Problem Chosen	2022	Team Control Number
F	MCM/ICM Summary Sheet	2222061

All for Asteroid and Equity for All

Summary

Global Equity, defined as the reasonable distributions aiming at a convergence in outcomes, is directly linked to the development opportunities among global countries. In the future, Asteroid Mining sector will come into existence, developing in several scenarios. Hence, it's necessary to analyze the impact laid on global equity by asteroid mining sector.

After K-means clustering on determining samples by HDI, our paper conduct a two-side model to figure out the interaction between global equity and asteroid mining. One side refers to evaluation on global equity while the other simulates the alteration of asteroid mining.

We first construct the **Global Equity Index** to evaluate the global equity level of development opportunities in two periods. For the first one, we advocate **National Development Opportunity Index (NDOI)** by **Improved Entropy weight Method** and **TOPSIS** to evaluate development potential with 9 indicators according to Human Development Report.

In the second period, we combine **Gini-coefficient method** and **Theil Index method** to calculate the global equity gap among NDOIs to obtain Global Equity Index. Moreover, analysis of the index has been operated according to time series, HDI clusters and diverse regions. Though decrease trend existing globally, two middle HDI clusters and Asia & Pacific region are revealed far from equity. Besides, a **Sensitive Analysis** is introduced.

Then based on the futural scenarios of asteroid mining, **Asteroid Mining Admission Model** is generated to quantitively assess the market-decisive results of pioneers and dominants by applying a **Two-dimension K-means Cluster**. Only with high NDOI and great demand on external mineral will firstly enter the sector. Besides, the weight of NDOI is adjusted considering the **Grey Relation Analysis** between mineral increment and indicators above.

After that, our models are applied to the two conditions of admits and resources. By fixing admits, we evaluate the impact of growing resource from asteroid on global equity through **OLS Regression Analysis** and generate the relation between equity and asteroid resource with **GM (1,1)**, thus rendering a prediction. Moreover, a changeable admission analysis assumes alteration of admits impacts the weights of NDOI, structurally influencing the trend of global equity.

Next, a portfolio of United Nations policies on asteroid mining sector is advocated concerning finance, economic, technology and space rights, thus promoting lower admissions, a more complete industry chain and larger scales of participations and earnings, and will eventually improve futural global equity.

Finally, we discuss strengths and weaknesses of our models.

Keywords: Global Equity Index; IEWM-TOPSIS; K-means Cluster; Grey Relation Analysis; Regression Analysis; GM (1,1); Futural Asteroid Mining; Equity-promotion policies

Contents

1 Introduction

1.1 Background

Many of the world's nations signed the 1967 United Nations Outer Space Treaty with the goal of promoting global peace and reducing inequity. The Outer Space Treaty provides the legal basis for promoting multinational access to space-related projects, such as the International Space Station, and the use of satellites to browse the Internet in the most remote places.

However, as human beings seek to acquire space resources, inequities will inevitably occur due to the different stages of development of different countries.

Thus, several problems will come into being listed as follows：What is global equity and how do we define it? How does asteroid mining affect global equity? Against this background, how can we formulate corresponding policies and measures to promote global equity?

1.2 Definition of Equity

As for global equity, the United Nations pointed out that economic globalization should be endowed with the connotation of social justice and reflect the universal moral norms of all man-kind to achieve win-win coexistence. The New Palgrave Dictionary of Economics explains fairness as follows: "A distribution in which no one admires the other is called a fair distribution." What this definition emphasizes is not the equality of "resource distribution", but the equity of "utility or satisfaction" and the subjectivity of fairness.

Global equity is not simply a matter of equal distribution of resources and inputs, but a matter of distribution approach by maximizing the efficiency of resource utilization and maximizing the utility benefits to countries at different levels of development. At the same time, necessity should be paid to reach a converge as Solow Economic Growth Model, instead of divergence. Small countries provide human and material resources and big countries provide technical resources, but both receive their due rewards so as to reach a similar level of outcome.

The need to ensure the satisfaction of all countries is higher, and the distribution of resources such as everyone thought the is relatively fair, utility is difficult to measure, but we can make use of the mineral resources production, research and development expenditure proportion, education investment proportion and other data to reveal the development opportunities of big and small, and then to real data depict subjective utility satisfaction.

The clear definition of global equity lays a theoretical foundation for the subsequent model building and policy proposal.

1.3 Restatement of Problems

Task 1: Certain definition and reasonable method of measuring global equity are required. For scientificalness and reliance, we will consider a certain time span and different regions.
Task 2: Description for the vision of asteroid mining sector is in need, and we should measure the impact of the development of asteroid mining on global equity by considering conditions such as mineral resources and technology investment.

Task 3: Asteroid Mining impact on equity altering with conditions above has to be measured.
Task 4: We're supposed to provide fresh policies for the development of asteroid mining sector from diverse perspectives. The initial intention of these policies is to promote global equity through the development of asteroid mining sector.

1.4 Our Work

Based on analysis of tasks above, our workflow is shown as follow:

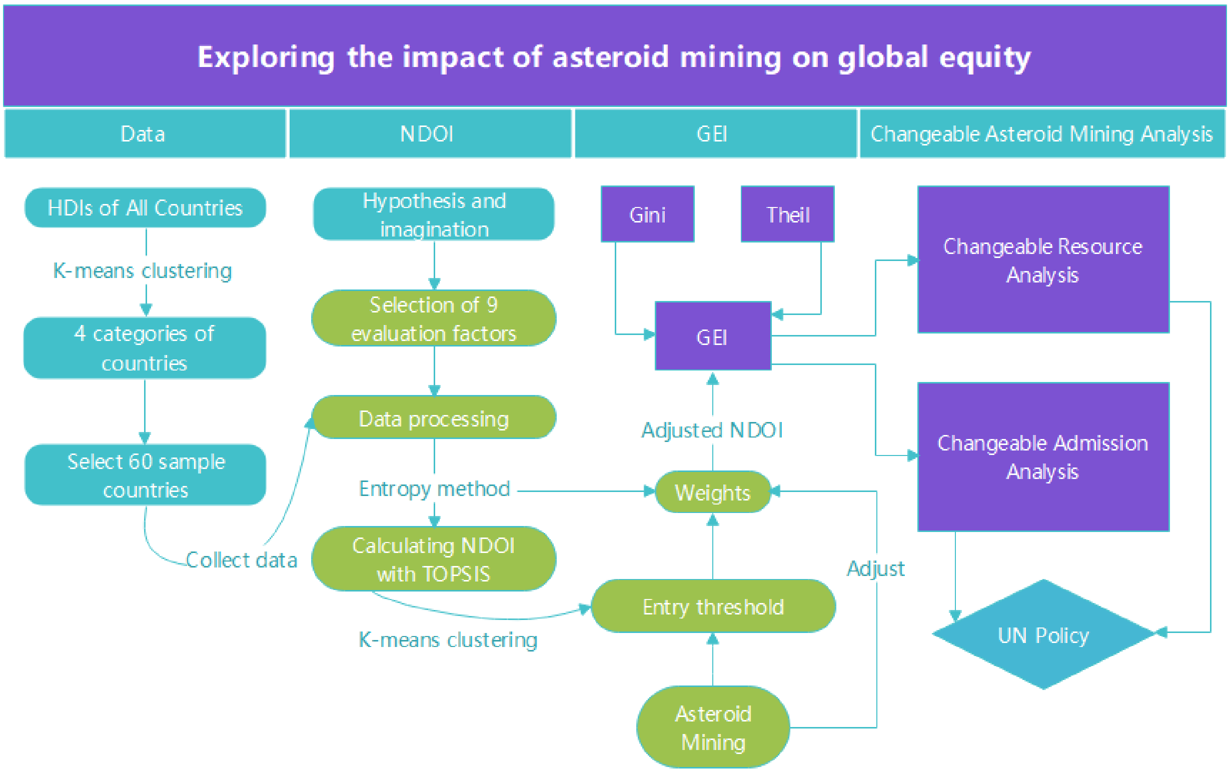


Figure 1: Our Workflow

2 Assumptions and Notations

2.1 Assumptions

- **Development Opportunities reflect the inputs of development while Development Levels equal to the outcomes.** This assumption makes inputs and outcomes concerning equity quantifiable, and relevant equity models can be constructed.
- **The sector of Asteroid Mining can be simulated by reality conditions and reasonable extrapolated.** Otherwise, discussion cannot be expanded.
- **There is a limited quantity of asteroid mineral resources that can be exploited and profited from at every short term but could grow in the long run.** The concept of equity makes sense only when resources are limited.
- **All countries want to exploit as many resources as they can, if they can, whether they are scarce or not.** According to the economic principle of dissatisfaction hypothesis, human desire is infinite, here we extend it to the national level.

- **In the short term, the global situation will remain basically unchanged. In the longer term, the global situation could change.** Based on Marshall's factor supply theory, the relative level of relevant factors in a country does not change in the short run, but can change in the long run.
- **Asteroid mining has certain market-determined entry barriers, not artificial.** It offers necessary conditions for asteroid mining to exacerbate global inequities.
- **In the short term, the asteroid mining market remains a laissez-faire one, without forceful monitoring from international organizations.** Thus, rationality on national interest works well, and each participant only decides for himself.

2.2 Notations

The primary notations used in this paper are listed in Table 1.

Table 1: Notations

Symbol	Description
c_i	Country i
x_{ijt}	Indicator j for Country i and Year t
y_{ijt}	Normalized form of x_{ijt}
w_j	Improved Entropy Weight of Indicator j
$NDOI_{it}$	National Development Opportunity Index for country i year t
$EDOI_t$	Global Equity Index in year t

3 Main Indicators, Samples and Data Explanations

3.1 Main Indicators Selection

According to the value principles of United Nations Development Programme (UNDP) and the construction of Human Development Index (HDI), 9 main indicators are selected from two prongs encompassing Economic and Social development opportunity ones.

Based on economic growth function $Y = AF(K, N, Z)$, the Economic prong includes: **Research and Development Expenditure**, evaluating its development opportunity of “A”; **Saving Rate**, assessing the growth potential of “K”; **Labor Increment**, equal to the marginal effect of “N”; **Energy consumption**, equal to its capacity and willingness to access to energy.

Considering HDI principles, the Social prong contains: **Military Expenditure**, concerning capacity of self-defense; **Poverty Ratio**, assessing gap of wealth; **Gender Development Index,** regarding opportunities between genders; **Education Expenditure**, investing in human capital; **Health Expenditure**, safeguarding the health of civilians.

3.2 Samples: Selected by K-means Clustering Method

First of all, for different countries have different levels of development, we did not use the same scale to judge the degree of equity for different countries. Instead, a classic K-means Clustering Method is adopted, whose aim is making cluster sum of square minimized, to distinguish countries of diverse development periods, thus filtering delegate samples.

$$\min J = \sum_{k=1}^{k=4} \sum_{i=1}^{n=184} \|c_i - u_k\|^2 \tag{1}$$

While k refers to quantity of cluster, we assume at 4; u_k points to cluster centres.

To better evaluating the equity of futural development opportunity or potential talent level, we adopt **average HDI of past 20 years**, showing the present level of development, to attain clustering results, which are simply shown as follows:

Table 2: Proportion of Clustering Categories

Cluster	Central HDI	Quantity of Countries	Representatives
Superior High	0.8734	46 (16 after selection)	US, Japan, Germany…
General High	0.7404	55 (19 after selection)	China, Brazil…
Medium	0.6168	31 (11 after selection)	India, Indonesia…
Low	0.4595	42 (14 after selection)	Pakistan, Benin…

Due to the large amount of missing data in some countries, it is difficult to carry out analysis, we selected sample countries and finally obtained 60 groups of sample data. The 60 selected samples cover the 81.87% of the world's population, 76.82% of the world's GDP and six continents. Our sample data can well represent the situation of global countries, and at the same time, we did not forget to consider the comprehensive inclusion of both developing and developed countries, thus better measuring the equity of the world. The time series chosen is 2000,2005,2010-2019. The selection of this time series is carefully considered, for previous data of incompleteness and abnormal 2020 data shocked by COVID-19.

3.3 Data Normalization and Description

After data cleaning, a certain degree of **MAX-MIN standardized** processing and **Panel Data Extraction**, we obtained relatively standard data.

$$y_{ijt} = \frac{x_{ijt} - \min x_{jt}}{\max x_{jt} - \min x_{jt}}, \ for\ positive \tag{2}$$

$$y_{ijt} = \frac{\max x_{jt} - x_{ijt}}{\max x_{jt} - \min x_{jt}}, \ for\ negative \tag{3}$$

The primary indicators used in this paper are listed in Table 2.

Table 3: Main Indicators and Data Description

Indicators	Symbol	Data sources	Effect	Unit
Research and Development	R&D	WB WDIndicators	+	%
Saving Rate	SR	WB WDIndicators	+	%
Labor Increment	LI	WB WDIndicators	+	%
Energy Consumption	EC	BP World Energy Statistics	+	EJ
Military Expenditure	ME	WB WDIndicators	+	%
Poverty Ratio	PR	UNDP	-	%
Gender Development Index	GDI	UNDP	+	-
Education Expenditure	EDU	WB WDIndicators	+	%
Health Expenditure	HEA	WB WDIndicators	+	%

4 Model I: Global Equity Index (GEI)

4.1 National Development Opportunity Index (NDOI) Model

4.1.1 Weight determination: Improved Entropy Weight Method (IEWM)

The Entropy Weight Method (EWM) is commonly used as a weighting method that measures value dispersion, assuming the greater the degree of dispersion, the greater the degree of differentiation, and more information can be derived. Thus, higher weight should be given to the index, and vice versa. We use it to estimate the weight values of the indicators.

However, while traditional EWM calculates the weights with Hj→1, a micro change may cause an exponential altering in entropy weight, bringing significant error. Hence, Ouyang Sen (2013) advocated an improvement, which is as follows:

$$p_{ij} = y_{ij}/\sum_{i=1}^{n} y_{ij}\,, H_j = -\sum_{j=1}^{n} p_{ij}\ln(p_{ij})\,/\ln(n) \tag{4}$$

$$w_j = \begin{cases} (1-\bar{H}^{35.35})w_{0j} + \bar{H}^{35.35}w_{3j} & H_j < 1 \\ 0 & H_j = 1 \end{cases} \tag{3}$$

$$w_{0j} = \frac{1-H_j}{\sum_{j=1}^{n}(1-H_j)} \tag{4}$$

$$w_{3j} = \frac{1+\bar{H}-H_j}{\sum_{k=1,H_k}^{n} 1+\bar{H}-H_k} \tag{5}$$

Above H_j represents the information entropy of indicator j, with its calculation omitted. Finally, the improved entropy weights of NDOI indicators are listed:

Table 4: IEW of NDOI Indicators

X_j	R&D	SR	LI	EC	ME	PR	GDI	EDU	HEA
IEW	12.99%	14.78%	13.98%	13.62%	8.87%	8.48%	8.65%	9.61%	9.02%

4.1.2 NDOI Calculation: IEWM-TOPSIS Method

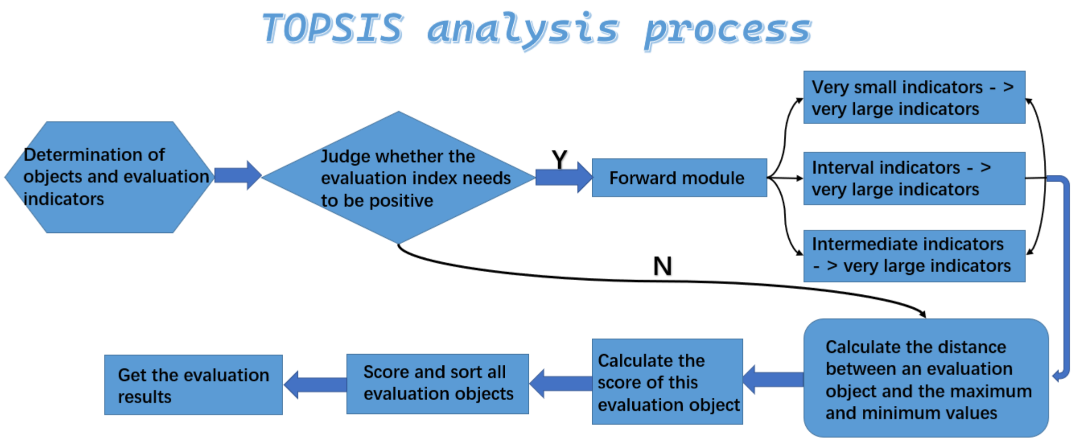


Figure 2: TOPSIS Analysis Process

TOPSIS comprehensive evaluation method are used to evaluate NDOI of 60 countries in 12 years. The better the score, the higher its relative development opportunity. In the process of TOPSIS, **the best and worst schemes D_{it}^{+} and D_{it}^{-} are determined by the relative de-**

velopment opportunity for a futural convergence outcome, but not simply using the MAX & MIN, for instance, the best scheme of GDI is 1, but not the maximum value over 1. In other words, the schemes cater to development periods concerning the HDI cluster above, thus **better consistent with the MEANING OF EQUITY**. Besides, the weight is determined by IEWM referred above.

$$D_{it}^{+}=\sqrt{\sum_{j=1}^{m}w_j(Y_{jt}^{+}-y_{ijt})^2},D_{it}^{-}=\sqrt{\sum_{j=1}^{m}w_j(Y_{jt}^{-}-y_{ijt})^2},NDOI_{it}=\frac{D_{it}^{-}}{D_{it}^{+}+D_{it}^{-}} \quad (6)$$

TOP and BOTTOM NDOI results are partly shown below:

Table 5: Results of NDOI by IEWM-TOPSIS

Year	2000	2005	2010	2015	2019
Rank 1	USA (0.610)	USA (0.591)	USA (0.711)	China(0.593)	USA (0.578)
Rank 2	Germany	China	China	USA	China
Rank 3	France	India	Germany	Japan	India
Rank 59	Congo	Congo	Mali	Cameroon	Benin
Rank 60	Benin(0.077)	Benin(0.066)	Benin(0.120)	Benin(0.074)	Cameroon(0.093)

4.2 Equity Calculation Model From NDOI to GEI

4.2.1 Calculation based on GE-GINI Method

We used method similar to calculate income gap to show NDOI gap, indicating equity.

Generally, there exists four differed methods which render methods of assessing the gap between global or regional distribution of equity, Gini Coefficient and Generalized Entropy Index included. According to Liu Zhiwei (2003), Gini Coefficient is sensitive to medium level while Generalized Entropy Index becomes sensitive to top or bottom level by α.

$$Gini=\frac{1}{2n^2\overline{NDOI}}\sum_{i_1=1}^{n}\sum_{i_2=1}^{n}\left|NDOI_{i_1}-NDOI_{i_2}\right|,GE=\frac{1}{\alpha^2-\alpha}\left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{NDOI_i}{\overline{NDOI}}\right)^{\alpha}-1\right] \quad (7)$$

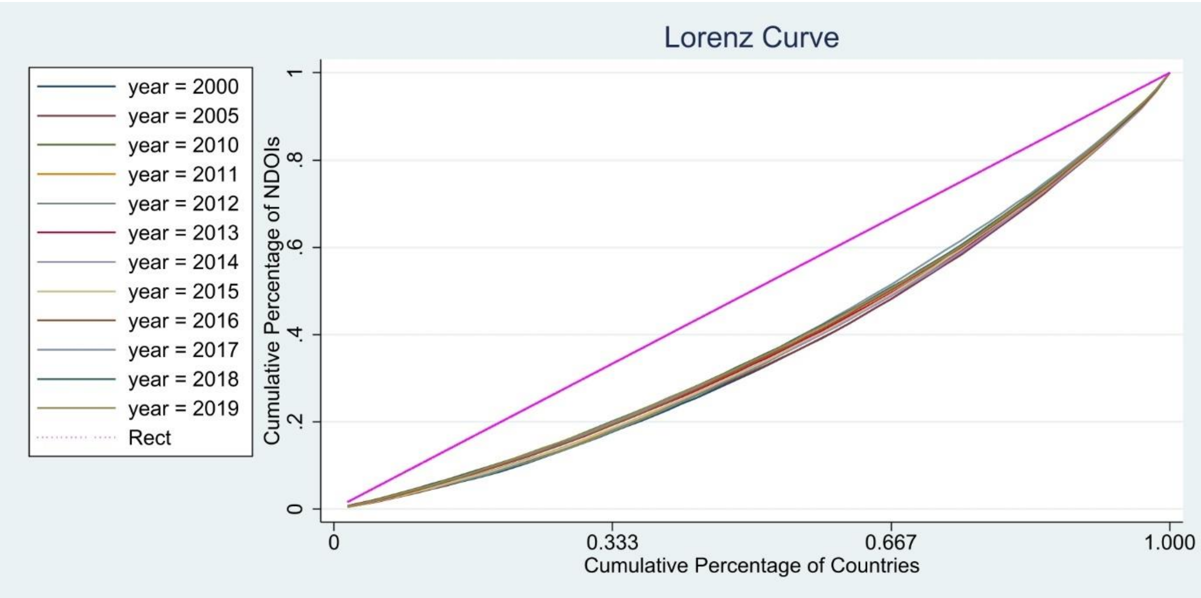


Figure 3: Global Lorenz Curve of NDOI

Simply, we assumed $\alpha \to 1$ in GE, meaning equity is sensitive to NDOI, like Theil Index. Firstly, we separately calculated the Gini and GE ($\alpha = 0$). Lorenz Curve is shown above while trend lines are listed below:

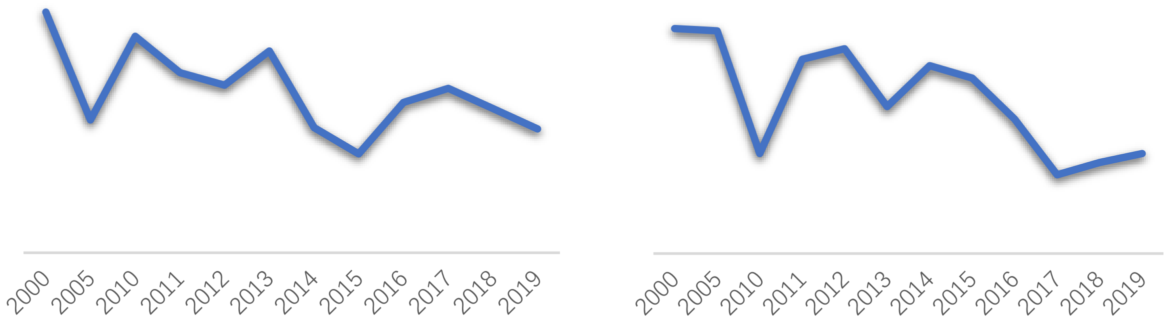


Figure 4: Trend Lines of NDOI (left: GE; right: Gini)

Secondly, since two types of methods performed similar trends with different natures on decomposability and sensitivity, there exists potential improvement. Thitithep Sitthiyot improved sensitivity of Gini by introducing a constant evaluating share gap between top and bot and combined by square average (2020). Hence, we combined the both methods to realize sensitivity and decomposability meanwhile, called Equity Calculation Model, shown below:

$$GEI = \sqrt{\frac{Gini^2 + GE^2}{2}} \tag{8}$$

Eventually, we obtain GEI. **The lower GEI is, the better global equity becomes.**

4.2.2 Results of Time Series

Based on GEI, we obtained the evaluation of global equity, which is shown on the right side (Figure 4), and thus a clear trend of downward is similar to the two figures above, but equipped with better natures in both aspects. Global GEI went down from 0.589 in 2010 to 0.559 in 2019.

Note: GEI 0.604 in 2000; 0.569 in 2005.

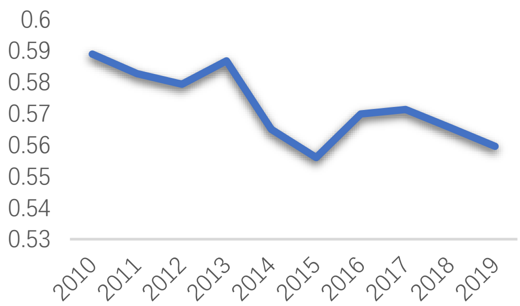
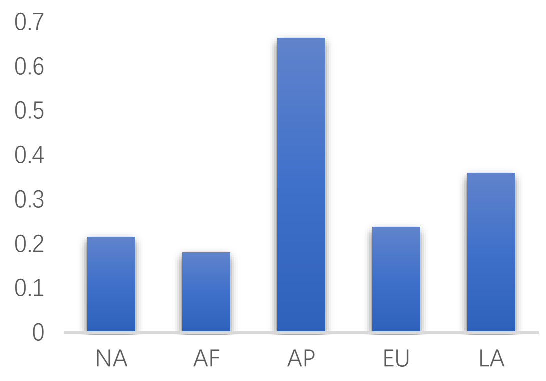


Figure 5: GEI

4.2.3 Regional & Cluster analysis

As for regional conditions, Asia & Pacific owned the highest GEI of 0.6633, nearly twice of the average GEI of five regions of 0.3322, which means an extremely huge inequity of development opportunity in this region. To some extent, the inadequate international cooperation or insufficient Open to international market led to such an unbalanced result. Besides, Africa had the lowest GEI, partly because of its commonly equal poverty.

The cooperative unions like the European Union and international value principles of North America and Europe makes a steady GEI between countries of different clusters.



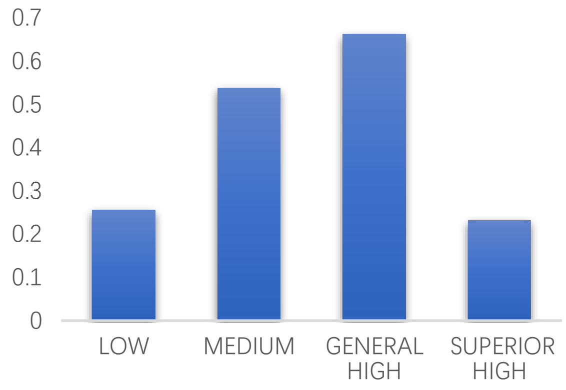


Figure 6: Results of GEI (left: Regions; right: Clusters)-2019

Inequity happened mainly in General High and Medium HDI clusters. To some degree, a huge inequity in distribution of development opportunity and potential lay in clusters of similar development levels, which indicates the inequity in marginal effects may leads to a gap in futural outcomes, thus deviating from the nominal equity.

4.2.4 Sensitivity Analysis

Since an improvement exerted in IEWM-TOPSIS and National Development Opportunity Model, we mainly conducted sensitivity analysis on Equity Calculation Model.

We changed down the sensitivity of GEI to NDOI α to a range of 0.8-0.95 in the figure 7 below. It can be seen that when sensitivity α changes, the error ratio is around 5%, but still meets our expectation. The model has passed the sensitivity analysis.

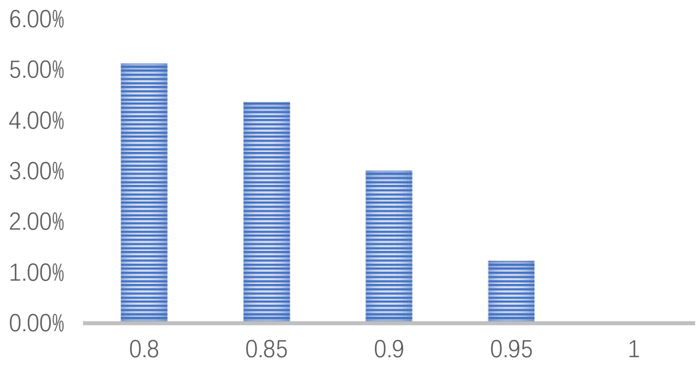


Figure 7: Sensitivity Analysis

5 Model II: Asteroid Mining Model

Alterable Assumption: in our future asteroid mining scenario (hereinafter referred to as "scenario"), the world pattern does not change significantly, that is, the relative level of countries does not change, which is short-term but different in long-term.

5.1 Futural scenario of Asteroid Mining

5.1.1 Mined asteroids and Ores

According to the study of near-Earth asteroids, they contain large amounts of rare metals. Near-earth asteroids are cheaper to transport. In addition, considering all kinds of minerals on the planet, rare metals have high application value and economic benefits, so they have the highest mining value. Therefore, in the scenario, near-Earth asteroids are the main mining objects, and rare metals are the main mining minerals.

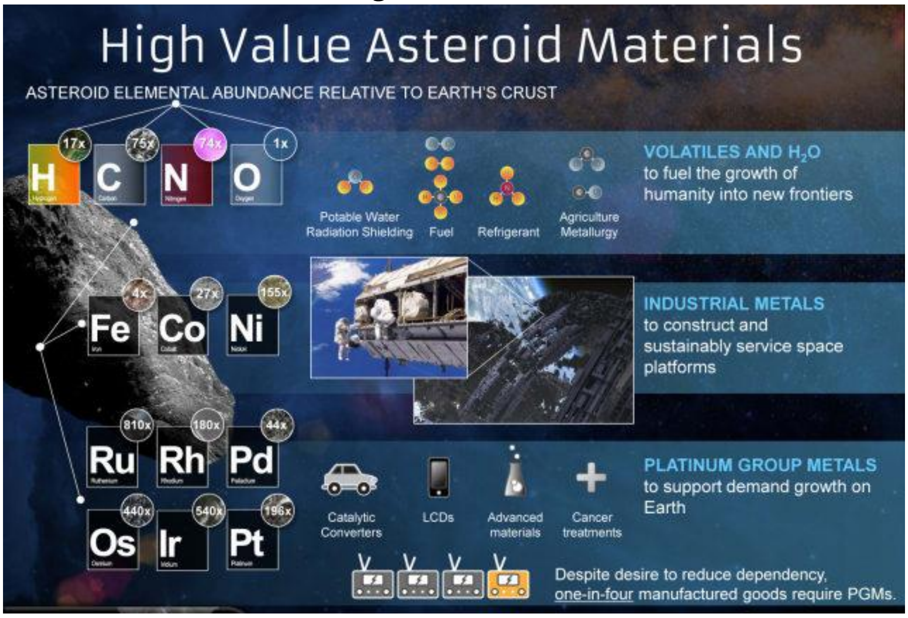


Figure 8: Mined Asteroids and Ores

5.1.2 Process of Asteroid Mining

Discovery: The main body is the Space Administration and the Research Institute, which monitors and studies the asteroids around the Earth. It mainly uses the asteroid detector or space telescope to conduct spectral analysis on the asteroids to determine the composition and overall value of the asteroids, and finds the asteroids worth mining. Their relevant research results will be handed to the mining department.

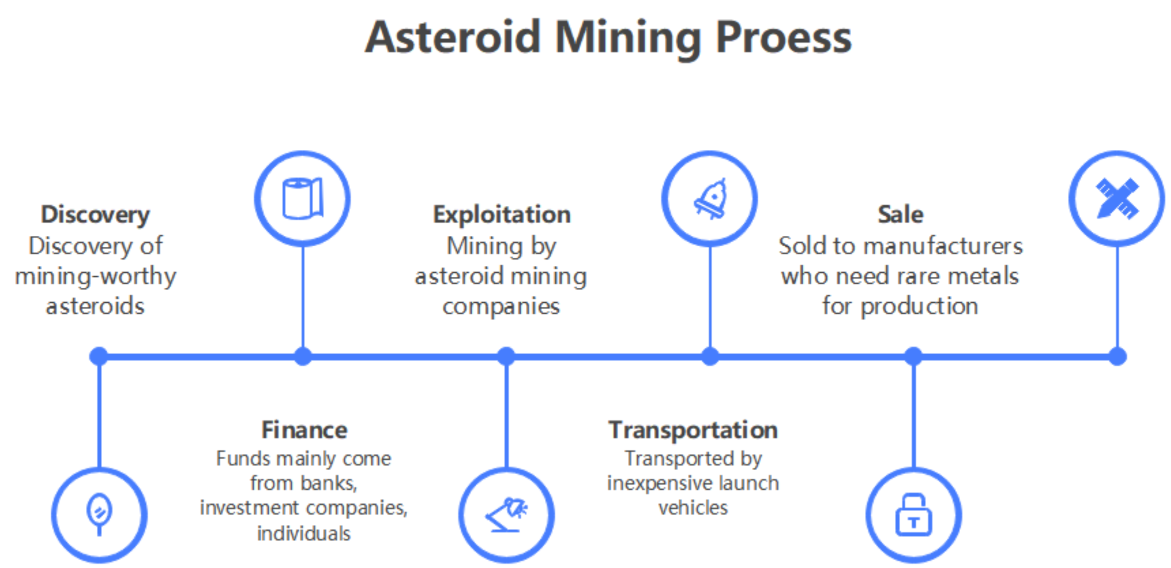


Figure 9: Asteroid Mining Process

Finance: The main entities are banks and the venture capital sector. The mining company uses the research report of the discovery sector as the main basis for financing from banks or the venture capital sector. The relevant investment department sets up an evaluation team to assess the risk of the project and decide whether to invest. In addition, mining companies use the proceeds as collateral for public financing, but this financing is less efficient.

Exploitation: Asteroid mining companies are responsible for the specific mining work, including state-owned enterprises (represented by China), private enterprises (represented by the United States) and government and social capital cooperation. Research institutes, universities and corporate R&D departments provide technical support for mining.

Since space communication has a communication time lag, to ensure smooth mining, mining monitoring stations need to be built on the asteroids and regularly patrolled and maintained by professional personnel.

For different asteroids, there are two main mining methods.

A. Launching a collector to log in the asteroid mining, this is suitable for larger asteroids, the capture is more difficult.

B. Capture the whole asteroid, drag it to the near-moon orbit with the help of solar thrusters, and then carry out mining, this way is suitable for smaller asteroids.

Transportation: In order to reduce transportation costs, most mining companies smelt the metal in situ after mining, and then send it back by transport rocket. This also means that the smelting equipment has already been delivered to the mining site first. The manufacture of transport rockets is undertaken by specialized rocket manufacturing companies to build inexpensive launch vehicles.

Sale: The main minerals mined are rare metals, and the main buyers are rare metal demanders, such as special steel manufacturers, new energy companies, automobile manufacturers, ceramic industry, atomic energy industry, electrical industry, chemical industry, and rocket manufacturers.

5.1.3 Boundless Imaginations

Replenishment by International Space Station:

The Space Station has multiple functions: as a resupply station for transporting rockets; monitoring and exploring asteroids; monitoring mining processes, etc.

The Asteroid Minerals Coalition (OAMC):

Among the countries engaged in asteroid mining, in order to avoid losses due to competition among themselves and to obtain higher returns, all participating countries signed the ***Outer Space Resources Development Management Treaty,*** forming the Organization of the Asteroid Minging Countries (OAMC).The price of rare metal resources extracted from asteroids is set uniformly by all member countries. The establishment of the OAMC has significantly challenged the interests of traditional minerals producing nations.

5.1.4 Possible Impacts

With the commercialization of asteroid mining, OMAC member countries could gain access to abundant energy resources and consequent lucrative profits. With the increase in rare metal resources, manufacturing industries that originally relied on rare metals within OMAC member countries are able to engage in production at a cheaper cost, promoting the progress and development of related industries.

On a global scale, the increase in the total amount of rare metals has led to lower prices for rare metals and lower manufacturing costs for manufacturing industries that require rare metals for production, and from this perspective it appears that all countries share the benefits of asteroid mining. But for the traditional rare metal exporters, their market share is reduced. And in the long run, it is always the OAMC member countries that gain more benefits in this new-born sector.

5.2 Asteroid Mining Admission Model (AMA)

This model is to select countries with capacity and willingness to take part in or dominant Asteroid Mining Sector, who primarily take the most of the benefits of it while revenue of others can be omitted compared to the main part of admitted ones. The admission isn't an artificial standard but a market-decisive citeria.

5.2.1 Indicators Selection

Based on the assumptions above, the relative comparation among global countries won't change before the appearance of Asteroid Mining, thus NDOI of each country is assumed to be adoptable for the Indicators Selection of Asteroid Mining Admission Model.

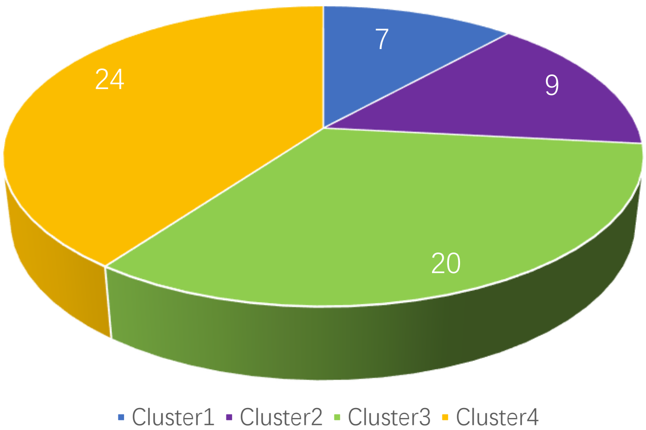
An old saying or definition long-termly exists in Economics, **"Demand is the convergence of capacity and willingness"**. So to assess the admission or demand of countries to Asteroid Mining sector, we selected another two-prong strategy for evaluation.

Capacity is delegated by **NDOI** advocated above, for NDOI represents the opportunity and potential of development, which will convert to true level of development in the future, thus rendering an evaluation for capacity of Asteroid Mining.

Meanwhile, we assumed above "the sector of Asteroid Mining can be simulated by reality conditions and rea-sonable extrapolated", so that we selected the demand gap between national **Net Import per capita** of Mineral Commodity, which means or willingness to obtain minerals on asteroid.

5.2.2 Two-dimension K-means Clustering Method

We reused K-means Clustering Method but in two dimensions of NDOI and Net import per capita. The clustering results are listed as follows:



Clustering Centers:
Cluster1: NDI 0.401; IM $939.326
Cluster2: NDI 0.313; IM $620.98
Cluster3: NDI 0.269; IM $113.26
Cluster4: NDI 0.227; IM $-1571.61
Data Source:
UN Comtrade STIC4.0 Commodity 3
WB World Development Indicators

Figure 10: Proportion of Two-dimension Clustering Categories

Thus, we selected seven countries into the cluster of both high level of capacity along with a high demand of import minerals, which are Japan, Korea, Belgium, Germany, United States, Netherlands and China. Countries above win the admission to Asteroid Mining.

The Asteroid Mining Admission: NDOI > 0.3551 & Net Import > $793.6828.

5.3 Weight Adjust Model: Based on Grey Relation Analysis (GRA)

5.3.1 Adoption of Grey Relation Analysis

Considering the impacts of Asteroid Mining sector, here we advocated a rapid adjustment on our IEWM-TOPSIS method so as to adapt to the external shock from Asteroid Mining. As for a macro and long term consideration, we mainly simulated its changes through a alteration on the weight of evaluation, which means Asteroid Mining sector will exert a structural influence on the development opportunity distribution and global equity.

In order to mine the structural impact of asteroid mining on the weighting among evaluation indicators in our NDOI, Grey Relation Analysis can be take in account, and thus we have its calculation below:

$$\xi_j(k) = \frac{\min_j \min_k \left|x_0(k) - x_j(k)\right| + \rho * \max_j \max_k \left|x_0(k) - x_j(k)\right|}{\left|x_0(k) - x_j(k)\right| + \rho * \max_j \max_k \left|x_0(k) - x_j(k)\right|} \quad (9)$$

$\xi_j(k)$ is the grey relation coefficient between the evaluated vector and the reference vector on the j indicator, and $\rho \in [0, 1]$ is the resolution coefficient (larger resolution is greater, and vice versa. Here we take ρ=0.5).

Aim is to measure the correlation between the asteroid mineral extraction and the 9 evaluation factors in NDOI Model. Since asteroid mining implies an increase in global mining production, we use the incremental global mineral extraction from 2013-2019 as the reference vector and the nine evaluation factors of NDOI as the evaluated vector to simulate the correlation between asteroid mining volume and the nine evaluation factors of NDOI.

In addition, in our hypothesis, asteroid mining will only have an impact on the countries involved in mining and not on other countries, so we only need to analyze the correlations of the indicators for 7 admits in 5.2Asteroid Mining Admission Model. The correlation between the quantity of asteroid mining in the asteroid mining countries and the other 9 evaluation factors is obtained:

Table 6: Results of Grey Relation Analysis

Factors	$\xi_j(k)$	Rank
Energy Consumption	0.8141	1
Research and Development	0.8082	2
Health Expenditure	0.8073	3
Saving Rate	0.8048	4
GDI	0.7844	5
Military Expenditure	0.7471	6
Education Expenditure	0.7412	7
Poverty Ratio	0.5063	8
Labor Increment	0.4868	9

5.3.2 Adjustment of Evaluation Indicator Weights

Since the correlation between the amount of asteroid mining and the different evaluation factors of countries engaged in asteroid mining is different, the impact of asteroid mining on the weights of each evaluation factor is also different. Based on the correlation we adjust the weights of the evaluation factors in the NDOI evaluation model as follows:

$$\widetilde{w}_j = w_j + \frac{\xi_j(k)}{\sum_k \xi_j(k)} - \frac{1}{k} \tag{10}$$

Table 7: IEW of Adjusted NDOI Indicators

X_j	R&D	SR	LI	EC	ME	PR	GDI	EDU	HEA
$\widetilde{w}_j$	14.31%	16.05%	10.36%	15.03%	9.25%	5.16%	9.61%	9.61%	10.33%

5.3.3 Calculating the New NDOI and GEI

Based on the updated evaluation factor weights, the NDOI for each country in the world is recalculated using the NDOI model. Based on the assumptions, the NODI for each country in the world is calculated under the new weights, using the data from 2019 as sample data.

Table 7: NDOIs of the Sample Countries(partial)

Country	Adjusted NDOI	Original NDOI
China	0.5447	0.5160
United States	0.5965	0.5708
Japan	0.4663	0.4366
Germany	0.4452	0.4303
South Korea	0.3641	0.3823
Netherlands	0.3695	0.3551
Belgium	0.3704	0.3845

Based on the Adjusted NDOI data, the GEI model was applied to calculate the inequity index for each country and compared with GEIs for 2019 in Model I:

$$GEI_a(2019) = \sqrt{\frac{{Gini_a}^2 + {GE_a}^2}{2}} = 0.586884 > GEI(2019) \tag{11}$$

Therefore, it is concluded that under the conditions of Model II, asteroid mining leads to an increase in the inequity coefficient, i.e., it is not conducive to global equity.

6 Model III：Changeable Asteroid Mining Analysis

Under the circumstance without **Spare Resource** of changeable analysis, the proper weights of NDOI are alternative according to the changing happened in the admission conditions while the distribution problem has to be included for there exist a specific quantity of exploited resources in the form of flow at a certain short term, though a total quantity of asteroid resources may keep growing as the development of the sector in the long term.

6.1 Changeable Resource Analysis

6.1.1 GEI Basic Analysis: Resource Model and Distribution Coefficient

Figure 11: Process of Changeable Resource Analysis

For this part, we assume that the resources will keep an increment trend in the long term, while at the short term resources is limited, rendering an distribution requirement for the admitted countries into Asteroid Mining. Thus, the admission conditions are fixed, which means only 7 countries above could enter the sector and divide up the most of benefits. Hence, the weights of NODI are justified by GRA of those 7 countries as 5.3.

By fixing the admitted ones and weights of NODI, we controlled the source of the impact in changeable analysis, Resource. Here, a growing yearly quantity of resource is introduced into the analysis with a fixed marginal growth. To simplify, we set the Resource model to $R = t$ while $MR = 1$, rendering a continuous normalized value. Besides, the yearly value has to be allocated between the admitted countries, and thus we introduced an Distribution Coefficient between admits, which is determined by NDOI last year, $DC_{it} = \frac{NDOI_{i,t-1}}{\sum_{i=1}^{7} NDOI_{i,t-1}}$.

Meanwhile, after the distribution of certain resources, the Asteroid resource may influence NDOI through nine indicators, but the possibility has to be examined. So we conducted a **OLS Regression Analysis** as well as **Significance Test** with the model of $Y_{jt} = a + bM_t + \varepsilon$, while Y_{jt} is the sum of indicator j in year t between 7 admits and M_t is incremental produced mineral on earth in year t. The P-values in Significance Test are listed below:

Table 8: Results of P-values in Regression Significance Test

Indicator	R&D	SR	LI	EC	ME	PR	GDI	EDU	HEA
P-value	0.000	0.005	0.135	0.000	0.269	0.021	0.018	0.710	0.000

As shown, R&D, EC and HEA have passed a Significance Test of level 0.001; SR has passed the test level of 0.01; PR and GDI have passed the level of 0.05; while others haven't passed Significance Test. The selected indicators impacted by Asteroid Resources are R&D, EC, HEA and SR, which are consistent with the results of GRA rank in 5.3.

Finally, it came to the basic indicator analysis model as follows:

$$\Delta Y_{ijt} = a_{ij} + b_{ij} * DC_{it} * R_t(t), Y_{ijt} = Y_{ij,t-1} + \Delta Y_{ijt} \quad (12)$$

In this model, a refers to the intercept of indicator j for country i; b_{ij} evaluates the transformation effect According to our assumption that global situation will remain basically unchanged, we assume $Y_{ijt}, t = 0$ is the same as Y_{ijt} in year 2019. As the benefits are distributed between 7 admits, indicators of other 53 countries get fixed. Based on changed Y_{ijt} of 7 and previous results of 53, we reconducted a data normalization, TOPSIS method based on weights in 5.3 and GEI so as to obtain futural NDOI and GEI under the impact of Asteroid Mining.The results of NDOI and GEI from t=1 to t=5 are as follows:

Table 9: Results of NDOI and GEI

R&t	R&t=1	R&t=2	R&t=2	R&t=2	R&t=2
NDOI			Countries		
Rank 1	USA (0.597)	USA (0.613)	USA (0.635)	USA(0.663)	USA (0.714)
Rank 2	China	China	China	China	China
Rank 3	Germany	Japan	Germany	Japan	Germany
GEI	0.5992	0.6073	0.6144	0.6325	0.6523

6.1.2 GEI & Resource Relative Analysis: GM (1,1)

Normally, the Regression Analysis is recognized as a splendid method to describe the statistical relationship and potential cause and effect. Hence, it was adopted in 6.1.1 for abundant data in a time series provided so as to reach a reliable and steady relation or impact between mineral increment and several indicators. However, in 6.1.2, to describe the relation between the quantity of Resource and GEI, which means influence from Asteroid Mining on global equity, isn't so proper for regression as it's short time series.

Here, a GM (1,1) Model is adopted. Normally, it's a method for forecast, describing the changing of the value with time going. Nevertheless, since our set of Resource Model $R = t$, the value of R goes equally consistent with time altering, which means resource inputs and time going together enjoy a same state for the GEI sequence in grey system. Furtherly speaking, GM (1,1) equation is endowed with the ability to show the relationship between GEI and Asteroid Resource.

Firstly, we had a grey differential equation:

$$\frac{dGEI^{(1)}}{dt} + aGEI^{(1)} = \mu \tag{13}$$

Then, we adopted OLS to figure out $\hat{\alpha} = \frac{a}{\mu}$ and came to the forecast equation:

$$\widehat{GEI}^{(1)}(t+1) = \left[GEI^{0}(1) - \frac{\mu}{a}\right] e^{-at} + \frac{\mu}{a} \tag{14}$$

Finally, we differently used residual test and post-test difference test.

As for results, we obtained the equation as follows:

$$\widehat{GEI}^{(1)}(t+1) = \left[GEI^{0}(1) - \frac{0.547}{-0.028}\right] e^{0.028R} + \frac{0.547}{-0.028} \tag{16}$$

Post-test difference ratio: 0.03< 0.35; Absolute error: 0.228%<10%. The results of both tests indicate that our fitting GM (1,1) equation has excellent accuracy.

From equation above and Figure 12 below, it is found that from t=1 to t=9, as resource brought by Asteroid Mining sector increasing at a constant speed, GEI has increased from 0.5992 to 0.7283, with an increase of 21.55% in 9 years, which indicates an even larger inequity brought by Asteroid Mining resource distribution. Considering a growing gap because of the limited admission to Asteroid Mining sector along with the advancing resource exploited, we can judge without a powerful global policy, equity will fail to realize but inequity may reach a period of wild growth, which is shown below:

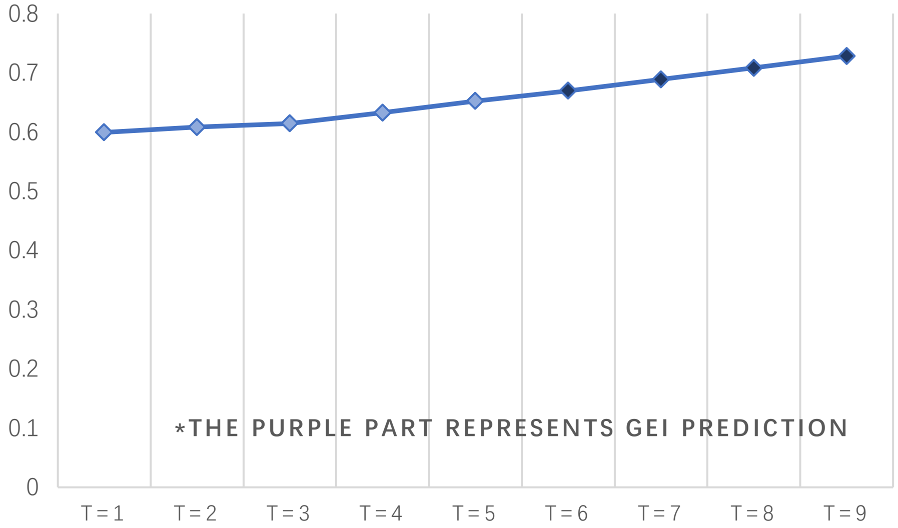


Figure 12: GM (1,1) Prediction of GEI

6.2 Changeable Admission Analysis

The impact of admission is mainly displayed in weight in our model. In model II, we set the entry threshold very high, i.e., only cluster 4 countries can engage in asteroid mining sector. Now we gradually loose this condition, and the order of entry for different clusters is NDOI as the main sequence and energy demand as the secondary sequence, i.e., countries engaged in asteroid mining cover Cluster 2, Cluster 3, and Cluster 4 in order from Cluster 1.

Hence we divided the access threshold into four categories based on the type of country involved in asteroid mining.

Table 10: Entry Threshold Classification

Categories	Entry Threshold Level	Types of Countries Involved in Asteroid Mining
A	HIGH	Cluster1
B	GENERAL HIGH	Cluster1,Cluster2
C	MIDDLE	Cluster1,Cluster2,Cluster3
D	LOW	Cluster1,Cluster2,Cluster3,Cluster4

6.2.1 Adjustment of Evaluation Indicator Weights

In this part, the number of countries involved in asteroid mining varies at different thresholds due to the reduced entry threshold for asteroid mining. According to our assumptions, asteroid mining will only have an impact on the countries involved in mining and not on other countries. So with the lowering of the entry threshold, we need to re-run the gray correlation analysis for all the countries involved in mining, and ultimately as follows:

Table 11: Gray Correlation under Different Entry Thresholds

Factors	A	B	C	D
EC	0.81409002	0.798817101	0.76008537	0.775073307
R&D	0.808153947	0.857126173	0.860342495	0.779839392
HEA	0.807305936	0.798536103	0.759794594	0.718239993
SR	0.804761905	0.796019708	0.690659231	0.687970858

GDI	0.784409654	0.775888546	0.736358878	0.749102641
ME	0.747097195	0.738981415	0.764698734	0.72332082
EDU	0.741161122	0.797403725	0.825154202	0.717025991
PR	0.506262231	0.455756932	0.538149139	0.69539426
LI	0.486757991	0.481470298	0.564757357	0.654032737

Using the method of adjusting the weights of evaluation factors in GEI, we get the adjusted weights as follows:

Table 12: IEW of NDOI Indicators under Different Entry Thresholds

X_j	R&D	SR	LI	EC	ME	PR	GDI	EDU	HEA
A	14.31%	16.05%	10.36%	15.03%	9.25%	5.16%	9.61%	9.61%	10.33%
B	15.07%	15.92%	10.28%	14.80%	9.13%	4.38%	9.48%	10.77%	10.19%
C	15.11%	14.29%	11.56%	14.20%	9.52%	5.65%	8.87%	11.19%	9.60%
D	13.88%	14.25%	12.93%	14.43%	8.89%	8.07%	9.06%	9.53%	8.96%

6.2.2 Calculating the Adjusted Global equity Index

Based on the adjusted evaluation factor weights and the data of 2019, the GEI model is applied to measure the change of the global inequity index as the entry threshold gets lower.、

The result: GEI(A)>GEI(B)> GEI(2019) >GEI(C)> GEI(D)

From the figure below, we can conclude that a lower barrier to entry can mitigate the negative impact of asteroid mining on global equity. Moreover, as the threshold is lowered to a certain level (e.g. Category C), more and more developing countries join the sector. In this case, the inequality coefficient is even lower than it would have been in the absence of asteroid mining, implying that global equity is enhanced.

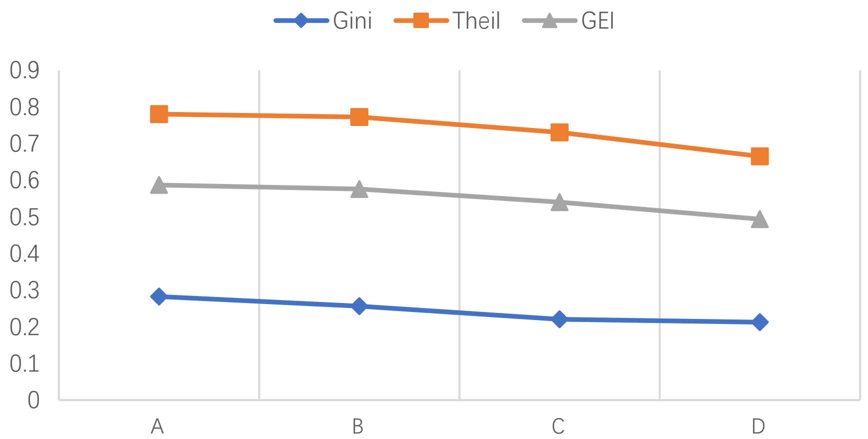


Figure 13: Changes in the GEI

7 Global Equity Promotion Policies of UN: on Asteroid Mining

Above we analyzed the previous part of the model and try to make some reasonable and effective recommendations to the UN. The aim is to strengthen global cooperation, focusing on easing access to the asteroid mining sector, increasing the amount of recoverable resources and equitably distributing them.

The natural access barriers in terms of capital are caused by the stage of national economic development. That is, because the economy has not yet reached a more developed state and the relevant idle funds are less, it is difficult for many countries to develop asteroid mining sector.

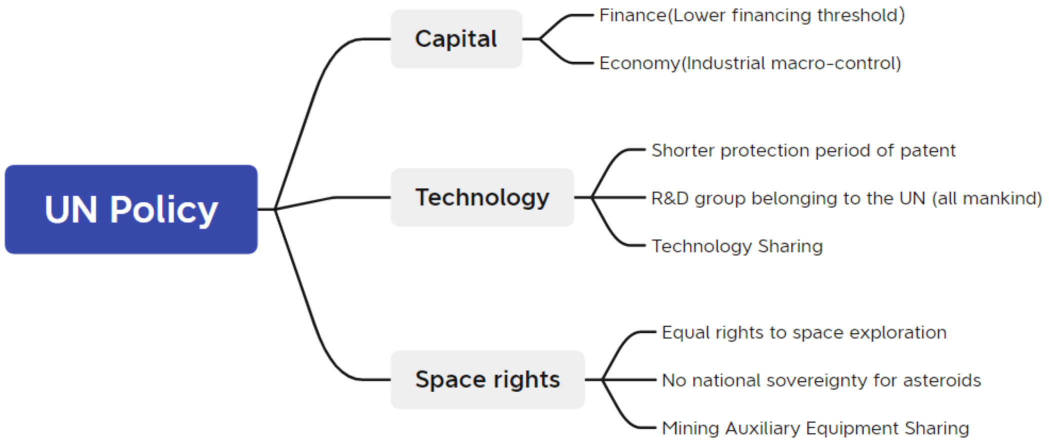


Figure 14: UN Policies on Asteroid Mining

7.1 Finance Policies:

(1) Strongly support the establishment of a dedicated foundation for asteroid mining, pooling dedicated funds. In this way, countries can make efficient use of funds that are idle or intended to be invested in this area.

To raise a large amount of sustainable funds from countries around the world, firstly, it can inject impetus into the development of asteroid mining industry and accelerate its development. Secondly, it can also involve more and more countries to promote global equity.

(2) The United Nations and the World Bank offer preferential loans to the asteroid mining industry. In this way, the availability and low cost of capital can be ensured to a large extent, thus providing financial support for countries with weaker economies to invest in the asteroid mining industry and promoting global equity.

7.2 Economic Policies:

Encourage the establishment of planning boards or planning committees to regulate the development of the global asteroid mining industry， from a macroeconomic perspective.

(1) Plan the strategy and prospect, regulate the development speed and process of asteroid mining industry from an overall perspective, and make it develop in the direction of promoting global equity.

(2) Coordination between earth mining and space mining to prevent negative interaction between earth mining and asteroid mining. To set up different special uses and utilization channels for earth mineral resources and asteroid mineral resources, so that the two can pro-

mote each other and develop together, asteroid mining industry should make up for the deficiency of earth mineral resources.

(3) Whole-industry participation, different countries can be responsible for different links of the asteroid mining industry chain.Because different countries are at different stages of development, they are also good at different fields. In accordance with the principle of optimization, the participation of the whole industry can maximize efficiency and promote global equity.

7.3 Technology Policies:

(1) Shorten the protection period of patents on asteroid mining technologies. On the one hand, for the patent-holding countries, a shorter protection period forces them to engage in asteroid mining more efficiently. On the other hand, the shorter protection period will allow more patented technologies to be owned by all mankind and narrow the technology gap between countries.

(2) Prepare a special international research team whose R&D results will be owned by all human beings. The team will be invested by the United Nations. When countries apply to use their technology, they pay a fee based on their position in the asteroid mining field - the leading countries in the field pay relatively high royalties, while the lagging countries are able to use it at a very low price.

(3) Promote technology sharing. Advocate for technical support from leading countries in asteroid mining technology for other countries.

7.4 Space rights: Update of Outer Space Treaty

(1) Give all countries equal rights to space exploration. All countries are free to explore and use outer space without violating international law.

(2) Sovereignty over asteroids belongs to all mankind. Any country engaged in asteroid mining shall not take the sovereign right to use asteroid resources in any form for itself. Such a regulation can avoid to a certain extent that OAMC members divide the territory in space and compete for resources, and protect the space rights of other countries.

(3) Opening up space and celestial mining aids to other countries on a reciprocal basis. This will allow countries that will later engage in asteroid mining to greatly reduce the financial and technical difficulties of the mining process.

8 Strengths and Weaknesses

8.1 Strengths

- **Innovation:** A new set of national development opportunity indices (NDOI) is innovatively developed, and a global equity evaluation model is obtained by analyzing the differences of development opportunity indices among countries. It also involves the innovative application of the Gini coefficient and the Theil index.
- **Scientific rigor:** The selection of evaluation indicators is scientific and comprehen-

sive. The selection of indicators is scientific and comprehensive.

- **Imagination:** Since asteroid mining is still in the theoretical stage, we boldly describe and justify the vision of future asteroid mining.
- **Reality:** Although asteroid mining is based on hypotheses, our predictions and descriptions are based on existing scientific results and reasonable analogies. An example is the Organization of Asteroid Mining Countries (OAMC) scenario.
- **Multi-case discussions**: For the consideration of different countries, we discuss the different clustering categories after performing K-means clustering. For asteroid mining, we consider the variation of barriers to entry and relative total extractable quantity.
- **Long- and short-term considerations (Economics Mindset)**: we assume that asteroid mining has different performance and impacts in the long and short term and then analyze them separately.

8.2 Weaknesses

- **Mutual impact among 9 indicators are omitted for simple analysis.** This can be optimized by Decision Making Trial and Evaluation Laboratory (DEMATEL), which evaluates the degree of mutual influence among indicators by scoring the influences between each two indicators with AHP-like process.
- **Only two types of conditions loosen are considered.** In other words, both conditions of admission and resource can be loosed at the same time, or more conditions may come into consideration.

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