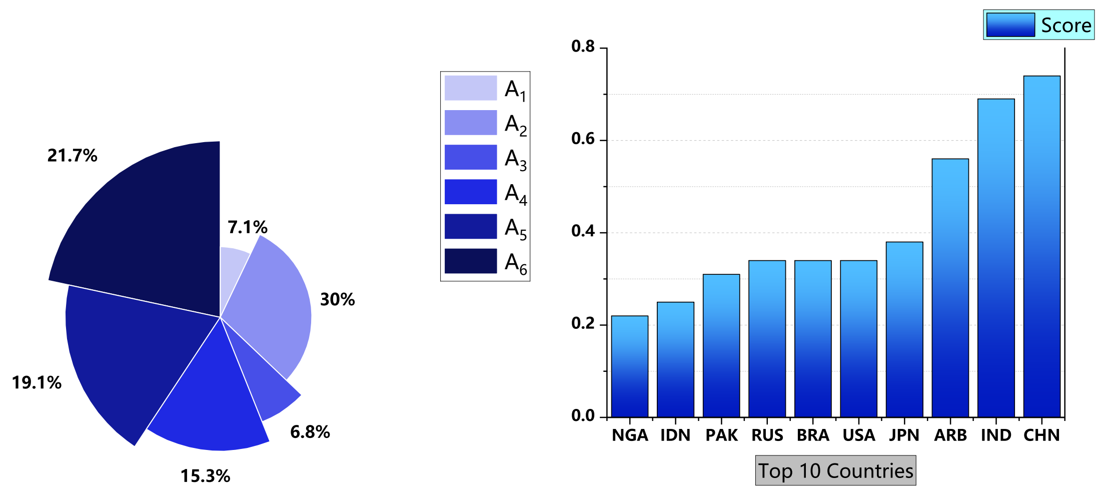
Then we first define the previously selected indicators Social development, Economic development, Mineral resouces, Degree of environmental pollution, Science and technology and Trade situation as A_1, A_2, A_3, A_4, A_5 and A_6 respectively. We put the relationship diagram in **Table 4**.

Because we only need one criterion to ensure the global equity of the income distribution obtained by asteroid mining, we only need to analyze a small sample, so that the obtained results will have better interpretability. In this way, we use entropy weight method to screen the most representative countries to validate our model.

In the entropy weight method, we believe that the data of the country with the largest information entropy is the most representative. We calculate the information entropy scores for all countries and placed the top ten countries and the scores of six indicators via entropy weight method in **Figure 10**.

Table 4: Relationship diagram

Index	Description
A_1	Social developmen
A_2	Economic development
A_3	Mineral resouces
A_4	Degree of environmental pollution
A_5	Science and technology
A_6	Trade situation



(a) The weight of six indicators in the entropy weight method

(b) The weight of six indicators in the entropy weight method

Figure 10: Entropy weight method to select representative countries

To simplify the dataset further, we select six countries by income level, and we put the results of the selection in **Table 5**.

Table 5: The six most representative countries

Income level	Countries
High income	USA JPN
Middle income	CHN IND
Low income	NGA RUS

5.4 Model Construction

When considering model selection, we first pay attention to the characteristics of the problem we need to solve. We need to build a model that takes all the six measurements we mentioned into account to achieve global equity. The weights of the six factors we select obviously cannot be equal, otherwise superpowers like China and the United States will be allocated with most of the resources generated from asteroid mining, which violates the principle of global equity. Therefore, we believe that the weights of these six factors should be country-specific, and that our strategies should take care of needy and backward countries.

In the field of decision-making, the concept of priority is quintessential and how priorities are derived influences the choices one would make. Priorities should be unique and not one of many possibilities, they must also capture the dominance of the order expressed in the judgments of the pairwise comparison matrix[4]. So we choose **Analytic Hierarchy Process(AHP)** to assist us make reasonable decisions to achieve global equity.

5.4.1 Establishment of the Judging Matrix

We have for an n by n consistent matrix $A : A^k = n^{k-1}A, A = \left(w_i/w_j\right)$. A near consistent matrix is a small reciprocal(multiplicative) perturbation of a consistent matrix. It is given by the Hadamard product: $A = W \cdot E$, where $W = \left(w_i/w_j\right)$ and $E \equiv \left(\varepsilon_{ij}\right), \varepsilon_{(ji)} = \varepsilon_{ij}^{-1}$. Small means ε_{ij} is close to one. Unlike an additive perturbation of the form $\alpha_{ij} + \gamma_{ij}$, a reciprocal perturbation $\alpha_{ij}\gamma_{ij}$, $\varepsilon_{(ji)} = \varepsilon_{ij}^{-1}$ is multiplicative. It can be transformed to an additive perturbation of a consistent matrix by writing:

$$\frac{w_i}{w_j} + \gamma_{ij} = \frac{w_i}{w_j}\varepsilon_{ij}, \varepsilon_{ij} = 1 + \frac{w_j}{w_i}\gamma_{ij} \tag{5}$$

$$\varepsilon_{ji} = \varepsilon_{ij}^{-1} = \frac{w_j}{w_i} + \gamma_{ji} = \frac{1}{1 + \frac{w_j}{w_i}\gamma_{ij}} \tag{6}$$

Note that with a reciprocal perturbation we ensure that $\lambda_{\max} \geq n$ which helps determine the validity of ω as a prioroty vector of a near consistent matrix. We have

$$\begin{aligned}\sum_{j=1}^{n} \varepsilon_{ij} &= \sum_{j} \alpha_{ij} w_j / w_i = [Aw]_i / w_i = \lambda_{\max} w_i / w_i \\ &= \lambda_{\max}\end{aligned} \tag{7}$$

The computation

$$\begin{aligned}n\lambda_{\max} &= \sum_{i=1}^{n} \left(\sum_{j=i}^{n} \varepsilon_{ij} \right) = \sum_{i=1}^{n} \varepsilon_{ii} + \sum_{\substack{i,j=1 \\ i \neq j}}^{n} \left(\varepsilon_{ij} + \varepsilon_{ji} \right) \\ &= n + \sum_{\substack{i,j=1 \\ i \neq j}}^{n} \left(\varepsilon_{ij} + \varepsilon_{ji} \right)^{-1} \geq n + \left(n^2 - n \right) / 2 = n^2\end{aligned} \tag{8}$$

reveals that $\lambda_{\max} \geq n$. Moreover, since $x + 1/x \geq 2$ for all $x > 0$, with equality if and only if $x = 1$, we see that $\lambda_{\max} = n$ if and only if all $\varepsilon_{ij} = 1$, which is equivalent to having all $\alpha_{ij} = w_i / w_j$. The foregoing arguments show that a positive reciprocal matrix A has $\lambda_{\max} \geq n$ with equality if and only if A is consistent[4].

In order to get a more reasonable judging matrix, we have consulted a large number of literatures and we found the following conclusions. According to research, Relationships of science and technology growth rate with both population and population growth rate in the past ten thousand years are non-linear[5]. And the positive correlation between human development and GDP is not due to reverse causality but that high levels of human development and of technology change both significantly improve economic performance[6].

While according to the research, findings from various countries confirm the positive effect of ICT on GDP growth. What's more, population growth, because it places increasing pressure on the assimilative capacity of the environment, is also viewed as a major cause of air, water, and solid-waste pollution. Furthermorethe relationship between population pressures and deforestation to create arable land is clearly affected by the use of modern agricultural technology, which reduces land requirements.

In order to obtain the relationship between the importance of the environment, energy consumption and fuel imports, we find that energy consumption and energy imports are of roughly equal importance[7]. And we all know the relationship between excessive energy consumption and environmental pollution, this means that an increase in energy consumption results in a rise in emissions[8].

Combining our findings above, we get the following judging matrix of size 6×6 in **Table 6** and **Figure 11**. And we put the compares of the scale of matrices in **Table 6**.

Table 6: The Judging Matrix

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	1	1/3	1/5	1/7	1/3
A_2	1	1	1/3	1/5	1/3	1/3
A_3	3	3	1	1/3	1/5	1/5
A_4	5	5	3	1	1/3	1/3
A_5	7	3	5	3	1	1
A_6	3	3	5	3	1	1

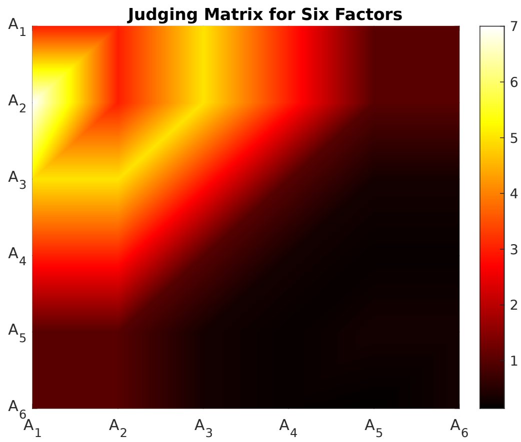


Figure 11: Heat map of judging matrix

Table 7: Compare the scale of matrices

scale	1	3	5	7	9
importance	the same	slightly stronger	strong	obviously strong	absolutely strong

5.5 Impact of Changing Conditions on Global Equity

We use the AHP algorithm to obtain the change in the proportion of resources that should be allocated to six countries over the years, and predict the trend of this proportion change until 2050. From the **Figure 12**, we can see that with the change of time, the various situations of countries are also changing, and the proportion of space minerals that should be allocated to each country is also changing. For example, according to our forecast, the proportion of the United States' asteroid mining revenue will be larger.

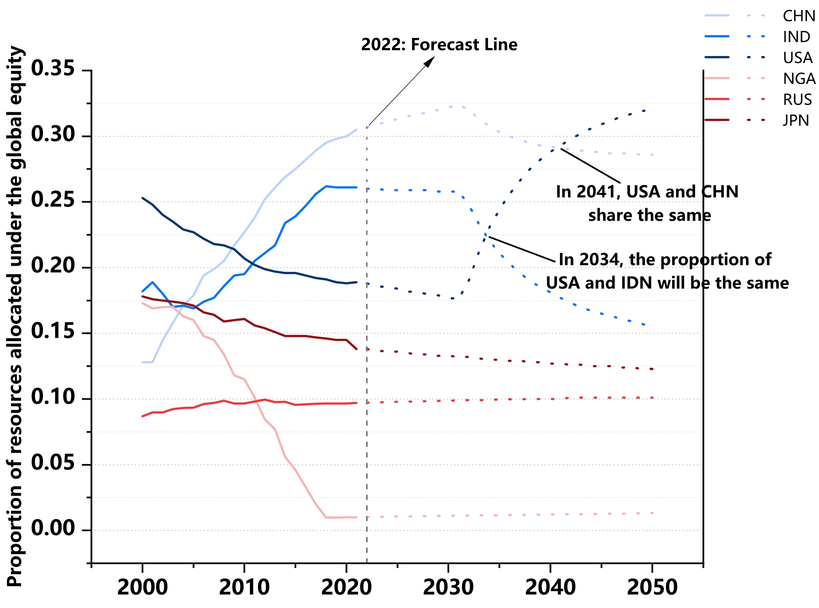


Figure 12: Proportion of the six countries over time and projections to 2050

In this subsection, we introduce the Gini index to measure the fairness property of resource allocation in different regions. The fairness property of dataset can be measured by the Gini value:

$$\mathrm{Gini}(D)=\sum_{k=1}^{|y|}\sum_{k'\neq k}p_k p_{k'}=1-\sum_{k=1}^{|y|}p_k^2 \tag{9}$$

Not only does the data for each country change over time, but the relative importance of the different indicators also changes over time. To make our model feasible, we adopt an attribute conditional independence assumption: for known classes, we assume that all the metrics we propose in this section are independent of each other. In other words, it is assumed that each attribute affects the classification result independently. For example, when we change the importance of technology to other factors, the importance of other factors does not change.

We select the factors of technology and environmental pollution, and through our model, we can get what impact they will have on the Gini index of the entire region as their importance increases. The increase in the Gini index means that the distribution of energy in the region tends to be more unequal, in other words, the index of equity falls.We present the results in **Figure 13**.

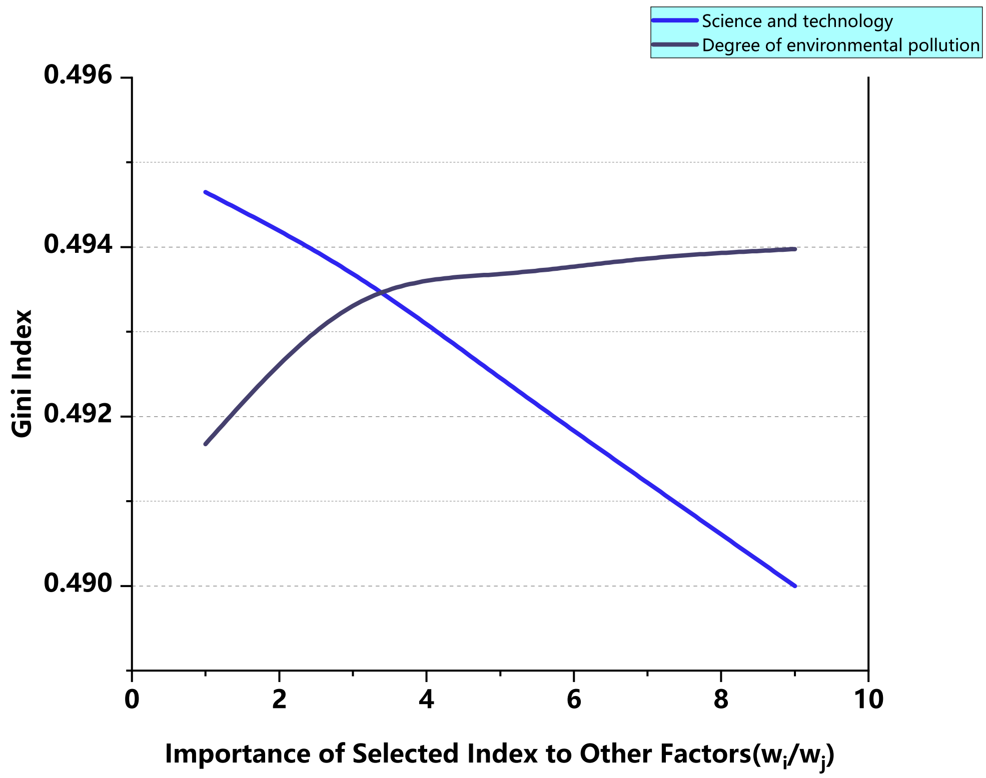


Figure 13: Variation of Gini index with changing importance

With the continuous development of science and technology, scientific and technological strength plays an increasingly important role in space mining. From the above figure, we can observe that if the weight of technology in energy distribution becomes larger, the Gini coefficient between different regions will become smaller, and the corresponding global equity will have a greater possibility. Conversely, if global mineral mining is constantly producing pollution, the world will tend to become more and more unequal.

5.6 Conclusion

To sum up, science and technology will undoubtedly play an increasingly important role in the future, especially in the field of asteroid mining. Through our analysis, if the importance of technological factors in the distribution of extraterrestrial energy is increasingly high, the world will tend to be more fair in resource allocation. Through our analysis of another indicator, we unfortunately found that if the world's degree of pollution is continuously rising, it will inevitably lead to unbalanced development among regions, and ultimately lead to devastation to global equity.

6 Policy Recommendations

Based on the conclusions reached in the previous subsection, we find that increasing the emphasis on science and technology can narrow the gap in the allocation of space resources between regions, which is meant to promote more global equity. In addition, we found that if we continue to look at the earth indifferently If the environmental pollution in China becomes more and more serious, then global equity will only be further damaged. Therefore, we put forward suggestions on the formulation of UN policies from the perspectives of scientific and technological development and environmental protection.

First of all, the policy recommendations we put forward have great limitations. This does not mean that the policy recommendations are incorrect, but that the policies of the United Nations cannot be fully implemented and carried out in the world. However, according to our previous analysis, if the policies we put forward are implemented, the world will become more fair and harmonious, and the people of all countries will have a better life.

Specifically, according to the previous conclusions, we find that the distribution of space mineral resources in an appropriate way will narrow the development gap between different countries in the world, that is, strengthening global equity. At the same time, strengthening the attention to science and technology can narrow the gap in the distribution of space resources among regions, which means promoting greater global equity. In addition, we find that if we continue to ignore the earth and if Chinas environmental pollution becomes more and more serious, global equity will only be further damaged. Therefore, we put forward suggestions on the formulation of UN policies from the perspective of resource allocation, scientific, technological development, and environmental protection.

6.1 Distribution of planetary mineral resources

We believe that the United Nations outer space treaty should face possible space mining in the future according to the following ideas:

- The allocation of space resources refuses the first-come, first-served rule, but is allocated according to a certain proportion. Even if a considerable number of countries are temporarily unable to mine, the countries that can mine should also trade resources with the countries that cannot mine after harvesting their share.
- The price of space mineral resources trade should be jointly set by mining countries and the United Nations to prevent mining countries from exploiting countries unable to conduct space mining.

6.2 Scientific and Technological Development

We believe that the UN Outer Space Treaty timetable should consider the following time points and the goals that should be achieved at the corresponding time points, which will better promote global equity. We present the timetable in the following figure.

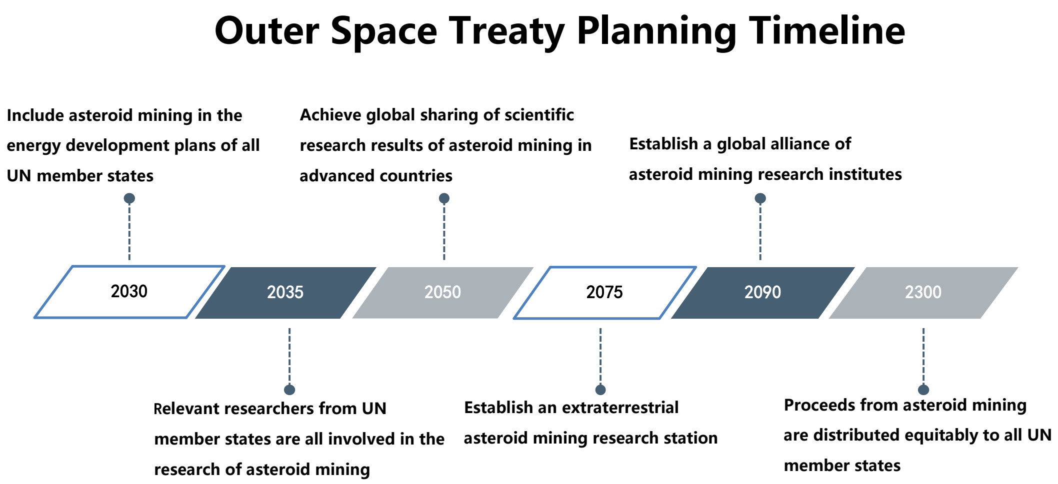


Figure 14: Outer Space Treaty Planning Timeline

6.3 Environmental protection

According to our conclusions in Section 3, environmental pollution will increase inequality between regions, so we believe that UN policy should take environmental protection into the scope of the Outer Space Treaty. We have put our recommendations in the table below.

The Promotion of Environmental Protection

Policy Recommendations	Specific Measure
Maximize the use of clean energy	Deploying renewable energy in end-use sectors
	Deploying renewable energy in the power sectors
Energy Saving and Energy Efficiency	Improve energy efficiency and increase energy efficiency in the heating and cooling
	Improve energy efficiency in the transportation sector
Utilization of asteroid mining resources	Replacing the energy extracted from the earth with the energy obtained from space mining, reducing the environmental damage and pollution caused by mining
	Gradually transfer the processing of energy from space mining outside the earth to reduce pollution to the earth
Reduce pollution in underdeveloped areas	Reduce the phenomenon of serious pollution caused by the exploitation of minerals in the developed areas by taking advantage of low human rights in the global development area, and increase tariffs on such incidents

Figure 15: The Promotion of Environment Protection

7 Strengths and Weaknesses

7.1 Strengths

1. Novelty. To the best of our knowledge, we are the rst to propose an AHP Hybrid Entropy Weight Method Model for global equity evaluations which involves historical and/or regional analyses.

2. Generazation. Our proposed framework can freely be implemented to any data set e.g., whether it is global equity within a region or a comparison of global equity between regions.

3. Robustness. Our model shows great robustness to most of the parameters.

4. Simpleness and Effectiveness. We can establish a simple and effective model without considering all the details of the problem.

7.2 Weaknesses

1. Missing other potentially relevant factors. For instance, we do not take types of energy obtained by asteroid mining into consideration when analyzing factors affecting global equity.

2. Missing data set partitions. If we divide the data set into a training set, validation set, and test set, we can optimize the hyperparameters of the model and greatly reduce the generalization error of the model with the validation set, as well as evaluate and improve the accuracy of the model with the test set.

3. Missing the careful consideration of the actual distribution of mineral resources recovered from the planet. We havent premeditated how and who will buy and sell between countries are not considered, but the simple assumption that the cost is consistent with mining on the earth is extremely incompatible with reality.

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Appendices

Appendix A Core Codes For Entropy Weight Method

Input python source:

```
def std_data(value,flag):
    for i in range(len(indicator)):
        #print(flag[i])
        if flag[i]=='+':
            value[:,i]=(value[:,i]-np.min(value[:,i],axis=0))/\\
            (np.max(value[:,i],axis=0)-np.min(value[:,i],axis=0))+0.001
        elif flag[i]=='-':
            value[:,i]=(np.max(value[:,i],axis=0)-value[:,i])/\\
            (np.max(value[:,i],axis=0)-np.min(value[:,i],axis=0))+0.001
    return value

#Define the entropy value method function, \\
#and the entropy value method calculates the weight of the variable
def cal_weight(indicator,project,value):
    p= np.array([[0.0 for i in range(len(indicator))]\\
                 for i in range(len(project))])
    #print(p)
    for i in range(len(indicator)):
        p[:,i]=value[:,i]/np.sum(value[:,i],axis=0)

    e=-1/np.log(len(project))*sum(p*np.log(p)) # Calculate the entropy value
    g=1-e     # Calculate the degree of consistency
    w=g/sum(g)      # Calculate weights
    return w
```

Appendix B Core Codes For AHP

some more text **Input Python source:**

```
class AHP:
    def __init__(self, criteria, b):
        self.RI = (0, 0, 0.58, 0.9, 1.12, 1.24, 1.32, 1.41, 1.45, 1.49)
        self.criteria = criteria
        self.b = b
        self.num_criteria = criteria.shape[0]
        self.num_project = b[0].shape[0]

    def cal_weights(self, input_matrix):
        input_matrix = np.array(input_matrix)
        n, n1 = input_matrix.shape
        assert n == n1, 'not a square matrix'
        for i in range(n):
            for j in range(n):
                if np.abs(input_matrix[i, j] *\\
```

```
                input_matrix[j, i] - 1) > 1e-7:
                    raise ValueError('not an \\
                    anti-mutually symmetric matrix')

        eigenvalues, eigenvectors = np.linalg.eig(input_matrix)

        max_idx = np.argmax(eigenvalues)
        max_eigen = eigenvalues[max_idx].real
        eigen = eigenvectors[:, max_idx].real
        eigen = eigen / eigen.sum()

        if n > 9:
            CR = None
            warnings.warn('Unable to judge consistency')
        else:
            CI = (max_eigen - n) / (n - 1)
            CR = CI / self.RI[n-1]
        return max_eigen, CR, eigen

    def run(self):
        max_eigen, CR, criteria_eigen = \\
        self.cal_weights(self.criteria)
        print('Criterion layer: maximum eigenvalue {:<5f}, CR={:<5f},
              test {} passed'\
              .format(max_eigen, CR, '' if CR < 0.1 else 'no'))
        print('Criterion layer weight={}\n'.format(criteria_eigen))

        max_eigen_list, CR_list, eigen_list = [], [], []
        for i in self.b:
            max_eigen, CR, eigen = self.cal_weights(i)
            max_eigen_list.append(max_eigen)
            CR_list.append(CR)
            eigen_list.append(eigen)

        pd_print = pd.DataFrame(eigen_list,
                                index=['criterion' + \\
                                       str(i) for i in \\
                                       range(self.num_criteria)],
                                columns=['plan' + \\
                                         str(i) for i in \\
                                         range(self.num_project)],
                                )
        pd_print.loc[:, 'largest eigenvalue'] = max_eigen_list
        pd_print.loc[:, 'CR'] = CR_list
        pd_print.loc[:, 'Consistency check'] = pd_print.loc[:, 'CR'] < 0.1
        print('Scheme layer')
        print(pd_print)

        # Criterion layer
        obj = np.dot(criteria_eigen.reshape(1, -1), np.array(eigen_list))
        print('\nCriterion layer', obj)
        print('The best scheme is the plan{}'.format(np.argmax(obj)))
        return obj
```