Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
F		2213595

Will global equity mind asteriod mining?

Summary

With the development of science and technology, mankind has made great achievements in space exploration, and at some point in the future, mankind will begin to utilize space resources. Undoubtedly, technology is getting more and more advanced, global equity, however. is not necessarily increasing. This article will center on how asteroid mining will affect global equity.

For question 1, we divide global equity into short-term equity, which refers to short-term reward allocation equity, and long-term equity, which refers to smaller gap between the comprehensive capacity of regions. Indicators from five dimensions: science and technology, economy, industry, mineral resources and educational resources as well as 20 typical countries, which are then divided into 6 regions, are selected, to build the **Model I: Comprehensive Capacity Model**, combined with entropy-based TOPSIS. Then the QSPM is used to build the **Model II: Short-term Equity Evaluation Model**. The Lorenz curve is introduced to establish the **Model III: Long-term Equity Evaluation Model**. The global equity coefficient (G) is calculated to be 0.423, with a D grade global equity, indicating relatively inequitable global development. Analyzing the indicators of 2000, 2010, and 2020, the global inequity increases over time.

For question 2, based on model I, after asteroid mining begin, the benefit allocation ratio of America, Asia, Europe, Australia, South America, and Africa are 0.4073, 0.3338, 0.1676, 0.0403, 0.0369, and 0.0149, leading to a more serious global short-term equity problem. **Model IV: Long-term Development Model** is built to observe the changes of global strength of each region. After 50 years, G is 0.422, the global inequity problem is still serious. Therefore, our vision is that with the proposed policy adopted, the short- and long-term global equity situation is promoted, with the benefit allocation ratio of 0.2620, 0.2147, 0.1078, 0.1296, 0.1899, and 0.0959, respectively. After 50 years, the expected scores of the six regions are 0.8515, 0.8121, 0.6942, 0.7393, 0.6377,and 0.6193, respectively. G is 0.066, with A grade global equity, which is absolute equity level.

For question 3, the amount of contribution of five dimensions are assumed to change, and how the short-term equity changes is observed. Combined increase in the participation of Australia, South America, and Africa in the five dimensions by 5, 8, and 10 times, the total benefits allocated to the two weakest regions, South America and Africa, is 0.2858, which doubles compared with separate increase. Therefore, the integrated adjustment of the five indicators is necessary to better improve equity.

For question 4, previous analysis suggests that polices related to the five dimensions are expected to adjust integratedly. Recommending policies, including specific terms, members of mining council, equity principle are proposed to update the Outer Space Treaty.

Keywords: Global equity, asteroid mining, entropy-based TOPSIS, Lorenz curve, QSPM

Contents

1 Introduction

1.1 Problem Background

On any planet, the mineral reserves of heavy elements are limited. For the Earth, from the current proven reserves and consumption, the three heavy metals of gold, zinc and lead have a reserve-to-production ratio of less than 20 and will face mining depletion in the next 20 years if they are not recycled. Similarly, nickel, copper, manganese, the three main metals used in industrial production will also be depleted in 50 years. Therefore, mining outer space resources outside the Earth can be a way to solve the energy problem. However, when asteroid mining comes into reality, we will also be faced with another problem: will the allocation of space resources lead to more global inequity? In the era of globalization, global equity is a widespread concern. Reducing global inequity has been the goal of the United Nation, and is also the consensus of international space treaty. However, the Outer Space Treaty lacks specific details to provide guidance to this goal[1].

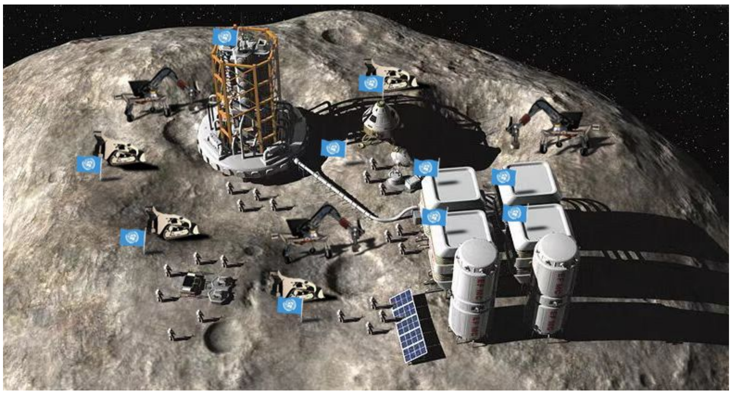


Figure 1: Vision of asteroid mining

1.2 Restatement of the Problem

- **Task 1**

  Define global equity and build a model to measure global equity, and validate our model.

- **Task 2**

  Put forward a vision for the future of asteroid mining, and analyze the impact of mining on global equity .

- **Task 3**

  Develop and apply an analytical approach to explore how changes in the asteroid mining sector could impact global equity.

- **Task 4** Propose policies on that asteroid mining sector, which help promote global equity.

1.3 Our work

For problem 1, we select 20 typical countries in the world and divide them into 6 regions according to geography and strength factors. We innovatively combined TOPSIS and entropy weight method to establish a comprehensive capacity assessment model from five dimensions of science, technology, economy, industry, mineral resources and education. On the basis of the comprehensive capability assessment model, the equity assessment model is established from the short and long term perspectives. In the short-term equity evaluation model, QSPM matrix is used to solve the problem of input and benefit distribution. In the long-term equity assessment model, we introduce Lorenz curve and define equity coefficient (G) to measure global development balance, and we measure changes in global equity by analyzing global aggregate capacity in 2000, 2010, and 2020.

For problem 2, by using the short-term and long-term equity evaluation model established in Question 1, we find that after asteroid mining, there is the problem of unfair income distribution, which will lead to a more serious global short-term equity problem. To analyze the changes in long-term equity, we build a long-term development model and plot the change curve of comprehensive capacity in different regions of the world after the 50 years of asteroid mining. We show that global inequality remains a serious problem unless policies are adopted to promote global equity. In this regard, we hope that by adopting targeted policies, the short-term equity can be changed and the comprehensive capacity gap of the six regions can be reduced within 50 years, and the vision of global equity can be presented in the future.

For problem 3, on the basis of question 1 and question 2, we change the contribution amount of each dimension respectively to observe the change of short-term equity. The participation of Oceania, South America and Africa in these five dimensions is changed to 5, 8 and 10 times of the original, respectively, and we calculate the distribution of countries.

For problem 4, we propose relevant policies to solve the global equity problems that asteroid mining may bring based on the vision of global equity in the future and the current situation of global equity. It is hoped that through policy adjustments, asteroid mining can promote global equity and truly benefit humankind.

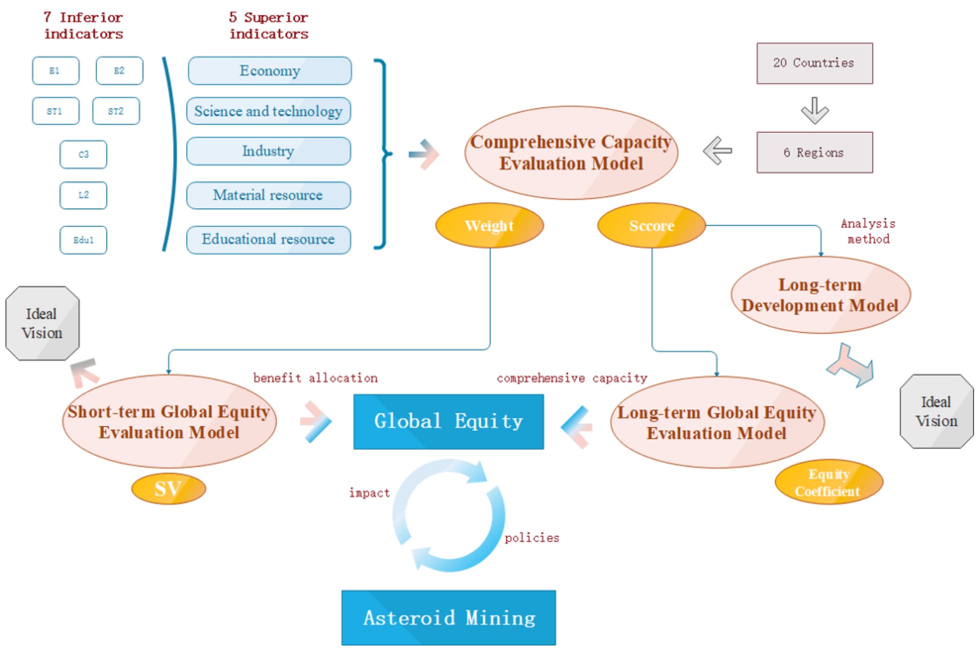


Figure 2: Our work

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.

1. **Assume that earth's resources can support space activities such as asteroid mining for a certain period of time.**

   With the rapid development of human technology, asteroid mining will become a reality in the near future, and earth resources can be used to support mining and space activities.

2. **Assume that all countries are willing to support and participate in asteroid mining.**

   Asteroid mining plays a very important role in the development of human beings, and all countries can obtain corresponding benefits by cooperating with planetary mining.

3. **Assume that the benefits of asteroid mining are distributed according to the degree of input of each country.**

   In order to encourage the development of planetary mining, the final benefit distribution is based on the degree of participation and contribution to asteroid mining.

4. **Assume that the relative strength of global power will be similar when asteroid mining is achieved.**

   Assume no large-scale wars, severe economic crises, natural disasters, etc., the relative strength of different regions of the world remains constant.

3 Notations

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

Table 1: Notations used in this paper

Symbol	Definition
W_i	The weight represents the influence degree of each evaluation index
$\tilde{S}$	Scores measure the degree of development in a region
ES	Evaluation Scores, The amount of input per participating unit
SV	A standard value for the distribution of profits per unit of input
G	Equity coefficient, a measure of global inequality in development

4 Global Equity Evaluating Model

Before the equity definition is given, we select indicators and build a model to evaluate the comprehensive capacity of the countries. Then, the equity is divided into long-term equity and short-term one, and the corresponding models to evaluate them are build.

4.1 Indicators Description

With the progress of science and technology, people have started to explore outer space. However, there exist many differences in aspects such as science and technology and economy, between different countries, due to history, region and other factors. There are also some unequal factors in the exploration and use of space resources. Seven indicators are selected from five dimensions: economy, industry, science and technology, mineral re-sources, and educational resources to measure a country's comprehensive resources, which will be used later to measure the Equity coefficient.

Table 2: Indicators and Corresponding Description

Superior	**Inferior**	**Description**
Economy (E)	Real GDP per capita	It reflects the level of economic development of a country or region.
	The number of listed companies	It reflects the economic dynamism and sustainability of a country.
Industry (Ind)	Carbon dioxide emissions	The greenhouse gas emissions generated by the production, transportation, use and recycling of products, which can reflects the industrial level.
Science & technology (ST)	Research expenditure	It includes the cost of research equipment, materials, etc., and is the foundation of governments exploring frontier science.
	The number of on-orbit satellite	It reflects the spaceflight level as well as a country's comprehensive strength.
Material resource (Ma)	Exploitable material reserve	Resource-rich countries can be less rely on imports of raw materials and benefit from its rich reserve.
Educational resource (Edu)	The number of colleges and universities	It reflects the opportunity a children have to receive education, and to live better lives.

4.2 Comprehensive Capacity Model

Considering that neighboring countries often have similar comprehensive capabilities and can easily conduct scientific and technological exchanges as well as strategic cooperation, we divide the countries according to their geographical location. Then, 20 typical countries in six continents: North America, Europe, Oceania, South America, Asia, and Africa, are selected for analysis.

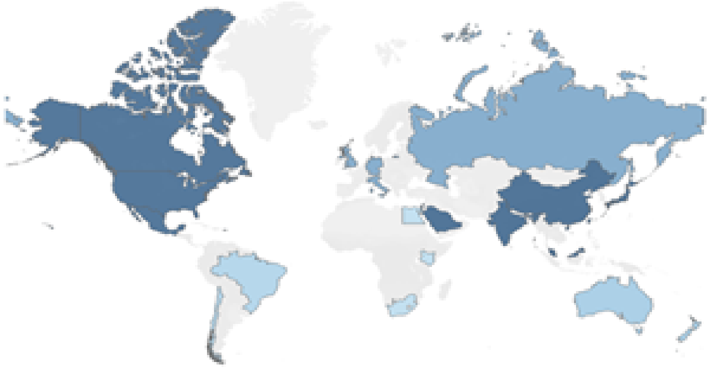


Figure 3: The countries we select in present of different continents

We consider using Analytic Hierarchy Process (AHP) or Technique for Order Prefer-ence by Similarity to Ideal Solution (TOPSIS) to evaluate comprehensive resources[2]. How-ever, the judgment matrix in AHP relies on experts, whose subjectivity can have a great impact on the results. Therefore, TOPSIS is used to build our model. In order to avoid the shortcoming of TOPSIS that it cannot weight the indicators, we combine the entropy weight method to improve it, and then determine the weights of the indicators. The entropy-based TOPSIS is divided into the following steps:

Step1: Unify the indicator types

In general, the indicators are classified into two types: benefit and cost. The benefit indicators means that a higher value is better while for the cost criterion is valid the opposite.

Cost indicators are all converted into benefit types. Then, we get positive-index matrix X.

$$X = \begin{array}{c} \\ C_1 \\ \vdots \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & \cdots & \cdots & A_m \end{array} \\ \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{pmatrix} \end{array}$$

Step2: Normalize the matrix X

The data of the decision matrix D come from different sources, so it is necessary to normalize it in order to transform it into a dimensionless matrix, which allow the comparison of the various criteria. In this work, we use the normalized decision matrix $\tilde{z} = \left[z_{ij}\right]_{m\times n}$ with i=1,..,n, and j=1,...,m. The normalized value is calculated as:

$$\tilde{z}_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{n} x_{ij}^2} \tag{1}$$

Step3: Calculate probability matrix P

$\tilde{P} = \left[p_{ij}\right]_{m\times n}$ with i=1,..,n, and j=1,...,n. The value p_{ij} is calculated as:

$$p_{ij} = \tilde{z}_{ij} / \sum_{i=1}^{n} \tilde{z}_{ij} \tag{2}$$

Step4: Calculate the entropy weight of each indicator

For the j-th indicator, the information entropy is defined as:

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij}\ln(p_{ij})(j=1,2,\cdots,m) \tag{3}$$

Utility value is defined as:

$$d_j = 1 - e_j \tag{4}$$

Normalize it and we can obtain entropy weight:

$$W_j = d_j / \sum_{j=1}^{n} d_j \, (j=1,2,\cdots,m) \tag{5}$$

Step5: Score using TOPSIS

Identify the maximal value Z^+ and minimal value Z^- as follows:

$$Z^+ = \left(Z_1^+, Z_2^+, \cdots, Z_m^+\right) = (\max\{z_{11}, z_{21}, \cdots z_{n1}\}, \max\{z_{12}, z_{22}, \cdots z_{n2}\}, \cdots, \max\{z_{1m}, z_{2m}, \cdots z_{nm}\})$$

$$Z^- = \left(Z_1^-, Z_2^-, \cdots, Z_m^-\right) = (\min\{z_{11}, z_{21}, \cdots z_{n1}\}, \min\{z_{12}, z_{22}, \cdots z_{n2}\}, \cdots, \min\{z_{1m}, z_{2m}, \cdots z_{nm}\})$$

Calculate the Euclidean distances from the maximal value Z^+ and minimal value Z^- of each evaluation object Ai , respectively as follows:

$$\begin{aligned} D_i^+ &= \sqrt{\sum_{j=1}^{m} W_j \left(Z_j^+ - z_{ij}\right)^2} \\ D_i^- &= \sqrt{\sum_{j=1}^{m} W_j \left(Z_j^- - z_{ij}\right)^2} \end{aligned} \tag{6}$$

Finally, we can calculate the score of evaluation object Ai as given by:

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{7}$$

And normalize it as follows:

$$\tilde{S}_i = S_i / \sum_{i=1}^{n} S_i \tag{8}$$

With entropy-based TOPSIS, importance of economy, industry, science and technology, mineral resources, and educational resources to the regional comprehensive capacity is calculated and shown in the following table:

Table 3: Indicators Weights for Regional Comprehensive Resources

Economy	**Industry**	**Science & Technology**	**Mineral resources**	**Educational resources**
0.1673	0.1267	0.4795	0.0796	0.1479

The results show that science and technology is the most important for the development of the region, with the percentages of 0.4795.

The scores for the 20 countries are as follows:

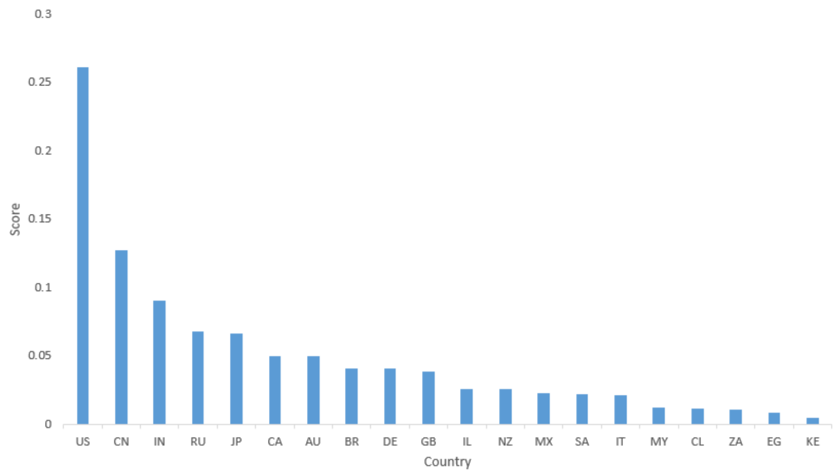


Figure 4: The scores for the 20 countries

Then, scores for 6 regions are calculated and shown as below:

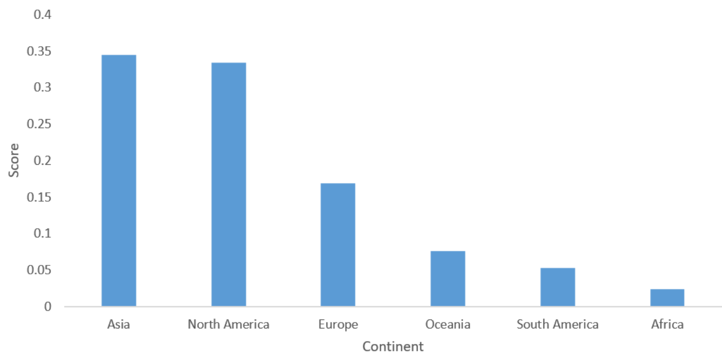


Figure 5: The scores for 6 regions

Table 4: Scores for 6 regions

Region	**North America**	**Asia**	**Europe**	**Oceania**	**South America**	**Africa**
Score	0.3344	0.3442	0.1687	0.0757	0.0529	0.0241

The development of different regions around the world varies greatly. Among them, North America and Asia have the highest scores, 0.3344 and 0.3442 respectively, while the development of South America and Africa is sluggish.

4.3 Global Equity Evaluation Model

4.3.1 Definition of Global Equity

Equity is divided into short-term equity and long-term equity.

Short-term equity: In a short term, countries are rewarded for their contribution.

Long-term equity: Gap between the strong and the weak countries is narrowed in a long term, so that global development is balanced.

4.3.2 Short-term Equity Evaluation Model

Quantitative Strategic Planning Matrix (QSPM) is a strategic management tool used in the evaluation of strategic options and determination of relative attractiveness of strategies. The QSPM technique determines which of the selected strategic options is feasible, and prioritizes these strategies. In our article, QSPM will be used to determine benefits allocation, which reflects equity in a short term.

Top row of QSPM consists of key external and internal factors, which are the seven indicator selected in the Section 4.1, and the Left column consists of strategies, which we define as the region that will take responsibility. In a row adjacent to the critical indicators, the respective weights received by each factor are listed. For each indicator, the evaluation score(ES) for each strategy is determined, and then the total evaluation score (TES) as well as the standard value of benefit distribution (SV) for each unit is calculated, specifically as follows:

Step1: Make a list of the key indicators, and assign weights W_i to the i-th indicator, which are given by Section 4.

Step2: The values of ES are given, which are related to the amount of input for each unit.

Step3: The TES are calculated: $TES_i = ES_i \times W_i$.

Step 4: Calculate the SV for each unit: $SV = \sum_{i=1}^{N} TES_i$.

Step 5: Normalize the SV.

4.3.3 Long-term Equity Evaluation Model

In measuring long-term global equity, we creatively introduce the Lorenz curve and Gini coefficient. The Lorenz curve is a way of showing the distribution of income or wealth within an economy. It was developed by Max O.Lorenz in 1905 for representing inequity of wealth distribution.

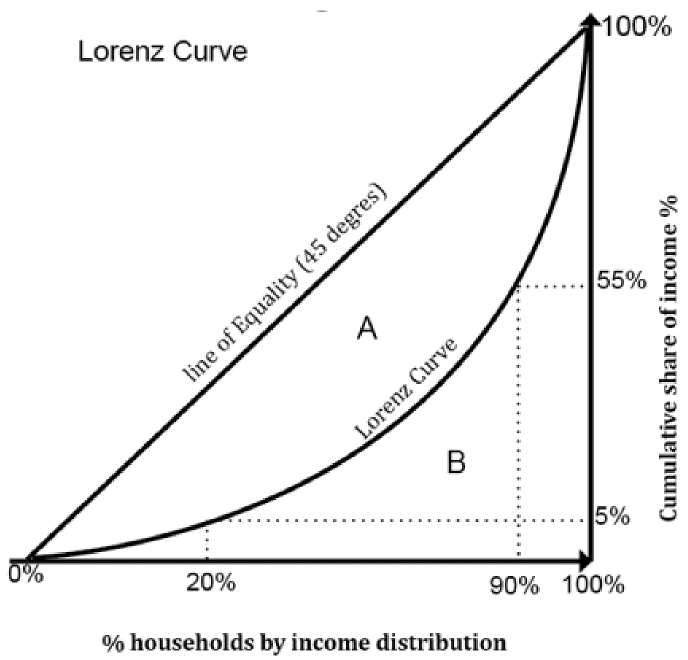


Figure 6: Diagram of Lorenz Curve

$\widetilde{OHL}$ & $\widetilde{ODL}$ is the Lorenz curve, and the line y = x is called the "line of perfect equity." Area A, the area between the Lorenz curve and the line of perfect equity, is called the "inequity area". When the income distribution reaches full inequity, the Lorenz curve becomes a dash $\widetilde{OHL}$. And the area between the $\widetilde{OHL}$ and the line of perfect equity, which is A+B, is the "perfect inequity area". Here, like Gini coefficient, equity coefficient G is introduced to quantitatively describe the degree of global equity. The equity coefficient G is given as follows:

$$G = \frac{A}{A+B} \tag{9}$$

When plotting the Lorenz curve, S_i(=1,. ,6) is rearranged in descending order, with the cumulative portion of the number of regions taken as X_i and the cumulative portion of the total scores obtained in Section 4.2 as Y_i , and then points (X_i, Y_i) are connected.

$$X_i = \frac{\sum_{j=1}^{i} n_j}{N} \tag{10}$$

$$Y_i = \sum_{j=1}^{i} \widetilde{S_i} \tag{11}$$

4.4 Results and Model Validation

From the results, the equity coefficient G is calculated as 0.423, and the Lorenz curve is plotted as below:

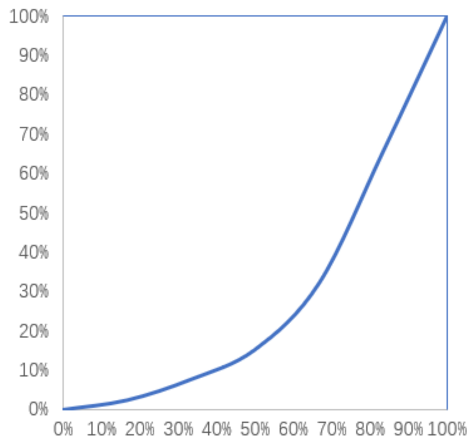


Figure 7: Calculated Lorenz Curve

When G is closer to 0, the global inequity is lower, and when G is closer to 1, the global inequity is higher. The scale for equity coefficient is defined in the following table(Table). It can be seen that there is relative inequity between global regions, with a D grade equity coefficient.

Table 5: Equity Coefficient Evaluation Scale

Equity Coefficient	Grade	Comment
<0.2	A	Absolutely equitable
$0.2 \sim 0.3$	B	Relatively equitable
$0.3 \sim 0.4$	C	Relatively reasonable
$0.4 \sim 0.5$	D	Relatively inequitable
$0.5 \sim 0.6$	E	Significantly inequitable

Considering the historical factors, the data of 2000, 2010 and 2020 is selected for analysis and their corresponding Lorenz curves are as follows:

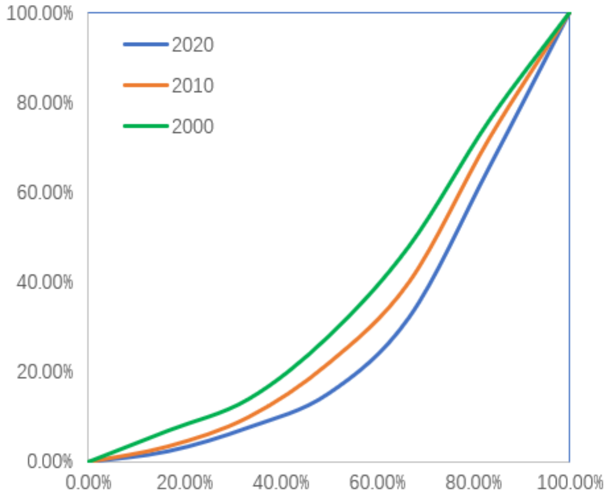


Figure 8: Lorenz curves for 2000, 2010 and 2020

From the graph, it can be seen that the global inequity gradually increases over the past 20 years as the real situation, and in the future with asteroids mining, there might be more se-rious global inequity.

5 Future with Asteroid Mining

As stated in previous section, there is extremely uneven across global regions. In a short term, the investment in mining asteroids varies and, therefore, the benefits obtained vary widely. In the long run, the power disparity among global regions is large, and even if the short-term distributional equity problem is solved, there will still be inequity in the long-term development. As a result, the impact of asteroid mining on global equity will be analyzed in both short- and long-term perspectives, and targeted policies as well as corresponding visions will bee given, to constitute a planning blueprint for short-term distributive equity issues and long-term development equity.

5.1 Asteroid Mining plan

Space mining is supposed to be conducted in the following three phases:

1.Reparation, including renewal and repair of global space assets, cleanup and maintenance of the space environment. Industries that used to rely on ground-based equipment and technology will be complemented by space-based.

2.Exploration, including solar energy, space telescopes and other technological developments. Near-Earth space applications are gradually improved, and the whole space industry moves toward more sophisticated use of space exploration.

3.Migration. Space manufacturing industry and process technology is more complete. Space technology will focus mainly on the exploration of Earth-like planets, soil analysis and planet transformation, base construction, etc. Cosmic 3D printing is mature, and planetary mining-related industrial chain is formed, including rocket engines, chips, new materials, precision devices, satellite remote sensing, satellite communications, satellite navigation, satellite research and development and component manufacturing, telescopes and robotic arms, astronautics batteries, astronautics 3D printing, etc.

5.2 Short-term Impact

In Model 1, we measure global equity, which turns out to be relatively inequitable. Since the underdeveloped regions are weak in science and technology and slow in economic development, these regions will lag behind the developed regions in space resource development. As a result, developed regions may monopolize most of the space resources, which will aggravate the global inequity.

Therefore, our vision involves cooperation between global regions, so that each region can play its advantages, and win-win in the exploitation of space resources. In this way, underdeveloped will be able to enjoy resources and benefits with developed regions, thus reducing global inequity.

In Model 1, seven key indicators affecting the regional strengths: science and technology, economy, industry, mineral resources, and educational resources, are selected and their weights are calculated, which are 0.4795, 0.1673, 0.1267, 0.0796, and 0.1460, respectively.

Therefore, we envision that for the six regions we have divided, each region, according to its strengths, provides support for cooperation in asteroid mining. Based on the data in 4.1 with the 7 evaluation indicators, the comparative advantage are defined as,

$$\eta_{ij} = d_{ij} / \sum_{j=1}^{N} d_{ij} \tag{12}$$

where d_{ij} is the value of the i-th indicator of the j-th region. A bar chart is made to visually present their values in the different regions (Figure 9).

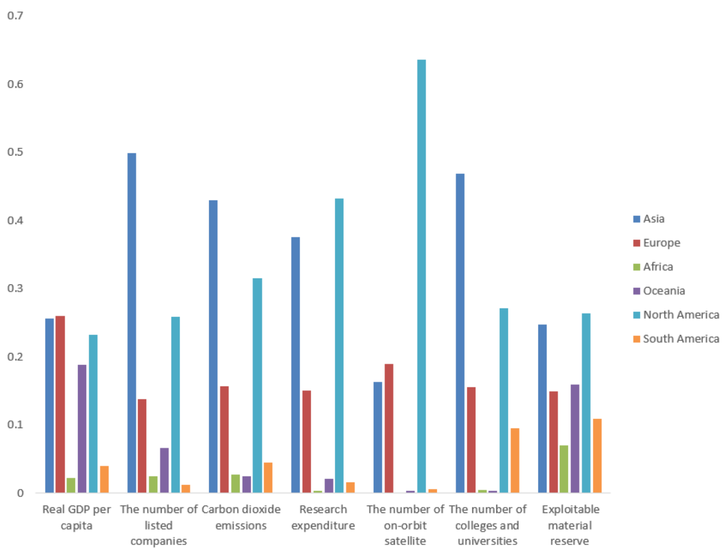


Figure 9: Values in the different regions

From the figure above, North America, Asia, and Europe have relatively large ad-vantages in these 7 aspects, while Africa and South America have a small gap with other regions only in the aspect of natural resources, and a large gap in economic, technological, and industrial development. Therefore, in the future with asteroid mining:

• The North America, Asia, Europe, and Oceania should provide support in technology and funding, and undertake relevant scientific research tasks.

• Most countries in Africa and South America should facilitate the launch of spacecraft and asteroid mining because of their proximity to the equator, and large populations.

• As for the distribution of benefits, besides the distribution according to contributions, Africa and South America should be given scientific, technological and economic sup-port by developed regions because of their weak regional strength.

Asteroid mining will involve global cooperation, and countries with strong comprehensive ability, especially those with outstanding science and technology and economic strength, can invest more resources and thus reap greater benefits[3]. For the Evaluation Scores (ES), we select the comparative advantage . The QSPM[4] is shown in the following table:

Table 6: QSPM for six regions

Superior indicator		**Economy**		**Science & Technology**		**Industry**	**Material resource**	**Educational resource**
Inferior indicator		E1	E2	ST1	ST2	Ind1	Ma1	Edu1
Wights		0.0568	0.1105	0.2002	0.2793	0.1267	0.0796	0.1469
North Ame	ES	0.2320	0.2594	0.4329	0.6368	0.3155	0.2643	0.2719
	TES	0.0132	0.0287	0.0867	0.1779	0.0400	0.0210	0.0400
Asia	ES	0.2567	0.4996	0.3760	0.1635	0.4297	0.2469	0.4694
	TES	0.0146	0.0552	0.0753	0.0457	0.0544	0.0197	0.0690
Europe	ES	0.2605	0.1381	0.1500	0.1894	0.1570	0.1488	0.1557
	TES	0.0148	0.0153	0.0300	0.0529	0.0199	0.0118	0.0229
Oceania	ES	0.1879	0.0663	0.0253	0.0030	0.0253	0.1598	0.0032
	TES	0.0107	0.0070	0.0051	0.0008	0.00321	0.0127	0.0005

South Ame	ES	0.0404	0.0124	0.0159	0.0059	0.0446	0.1097	0.0954
	TES	0.0023	0.0014	0.0032	0.0016	0.0057	0.0087	0.0140
Africa	ES	0.0224	0.0243	0.0037	0.0015	0.0279	0.0705	0.0044
	TES	0.0013	0.0027	0.0007	0.0004	0.0035	0.0056	0.0006

The values of SV for North America, Asia, Europe, Oceania, South America, and Africa are: 0.4073, 0.3338, 0.1676, 0.0403, 0.0369, and 0.0149, respectively.

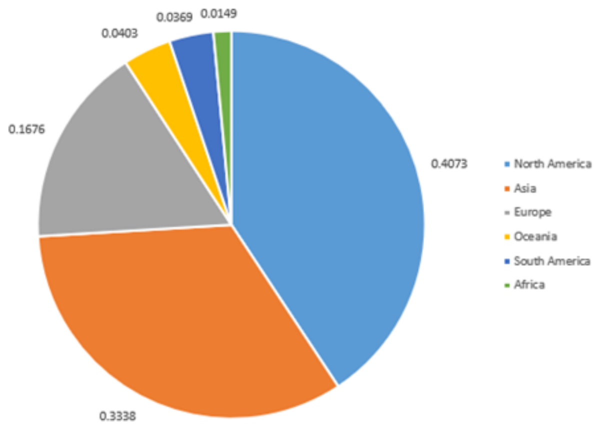


Figure 10: Benefit allocation for each region

From the figure, it can be seen that North America, Asia, and Europe occupy a dominant position in the allocation of benefits, because they are better than other regions in terms of economy, science and technology, and industry, and have invested sufficient resources in asteroid mining such as science and technology, equipment, capital, and researchers. How-ever, South America and Africa are allocated less than 5% of the benefits. Therefore, asteroid mining will further aggravate the global inequity, and corresponding policies are needed to reduce the gap in benefit distribution and achieve global.

5.3 Long-term Impact

5.3.1 Long-term Development Model

In Model 2, due to the uneven development of economy, science and technology in various regions of the world, there is a big difference in strength, which in turn leads to the problem that underdeveloped regions get less benefits in the process of asteroid mining. With preferential policies, underdeveloped regions are able to achieve global equality in asteroid mining. However, it still remains a big gap between regions due to lack of strength of underdeveloped regions in the long-term.

Here, policy recommendations are proposed to achieve equitable development rights in both short-term asteroid mining and long-term development. With supportive policy, underdeveloped regions are able to catch up with developed regions after long-term development, and then achieve global equality.

Differential equations are established to evaluate the changes of the strength of each region. Considering that it is difficult for the strength of a region to maintain linear growth, the restriction factor α is introduced to represent the hysteresis caused by the policy, competition and other factors on the development. The differential equation of long-term development is:

$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = \gamma_i (1 - \alpha_i x_i) \tag{13}$$

where γ_i refers to the growth factor, α_i refers to growth rate of the score, x_i (i=1,2,3...6) is the score of each region.

5.3.2 Analysis

The values of parameters are as shown in the Table 7. Among them, x_0 is the initial scores for each region, which is given in Model 1.

Table 7: Parameters of the long-term development model for each region

Parameter	x_0	γ_i	α_i
North Ame	0.3344	1.00	0.030
Asia	0.3442	1.00	0.025
Europe	0.1687	1.00	0.020
Oceania	0.0757	1.00	0.015
South Ame	0.0529	1.00	0.010
Africa	0.0241	1.00	0.010

The development of the six regions in the next 50 years is plotted as following:

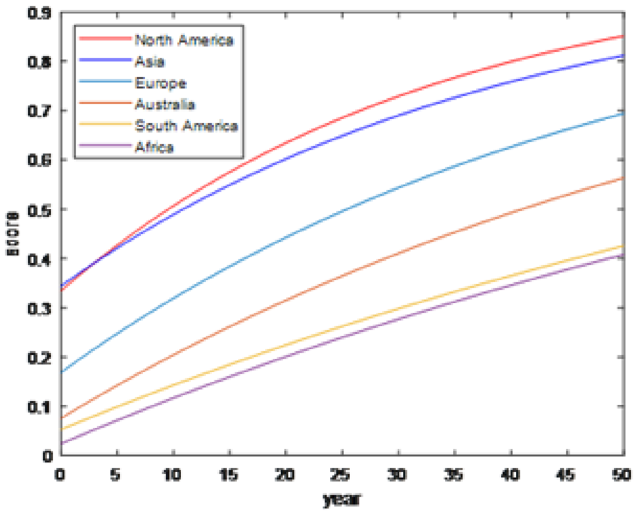


Figure 11: Region development over the next 50 years

From the figure, it can be seen that only equity of benefits obtained from asteroid min-ing, without improving the development situation of underdeveloped regions, will lead to a bigger and bigger power gap between developed and underdeveloped regions. Therefore, a long-term development strategy is in need to promote global equity.

5.4 Vision of asteroid mining

5.4.1 Short-term Vision

In previous sections, the Evaluation Scores(ES) is defined as the amount of input for each participating unit, and is based on the comparative advantage of regions. However, since South America and Africa are relatively weak and receive very little benefit, the participation(input) of the underdeveloped regions should be increased, so that they could receive relatively equitable benefits.

In this regard, mining sector is expected to adopt some policies.

Overall picture

Space powerhouse countries provide technical support, and space consumables are provided by mineral-rich countries for a fee. Parts are processed in developing countries close to the equator and shipped by developing countries with stronger maritime transport, to international launch bases in equatorial countries for assembly and launch. Underdeveloped regions assist in basic research and maintenance.

Supports in five dimensions

• Economy

Space powers assist South America, Africa in basic works of planetary mining, such as planetary exploration and space component manufacturing technologies. The introduction of basic research will promote the training of space talents in weaker countries, provide a large number of jobs, and drive the development of GDP per capita in less developed regions. Meanwhile, space industry will develop with a number of state-run and private companies related to the space industry chain spring up, increasing the number of listed companies. The early funding for the asteroid mining program is provided by economically powerful countries and countries with well-developed space research but with site constraints. The United Nations is responsible for coordinating the program without touching the military and political interests of the countries, while maintaining national space security.

• Industry

Carbon emission is an important indicator of industrial development. The space industry in underdeveloped regions is encouraged, which also benefits civil sectors such as infra-structure development. Processing of high-volume components contributes to the reduction of carbon emissions in aerospace powerhouses but higher emissions in weaker region.

• Science and Technology

The allocation of scientific tasks to conduct the asteroid mining program is given through experts meeting, which increases research efficiency, encourages developing countries to increase their research expenditures, and encourages underdeveloped regions to in-vest in launching satellites, facilitates ground-based construction, promoting equity. These regions are also obliged to form satellites to serve planetary exploration.

Countries and regions with developed space technology will provide launch vehicles, planetary equipment; countries with developed mining technology, together with countries with developed space technology, will tackle the technical problems in microgravity environment. When the technology is mature, assistance can be given to the underdeveloped regions.

Table 8: Talent Ecological Health Scale

Recommended Unit	Planetary exploration mission	Deep space exploration program
Developing countries	Spacecraft fly over the planet to survey it	Basic astrometric measurements, surface environment mapping, atmospheric and magnetic field measurements, basic element analysis, search for signs of life
	Probe land on planet	Atmospheric and soil analysis, astronomical data recording, deep geographic mapping, deep resource analysis
	Bring back planetary soil	Analysis of available resources, feasibility of in-situ utilization of resources
Space powerhouse	The spacecraft orbit the planet	Long-term geological activity observation, 3D mapping, communication and navigation, special surface environment
	Human land on the planet	All above are included, base construction

• **Mineral resource**

Conducting space research and processing space products requires large amounts of mineral resources to support them. Due to the limited resources, the minerals extracted are valued and allocated after they are brought back to Earth. In short term, benefits are equitably distributed according to "able person get more and all are cared for". At the same time, the targeted policy of global equity in longer term will work for centuries to come, so that intergenerational equity can be achieved.

In addition to the above allocation, the resources obtained from space could be traded as commodities under the supervision of the United Nations, which could be purchased by countries with scarce mineral resources at reasonable prices. The United Nations calls on powerful nations to provide basic technological support, such as new energy technologies, to reduce such occurrences.

• **Educational resource**

Help underdeveloped regions with high-quality education, including teachers and educational materials. Also, universities should focus on the development of high-tech talent. Underdeveloped regions is encouraged to establish aerospace-related polytechnics as well as vocational and technical schools.

After adopting the above policies, the participation of Australia, South America and Africa in these five dimensions is expected to increase significantly, 5, 8 and 10 times of the original, respectively, and the distribution of benefits has changed accordingly due to the increase in resources invested in their participation, including personnel, science and technology, and economy.

Table 9: QSPM for six regions

Superior indicator		**Economy**		**Science & Technology**		**Industry**	**Material resource**	**Educational resource**
Inferior indicator		E1	E2	ST1	ST2	Ind1	Ma1	Edu1
Wights		0.0568	0.1105	0.2002	0.2793	0.1267	0.0796	0.1469
North Ame	ES	0.2320	0.2594	0.4329	0.6368	0.3155	0.2643	0.2719
	TES	0.0132	0.0287	0.0867	0.1779	0.0400	0.0210	0.0399
Asia	ES	0.2567	0.4996	0.3760	0.1635	0.4297	0.2469	0.4694
	TES	0.0146	0.0552	0.0753	0.0457	0.0544	0.0197	0.0690
Europe	ES	0.2605	0.1381	0.1500	0.1894	0.1570	0.1488	0.1557
	TES	0.0148	0.0153	0.0300	0.0529	0.0199	0.0118	0.0229
Oceania	ES	0.9395	0.3315	0.1265	0.0150	0.1265	0.7990	0.0160
	TES	0.0534	0.0366	0.0253	0.0042	0.0160	0.0636	0.0024
South Ame	ES	0.3232	0.0992	0.1272	0.0472	0.3568	0.8776	0.7632
	TES	0.0184	0.0110	0.0255	0.0132	0.0452	0.0699	0.1121
Africa	ES	0.2240	0.2430	0.0370	0.0150	0.2790	0.7050	0.0440
	TES	0.0127	0.0269	0.0074	0.0042	0.0353	0.0561	0.0065

With measures taken, the recalculated SV for North America, Asia, Europe, Oceania, South America, and Africa are: 0.2620, 0.2147, 0.1078, 0.1296, 0.1899, 0.0959, respectively.

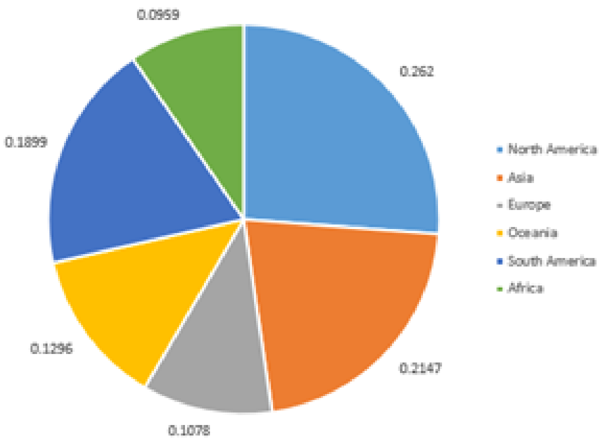


Figure 12: Benefit allocation after measures taken

From the figure, we can see that with the supportive polices for the underdeveloped regions, their participation(input) in economy, science and technology, industry, mineral re-sources, research, etc. has increased greatly, and thus gain more benefits and promote global equity.

5.4.2 Long-term Vision

The development of each region after the adjustment of the mining sector and the adoption of policies by the United Nations, is estimated based on the long-term development model. After the implementation of the targeted policies, the growth factor of the underdeveloped regions will increase, while the restriction factor will decrease to a certain extent. New parameters with the policy adjusted is shown in the Table 10 where x_e refers to the expected score.

Table 10: Parameters after policies adopted

Parameter	x_e	γ_i	α_i
North Ame	0.8515	1.00	0.030
Asia	0.8121	1.00	0.025
Europe	0.6942	1.00	0.020
Oceania	0.7393	0.75	0.020
South Ame	0.6377	0.60	0.015
Africa	0.6193	0.60	0.015

The expected development curves for each region after the implementation of targeted policies are shown in the figure below.

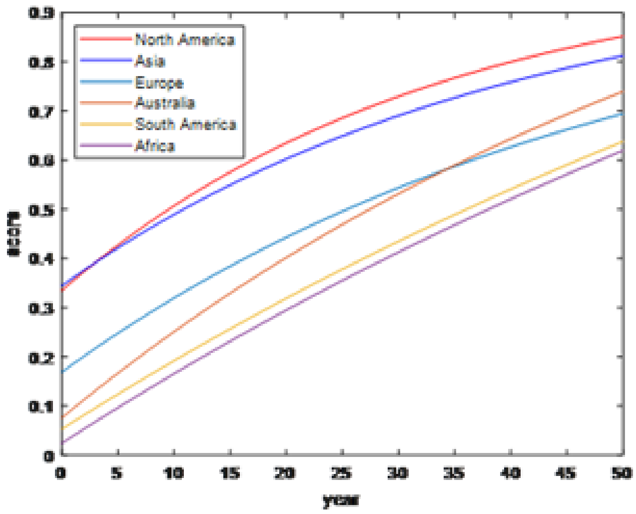


Figure 13: The expected development curves

After 50 years, the expected scores for North America, Asia, Europe, Australia, South America, and Africa are close, which are 0.8515, 0.8121, 0.6942, 0.7393, 0.6377, and 0.6193, respectively.

With the implementation of targeted policies, the expected scores of six regions are applied into the long-term equity assessment model. The corresponding Lorenz curve is as follow:

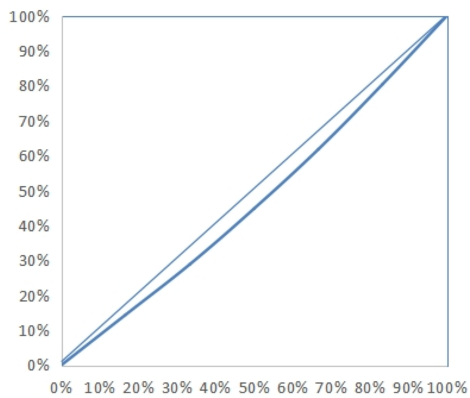
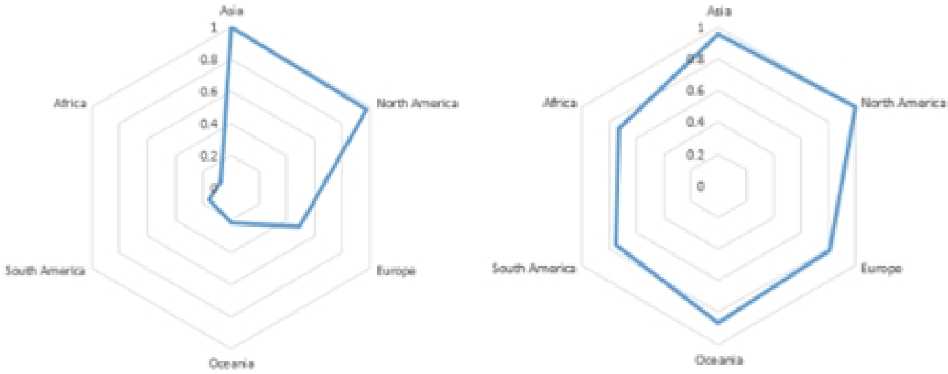


Figure 14: corresponding Lorenz curve after policies

Here, the global equity coefficient G is 0.066, with the equity evaluation grade A. The global development level reaches the absolute equity level.



(a) Before (b) After

Figure 15: Development of regions before(left) and after (right) policies adopted

Figure 15 shows the global development level of each region before and after the implementation of the policy. It is obvious that the comprehensive capacity gap between regions is narrowed and the global equity is increased.

6 Policy Recommendations

6.1 Impact of changes in conditions

Considering the realistic factors that may have an impact on the asteroid mining sector, such as: the sluggish development of a region's economy, the depletion of industrial re-sources, and other factors, changes in mining sector is studied in this section. If the mining sector is adjusted, the distribution of the benefits obtained from mining in each region will change accordingly. Here, the amount of contribution of each dimension is changed separately to observe the change in short-term equity. The participation(input) of Australia, South America, and Africa in these five dimensions are changed to 5, 8, and 10 times the original ones, respectively, and the allocation for each region is calculated. Because the change in the mining sector only affects short-term equity and does not affect the long-term global development, only the short-term equity evaluation model is needed for the analysis.

Table 11: Distribution of earnings by region after changes in the mining sector

	North Ame	Asia	Europe	Oceania	South Ame	Africa
Economy	0.3529	0.2892	0.1452	0.1148	0.0542	0.0438
Sci&Tech	0.3812	0.3123	0.1568	0.0598	0.0662	0.0237
Industry	0.3754	0.3076	0.1545	0.0490	0.0705	0.0431
Mineral	0.3501	0.2869	0.1441	0.0784	0.0843	0.0562
Edu	0.3681	0.3016	0.1515	0.0381	0.1220	0.0187

From the results, if only one of the five dimensions is changed, the total benefits allocated to the two weaker regions, South America and Africa, is 0.0980, 0.0899, 0.1136, 0.1405, and 0.1407, respectively, while changing the five dimensions together results in the benefit of 0.2858. Therefore, adjusting the five dimensions separately could not improve global equity well, and combined adjustment is required. Moreover, a equitable distribution of only the benefits from mining does not solve the long-standing regional development inequity. Therefore, reasonable policies are required to achieve the vision of global equity.

6.2 Update of Outer Space Treaty

Recognizing the desirability of solving problems in terms of asteroid mining and spirit of cooperation, a legal order for the space which will promote peaceful uses of the space, the equitable and efficient utilization of its resources , is of great importance.

Bearing in mind that this treaty will contribute to the realization of a just and equitable international economic order which considers the interests and needs of mankind as a whole, in particular, the special interests and needs of developing countries.

Space resource acquisition can be divided into five stages: finding, prospecting, landing, mining, and transportation, each of which requires significant and continuous capital investment, and multi-disciplinary technologies. Joint efforts of all sectors and industries are required to truly complete this great project.

Part 1 Use of terms and scope

1. For the purpose of this Treaty

(1) “Area” means the surface of asteroids and their mining layers within the reach of human technology.

(2) “Authority” means the International Mining Management Sector.

Part 2 Mining Sector Council

Article 1 Composition of members

1. The Council shall be composed of thirty-six members of the Mining Sector elected by the General Assembly in the following order:

(a) Four members from those States Parties whose consumption of commodities derived from all types of minerals available from the Area exceeds two percent of total world consumption, or whose net imports exceed two percent of total world imports, in any case one country belonging to the Eastern European (socialist) region, and the largest consumer, in the most recent five years.

(b) Four members from the eight States Parties which, directly or through their nationals, have made the largest investments in the preparation and conduct of activities in the Area.

(c) Four members from States Parties that are major net exporters of all types of minerals available from the Area by virtue of production within their jurisdiction, at least two of which should be developing countries whose economies are significantly concerned by the export of such minerals.

(d) Six members are from developing country and represent special interests. The special interests represented shall include the interests of populous or geographically disadvantaged countries, major importers of the types of minerals available from the Area, potential producers of those minerals, and least developed country.

(e) Eighteen members elected in accordance with the principle of ensuring equitable geographical distribution of seats on the Council as a whole.

Article 2 Functions

1. The States Parties may adjust their policies as appropriate after consultation with the Mining Sector, with the adoption of half or more of the votes of the Council.

2. Countries that have made outstanding contributions to mining practices shall be voted on by the Council to increase the distribution of benefits without violating basic equity.

3. The principle of "first discover, first exploit" shall be followed, but the upper limit of benefit distribution shall not be exceeded. After the upper limit is reached, the activities shall be transferred to exporting mineral resources to other countries, under the supervision of the Council.

6.3 Supplement to Equity

Part 1 Risk-Revenue Equity

Article 1 Benefit distribution

1. The distribution of proceeds includes asteroid minerals, asteroid mines and options to use equipment.

Article 2 Risk-taking

2. Accommodating innovation and trial-and-error behavior. The use of immature technological tools will be decided after risk assessment. Mining activities conducted in joint ventures between different countries require shared risk taking.

Part 2 Short-Term and Long-Term Equity

Article 3 Short-term equity

1. Due to the weakness of some countries and regions, they cannot achieve equity in the distribution of benefits or the sharing of space technology in a short period of time, They can only undertake some synergistic work and call for more countries to join the planetary mining enterprise.

2. Less developed regions need to transition to specialization according to their location advantages. For example, countries near the equator can be allowed to set up launch bases, and countries near the sea can provide transportation facilities.

Article 4 Long-term equity

1. Space power countries help weaker countries with basic space technology support, and improve exchanges. Weaker countries are encouraged to participate in basic scientific research projects, such as undertaking Earth-like planet exploration missions. Countries around the equator are encouraged to undertake tasks such as building launch bases. Stronger countries are encouraged to explore more mining-difficult planets that are farther away from Earth. It is expected that a comparable level between the countries in can be reached.

2. The resources of any planet are finite. Two convergent long-term equity principles are proposed, which are the same amount of mining in the convergence year, and the same total amount of mining from the first year of planetary mining to the convergence year.

3. Allow weaker nations more opportunities for trial and error, including launch experiments and survey behavior.

4. Appropriately increase the number of seats for weaker nations on the Mining Sector Council.

7 Sensitivity Analysis

We build a short-term equity model based on QSPM matrix, and give the vision of short-term equity after the implementation of the policy. The ultimate benefits will vary depending on the region's contribution to asteroid mining. We analyzed the contribution of each region to achieve the vision and increased it by 5%, 10% and 15% respectively to observe the distribution of benefits of 6 regions. The results are as follows:

Table 12: The proportion of regional benefit distribution after changing the contribution degree

	North America	**Asia**	**Europe**	**Oceania**	**South America**	**Africa**
Original	0.2620	0.2147	0.1078	0.1296	0.1899	0.0959
+5%	0.2567	0.2104	0.1056	0.1333	0.1953	0.0987
+10%	0.2516	0.2062	0.1035	0.1369	0.2001	0.1013
+15%	0.2467	0.2021	0.1015	0.1403	0.2055	0.1038

We can see that although the contribution degree of each region changes to a certain extent, the proportion of benefit distribution of each region has relatively little change. It can be seen that the short-term fairness model based on QSPM matrix has good stability.

8 Model Evaluation and Further Discussion

8.1 Strengths

1. The combination of entropy weight method and TOPSIS evaluation method avoids the problem of strong subjectivity caused by AHP.

2. The quantitative strategic plan matrix (QSPM) is innovatively used to solve the profit distribution after asteroid mining, and the profit distribution is determined fairly according to the input from all aspects.

3. Analog the Gini coefficient, we define the equity coefficient to evaluate global equity, and through the Lorentz curve, we can clearly observe global equity.

8.2 Weaknesses

1. Indicators can be selected from more dimensions and evaluate the strength of countries and regions from more aspects.

8.3 Further Discussion

1. The quantitative strategic plan matrix (QSPM) can be used to solve the problem of input and benefit distribution, and can be used for other benefit distribution related problems.

2. Lorentz curve combined with equity coefficient can be used to measure equity effectively and can be used to analyze other equity models.

9 Conclusion

† We combine TOPSIS and entropy weight method to establish a comprehensive capability assessment model. The selected region is evaluated from five dimensions of science and technology, economy, industry, mineral resources and education, and the weight of these five dimensions is 0.4795, 0.1673, 0.1267, 0.0796 and 0.1460, respectively.

† We construct a model of equity assessment from both short - and long-term perspectives. In the short-term equity evaluation model, QSPM matrix is used to solve the problem of input and benefit distribution. After the asteroid mining, the profit distribution ratio of America, Asia, Europe, Oceania, South America and Africa is 0.4073, 0.3338, 0.1676, 0.0403, 0.0369 and 0.0149 respectively. In the long-term equity assessment model, after 50 years of asteroid mining, the global equity coefficient is 0.422, and the global inequality problem is still severe.

† We expect that the short-term global equity situation improves well after the implementation of the policy. The proportion of profit distribution in America, Asia, Europe, Australia, South America and Africa is 0.2620, 0.2147, 0.1078, 0.1296, 0.1899 and 0.0959 respectively. After 50 years, the expected scores of the six regions were 0.8515, 0.8121, 0.6942, 0.7393, 0.6377 and 0.6193. The global equity coefficient is 0.066, and the evaluation grade is A. The global development level has reached the absolute equity level, and the long-term equity problem has been well solved.

† Adjusting the five dimensions separately cannot improve global equity, so comprehensive and targeted policy adjustments are needed.

† Based on the relevant treaties of the United Nations, reasonable suggestions are put forward from the perspectives of short-term equity and long-term equity. The implementation of policies will make global equity reach our desired goal.

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