

Research on the Impact Mechanism of Asteroid Mining on Global Equity under the Comprehensive Evaluation System

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Abstract. In order to scientifically measure the global equity connected with asteroid mining, we establish a comprehensive evaluation system of global equity based on five criteria layers involving economic, environmental, educational, social, and health. We also measure the Global Equity Index (GEI) based on entropy weight method and AHP. The countries are grouped into three categories according to GEI. We Use grey relational analysis to screen out the indicators of significant impact of GEI for different categories of countries, and deeply study the mechanism of asteroid mining on global equity. For the definition and analysis of Global Equity, this paper comprehensively evaluates the level of global equity from five aspects involving economy, environment, education, society, and health. This paper selects representative indicators such as GDP per capita, resident consumption per capita, carbon dioxide emissions, forest area, etc., and uses the entropy weight method and the analytic hierarchy process to quantify the level of sample country's equity. We select the developed and developing countries of each continent respectively, multiply the scores of each sample by the corresponding number of developed or developing countries in its continent, we use weighted average to arrive at the equity score of one continent and the global equity score finally. For the future vision for asteroid mining, we will describe in detail the subjects, costs and benefits, resource division, and profit distribution of the asteroid mining. After using the entropy weight method to determine weights, we screen out indicators which produce a significant impact on global equity, and analyze the impact mechanism of asteroid mining on global equity. For the future impact of asteroid mining, we divide countries into three categories: countries with high equity level, medium equity level, and low equity level by clustering. We use grey correlation analysis to find the indicators that have a significant impact on the GEI of different countries, and analyze the impact of the three-stage changes in asteroid mining on these three types of countries.

Keywords: Analytic Hierarchy Process; The Comprehensive Evaluation System of Global Equity; Grey Relational Analysis.

1. Introduction

1.1 Problem Background

Human mining of asteroid minerals is a classic part of science fiction works, but with the increasing consumption and pollution of the environmental resources, the plot of this movie gradually becomes a reality. [1] The development and utilization of space resources is a new frontier in the current game of great powers, and it is also the commanding heights of scientific and technological competition.

The United Nations has always been promoting global peace and reducing inequality. As early as 1967, most countries in the world signed the "United Nations Outer Space Treaty"[2]. As the foundation of international space law, the Outer Space Treaty has provided the legal underpinnings for projects that have promoted multinational access to space, such as the International Space Station and the use of satellites to browse the Internet in even the most remote locations.

However, with the development of economic globalization and the new scientific and technological revolution, traditional global problems such as resource shortage and environmental degradation have not been solved, and new hot spots like COVID-19 Outbreak are constantly emerging. Global development has fallen into the predicament of a century of changes and a century-old epidemic. Worse still, international treaties are becoming less binding, and global equity

connected with asteroid mining continues to decline. The situation of global equity in the future may not be optimistic.

1.2 Restatement of the Problem

In this paper, we need to address several critical questions: What is global equity and how is it measured? How will asteroid mining affect global equity? What can we propose to promote global equity connected with asteroid mining in the future?

Specifically, in the definition and analysis of Global Equity, we need to explain the definition of global equity, and give the measurement methods and tools. Based on the meaning of global equity, we build a global equity evaluation model to scientifically quantify the level of global equity. We need to justify the conclusions and verify the accuracy and rationality of the model according to the historical, humanistic and geographical characteristics of different regions.

In the future vision for asteroid mining, we imagine general situation of future asteroid mining and describe who is mining, how the activities are funded, who will receive the value of minerals, how the profits are distributed, etc. We need to confirm what is stated above. In fact, we don't know what the asteroid mining in the future would look like, whose conditions are uncertain and unknown, so our imagination may inevitably be subjective. In addition, we need to build models to deeply analyze the impact of asteroid mining on global equity.

In the future impact of asteroid mining, we need to discuss how changing conditions of the asteroid mining in the future will affect global equity. We need to build models to quantify changes in global equity under different conditions and categorize positive and negative impacts.

2. Problem Analysis

For the definition and analysis of Global Equity, we give a definition of global equity. In order to measure global equity scientifically, this paper comprehensively evaluates the level of global equity from the perspectives of five aspects: economy, environment, education, society and health. To achieve global fairness, we must eradicate poverty and hunger, improve health and well-being, facilitate quality education and promote the use of clean energy [4]. Based on the five dimensions under the equity framework, this paper sets economy, environment, education, society, and health as the criterion layers and selects representative indicators such as GDP per capita, resident consumption per capita, carbon dioxide emissions, forest area, etc. Next, the entropy weight method and the analytic hierarchy process are employed to calculate equity scores of sample countries. We choose typical developed and developing countries in each continent as representative samples, calculate the average equity score and multiply it by the corresponding number of developed or developing countries to obtain the overall equity score of that continent. By arithmetically averaging the equity scores across continents, we can obtain the global equity score. Finally, the data analysis results are analyzed in detail to verify the model according to the historical and geographical conditions of various regions.

For the future vision for asteroid mining, we will describe the possible future vision of asteroid mining, including the subject, cost and income of minerals, resources division, and profits distribution of the asteroid mining. We determine the weights through the entropy weight method, and screen out indicators that conduct a significant impact on global equity. By analyzing the impact of asteroid mining on the index, we analyze the impact mechanism of asteroid mining on global equity.

For the future impact of asteroid mining, we cluster countries into three categories. We use grey relational analysis to find out the indicators that have a significant impact on each type of country. We analyze the impact of changes in asteroid mining on fair countries and unfair countries, and categorize the positive or negative impact on global equity caused by changes in asteroid mining conditions. We analyse the different impacts of asteroid mining on each country at different stages.

3. Assumptions and Symbol Description

3.1 Assumptions

The indicators we choose are representative and reflect global equity.

The asteroid mining industry is economically and technically viable in the future. It can relieve the pressure on the earth's resources and promote social development.

We assume that the United Nations remains committed to promoting global peace and reducing inequality, and that a series of policies will be developed in the future to support human participation in asteroid mining.

All countries in the world conscientiously abide by the external space policy formulated by the United Nations and take the global common interest as the criterion for their actions.

The 16 countries we chose are representative and reflect the equity index of the country's continent.

Asteroid mining could be divided into three stages, namely embryonic stage, development stage and mature stage. As the asteroid mining industry continues to grow, more and more countries are participating.

3.2 Symbol Description

Table 1. Symbol description

Symbols	Definition
GEI	Global Equity Index
x_{ij}	Index value, i for countries, j for different indicators
β	Index direct weight
β_1	Weight of First-level indicators
β_2	Weight of Second-level indicators

Notation that we use in the model are shown in the following table.

4. The Definition and Analysis of Global Equity

4.1 Model Establishment

4.1.1 Establish an Indicator System

When measuring global equity, we need to consider multiple perspectives. This paper studies equity from five dimensions involving economy, environment, education, society, and health. Economic equity means that everyone can afford the necessary consumption of their own lives and the country can conduct all economic activities of the whole country within budget. Environmental equity means that everyone can enjoy the green environment. Education equity means fair distribution of educational resources where everyone is equipped with equal chance to go to school and learn knowledge. Social equity means social equality and public resources are shared by the whole people. Health equity means that everyone should enjoy health care. Based on the above preliminary elaboration on global equity, this paper further selects secondary indicators for these five aspects to construct a comprehensive indicator evaluation system.

In respects of economic equity, we choose GDP per capita, resident consumption per capita and total savings. In respects of environmental equity, we select CO2 emissions (metric tons per capita), forest area (% of land area) and Grain yield (kg per hectare). In respects of educational equity, we choose years of primary education, enrollment rate and compulsory education years. In respects of health equity, we select current health expenditure (% of GDP), life expectancy at birth and probability of death of children aged 5-9 (per 1,000). In respects of social equity, we choose unemployment rate and service sector employment (% of total employment).

As shown in Figure 1, yellow represents a positive correlation between the indicator and the Global Equity Index, and red represents a negative correlation between the indicator.

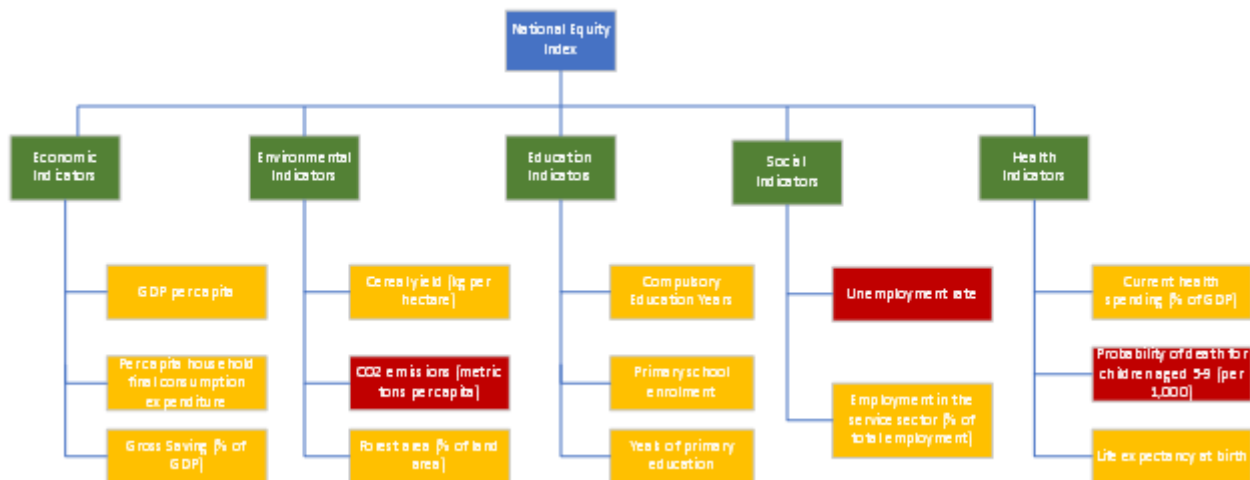


Figure 1. Global equity indicator system

4.1.2 First-level Indicator Score Determination

First, normalize each type of secondary indicators, since the values of positive indicators and negative indicators have different meanings. The higher the positive indicator value, the better the result. The lower the negative indicator value, the better the result. Therefore, for the high and low indicators, we use different algorithms to normalize the data. The specific method is as follows.

For positive indicators:

$$x_{ij} = \frac{x_{ij} - \min \{x_{1j}, \dots, x_{nj}\}}{\max \{x_{1j}, \dots, x_{nj}\} - \min \{x_{1j}, \dots, x_{nj}\}}$$

For negative indicators:

$$x_{ij} = \frac{\max \{x_{1j}, \dots, x_{nj}\} - x_{ij}}{\max \{x_{1j}, \dots, x_{nj}\} - \min \{x_{1j}, \dots, x_{nj}\}}$$

Then calculate the proportion of the program index value under index and the weight of each indicator by entropy weight method. And then we get the overall score. The overall score is calculated by the following formula.

$$S_i = \sum_{j=1}^m w_j p_{ij}$$

Among them, S_i is the comprehensive score of a first-level indicator of the country i .

4.1.3 Calculating GEI

According to the first-level index score matrix obtained above, the weight coefficient of each first-level index is determined by the entropy weight method again, and finally the equity index (GEI) of each country is obtained. The formula is as follows.

$$GEI = \sum_{j=1}^m W_j P_{ij}$$

Among them, W_j is the weight coefficient vector of each first-level indicator. P_{ij} is the proportion of the first-level indicator j of the country i .

Since the obtained values GEI are all small, the following transformation is performed here.

$$GEI = GEI * 1000$$

When calculating the GEI value of the corresponding continent by country, considering that there may be differences in the GEI value of developed and developing countries, it may affect the final calculated GEI value of the continent. So as to eliminate differences caused by different sample countries, we choose the weighted arithmetic average of the GEI values of the selected sample countries in the state to obtain the total GEI value of the continent. The denominator of the calculation formula is the number of all countries in the state. Among them, the weight calculation formula for developed countries is as follows.

$$\alpha_1 = \text{the number of developed countries in the state} / \text{sample}$$

The weight calculation formula for developing countries is as follows.

$$\alpha_2 = \text{the number of developing countries in the state} / \text{sample}$$

Finally, when calculating the global GEI , the GEI value for the six continents is averaged.

4.2 Model Solving

4.2.1 Sample Determination

In order to increase the credibility of the model, this paper selects countries on six continents, a total of 16 countries, and selects data from 2011 to 2019. The selection of countries is shown in Table 2.

Table 2. Country selection

Continent	Nation	Continent	Nation
Asia	China,India,Japan	Europe	Hungary,Poland,U.K
Africa	South,Africa,Kenya Ethiopia	Oceania	Australia,new Zealand
North America	Canada,America	South America	Brazil,Colombia,Mexico

4.2.2 GEI Calculation Results

Table 3. GEI score for the country

Country	GEI	Country	GEI
China	53.1	Ethiopia	22.2
India	20.5	Australia	85.5
Japan	84.5	new Zealand	85.7
Hungary	57.5	Canada	83
Poland	45.9	America	111.7
U.K	86.3	Brazil	71.8
South Africa	26.7	Colombia	66.5
Kenya	36.2	Mexico	62.9

Because of the large number of calculation results containing a total of nine years and sixteen countries' results data, so we only show the data of 2019 as follows. The weight coefficient corresponding to each index is calculated using the entropy weight method. The score of each country is obtained by the analytic hierarchy process, that is, the GEI value. as shown in the table below. Among them, the GEI of the United States, the United Kingdom, and Japan is relatively high, which

is more in line. Finally, the *GEI* values of each continent and the world are obtained from the national *GEI* values.

4.2.3 Analysis of Results

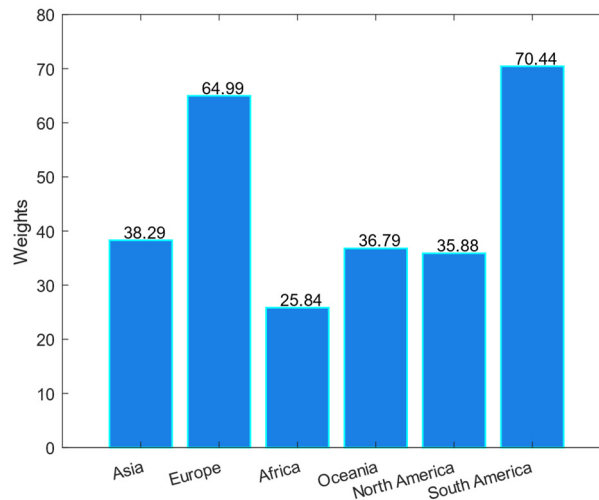


Figure 2. The 9-year average *GEI* across continents

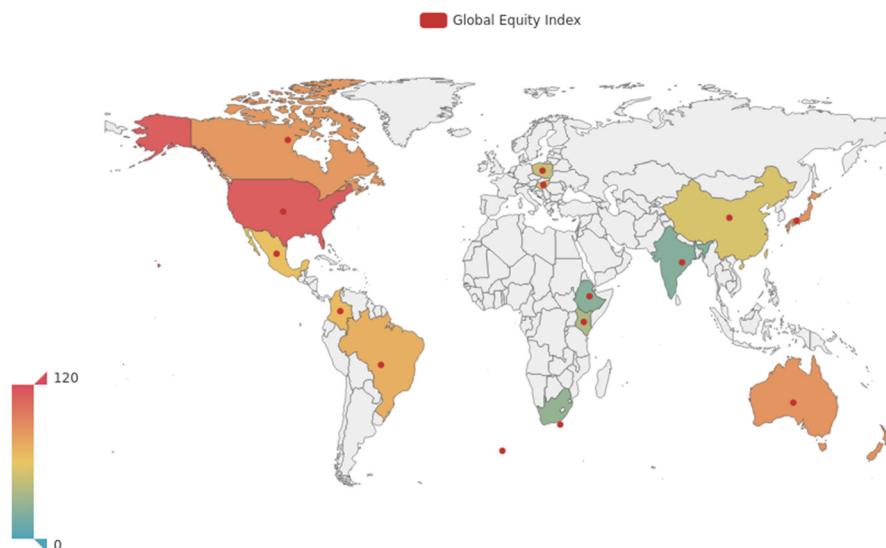


Figure 3. The 9-year average *GEI*

From the 9-year average *GEI* of each continent in the figure 2 or figure 3, it can be found that the *GEI* of Europe and South America is the highest, followed by Asia, Oceania and North America. The Africa index is the lowest, only 25.84. Among them, Europe and the Americas, as the birthplaces of the first and second industrial revolutions, are relatively developed as a whole, and the national quality is generally high, so the equity index ranks at the forefront of the six continents. Asia and Oceania The number of countries is large, but the overall level of development is in the middle, so the equity index is also in the middle. Since Africa has been relatively backward without developed country, so most of the indicators are lower than the other five continents, and the lowest equity index is in line with the actual situation, reflecting the model and the rationality of the results.

According to the calculation results of our model, a trend graph of the global equity index over time is drawn, as shown in the figure 4.

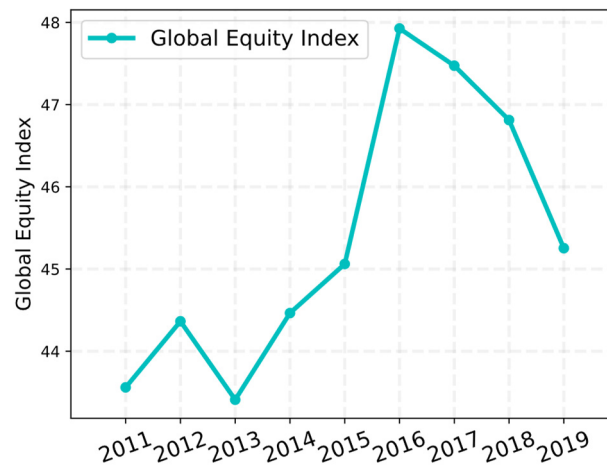


Figure 4. Global Equity Index Trends Over Time

From the figure, it can be found that the change trend of the global equity index can be roughly divided into two stages. The overall trend was upward from 2011 to 2016, while it became a downward trend after 2016. We know that equality and freedom are the common pursuit of everyone, so the global equity index showed an upward trend at the beginning. In 2016, many major events exacerbated the inequality, such as Trump's participation in competition and ultimately Becoming the President of the United States, the rampant terrorism has seriously impacted the national and regional security order. The Google Go AI program AlphaGo in the information field defeated the world champion chess player Lee Sedol, setting off a new chapter in artificial intelligence. It is the result of developed countries and most countries have not benefited from this. Therefore, the inequity of the world will be exacerbated in the early stage of information change. The world equity index GEI has shown a downward trend in a short period of time, which verifies the rationality of our model.

5. The Future Vision for Asteroid Mining

5.1 Asteroid Mining Vision Statement

According to reference materials [5], asteroid mining is economically feasible and technically feasible. Moreover, international space law treaties such as the Outer Space Treaty and the Moon Agreement [6] have also enhanced legal feasibility. Base. We know that the goal of the United Nations is to promote global peace and reduce inequality. We envisage that the future asteroid mining belongs to all mankind, and the results are shared by all mankind. Asteroid mining will promote the development of industry, science and technology and positively affect global equity.

In the future, asteroid mining will be the object of investment by all companies, national governments, international cooperative institutions, and even individuals. The income obtained from asteroid mining will be shared by all investors and the benefits will be distributed according to the proportion of investment. The specific mining practice may be conducted by scientific research institutions around the world, but the funds come from all over the world. Besides the international organizations and governments, the public can also participate in asteroid mining and gain benefits. Asteroid mining itself is a beneficial investment that is conducive to alleviating the pressure on the environmental resources and promoting the development of industries such as economy and technology. We hold the belief that asteroid mining cannot be monopolized by some certain country, institution, or company. The monopoly of developed countries cannot be accepted by the developing country. The antitrust movement in the United States also shows that we do not accept the monopoly of large companies, so we forecast that asteroid mining should be a popular "gold rush" in the future.

5.2 Identifying Significant Impact Indicators

Since the equity model in question 1 has calculated the weight of each indicator twice with the entropy weight method, which represents its influence on *GEI*. So we can calculate the direct weight of the indicator on *GEI* through two weights, thus determining the degree of influence of each indicator on *GEI*. We use the 2019 index weights. The formula for calculating the direct weight of the indicator is as follows.

$$\beta = \beta_1 * \beta_2$$

Among them, β represents the direct weight of the index. β_1 represents the weight of the secondary index. β_1 represents the weight of first-level indicators.

The calculated direct weight results are shown in Table 4. The four indicators with higher weights are selected, from large to small, they are primary school enrollment rate, consumption expenditure per capita, compulsory education time, and GDP per capita.

Table 4. The direct weight of the indicator

Indicators	Weight	Indicators	Weight
ER	0.21702	LE	0.04801
RCPC	0.10555	YOPE	0.04264
CEY	0.10264	UR	0.03969
GPC	0.09960	FA	0.03829
SSE	0.08341	GY	0.03761
CHE	0.07042	POD	0.03297
TS	0.04925	CE	0.03290

ER, RCPC and so on respectively represents enrollment rate, resident consumption per capita, compulsory education years, GDP per capita, service sector employment, current health expenditure, total savings, life expectancy, years of primary education, unemployment rate, forest area, Grain yield, probability of death and CO2 emissions.

5.3 Results Analysis

As can be seen from question 1, this paper has explained and quantified the definition of global equity. So when discussing the impact of asteroid mining on global equity in question 2, we can focus on the impact of asteroid mining on fourteen indicators. What kind of impact can it conduct on global equity. Since the indicators mentioned above that significantly affect *GEI* have been calculated, we only need to discuss the impact of asteroid mining on the significant indicators, and analyse the impact of global equity.

5.3.1 Primary School Enrolment

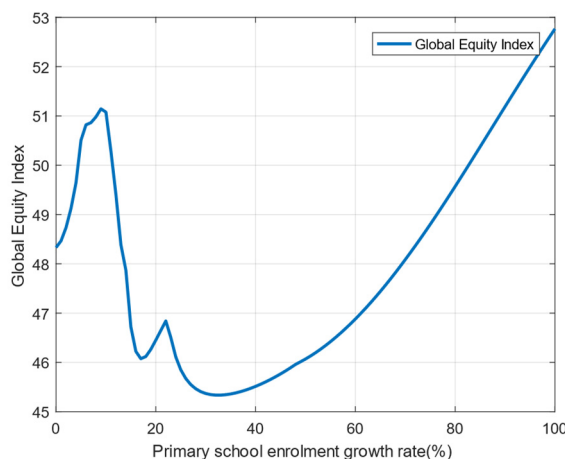


Figure 5. GEI variation

With the advancement of asteroid mining technology, more and more countries begin to cultivate relevant talents and increase education investment. [7] Therefore, primary school enrollment will increase.

As the primary school enrolment rate in each country increases, it can be seen from figure 1 that t global equity fluctuates violently, but overall, it promotes the improvement of global equity. Ultimately, when primary school enrolment doubled, the *GEI* improved by 9.10%.

5.3.2 Household Final Consumption Expenditure Per Capital

Asteroids are rich in metal raw materials such as iron and platinum with higher purity. Once humans can successfully use these mineral resources in outerouter space, the cost of microelectronics, energy storage and other fields will fall. Therefore, national economic strength will increase, and so will promote consumption expenditure per capita.

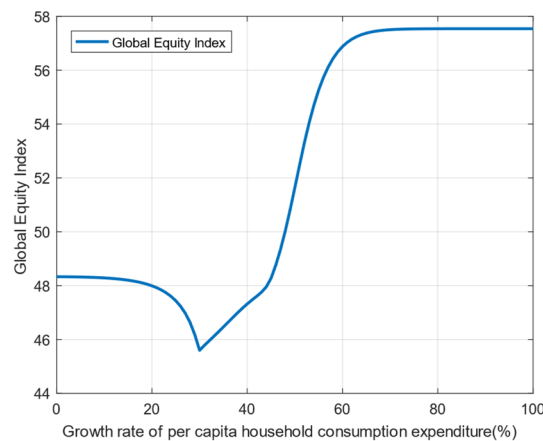


Figure 6. GEI variation

5.3.3 Compulsory Education Years

As can be seen from the previous description, asteroid mining has a significant impact on education level, and also has a positive impact on economic level. Therefore, in order to enhance its scientific and technological strength, the country will increase its investment in the education industry, and the number of years of professional education will also be increased.

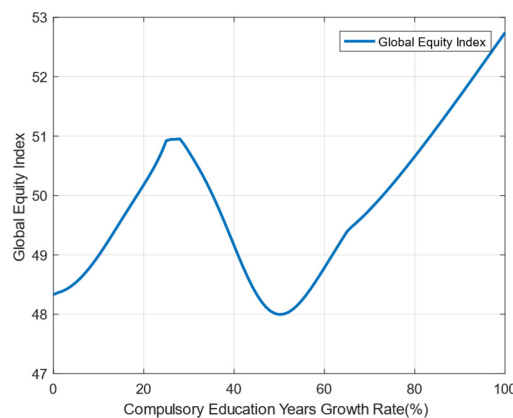


Figure 7. GEI variation

5.3.4 GDP Per Capital

With the increase of GDP per capital of each country, it can be seen that its trend of change is very similar to the curve of per capital consumption expenditure. In the end, after doubling the per capital GDP, the *GEI* increased by 18.71%.

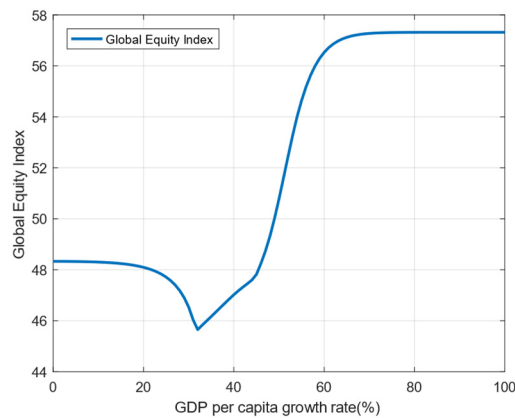


Figure 8. GEI variation

6. The Future Impact of Asteroid Mining

6.1 National Classification

Firstly, cluster analysis was carried out on the equity index of 16 countries in the past 9 years. The elbow method was used to select the number of cluster centers K as 3. The results of Kmeans clustering are shown in the Table 5.

Table 5. Country classification results

Category	Country
0	China, India, Poland, South Africa, Kenya, Ethiopia
1	Hungary, Brazil, Colombia, Mexico
2	Japan, UK, Australia, New Zealand, Canada, USA

6.2 Index Selection

We use the grey correlation analysis model to analyze the above three types of countries respectively. We analyze related data in 2019, which is the most valuable reference for the future. The reference number is listed as the national equity index in 2019, and the comparison sequence is 14 indicator values for various countries in 2019. We calculate the gray correlation index of each indicator of the first category of unfair countries. We draw the index correlation matrix according to the results, as shown in the Figure 9.

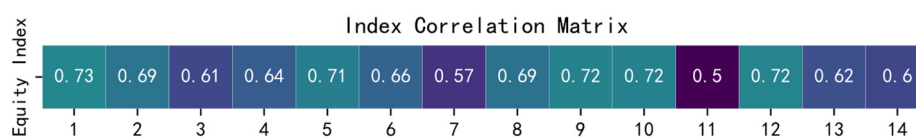


Figure 9. Grey correlation degree matrix of unfair countries

As can be seen from the figure, the significant impact indicators of countries with low level of equity are: GDP per capita, health expenditure, and compulsory education time in the descending order.

Next, as to the gray correlation index of each indicator of the second category of fairer countries, we draw the indicator correlation matrix according to the results, as shown in the figure 10.

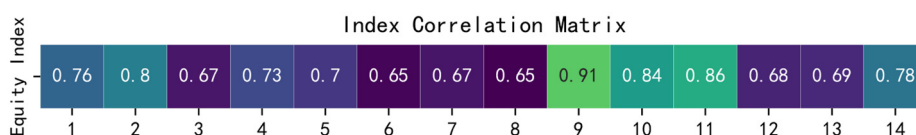


Figure 10. Grey correlation degree matrix of medium fair countries

As can be seen from the figure, the significant impact indicators of countries with medium level of equity are: service sector employment, GDP per capita, consumption expenditure per capita in the descending order.

Finally, as to the grey correlation index of each indicator of the third type of fair country, we draw the indicator correlation matrix according to the results, as shown in the figure 11.

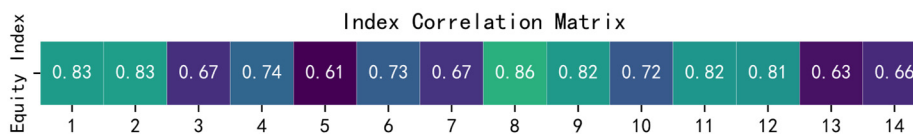


Figure 11. Grey correlation degree matrix of fair countries

As can be seen from the figure, the significant impact indicators for countries with high level of equity are current health expenditure, probability of children death, and compulsory education time in the descending order.

6.3 Results Analysis

According to our assumption, the changes of the asteroid mining can be divided into three stages, namely the embryonic stage, the development stage and the mature stage. In the embryonic stage, due to economic and technological constraints, asteroid mining was mainly participated by countries with relatively high equity index. At this stage, the scale of asteroid mining was relatively small and related technologies were immature. For example, the United States and the Soviet Union conducted lunar mining before, which is mainly used for scientific research, the benefits are not obvious considering their huge cost. Through the grey correlation analysis above, we find that the significant impact indicators of countries with high level of equity are current health expenditure, death probability of children and compulsory education time. In this stage, asteroids mining does not affect these indicators, only affects some insignificant indicators through technological progress or accidental economic benefits, so it has little impact on global equity. Because only developed countries participate, it reduces global equity index.

During the development period, as more fair countries joined in, asteroid mining gradually showed a scene of "a hundred schools of thought contending", which further promoted the development of economy, technology and other aspects. At this stage, the asteroid mining industry has begun to generate stable income. At this stage, asteroid mining has increased service sector employment in the countries with medium level of equity by promoting the development of the tertiary industry, and increased GDP per capita and consumption expenditures per capita by promoting economic development.

Since the bottleneck period has been reached, the improvement of various indicators is not obvious. Generally speaking, the equity index gradually picks up at this stage. One of the premises of our second-stage assumption is that the United Nations formulates relevant policies to support it. If the United Nations does not regulate, it will result in fair countries forming a monopoly by occupying near-Earth asteroids or leading technology. Even if asteroid mining industry itself will promote economy development, advancement of science and technology and other fields, but the different levels of development in different countries have exacerbated the inequity.

In the mature stage, with the participation of unfair countries and even companies and individuals, a common fashion trend of "gold rush" has formed around the world. At this time, since it will further promote economic development, it will affect other fields after economic development. For example, the increase of national income will increase the investment in education and medical care. In this stage, the development potential of unfair countries is relatively large, while the progress of fair countries and relatively fair countries is less under the influence of the law of diminishing marginal returns. So, the GDP per capita of unfair countries is relatively small. And the current health expenditure and compulsory education time under the influence of economic improvement will

increase significantly, so the submission of the equity index in this stage will be further improved on the basis of the second stage. The assumption at this stage also needs the support of relevant policies. For example, some unfair countries do not have the ability to independently conduct asteroid mining, whether individuals can invest in mining and the legality of companies to conduct mining. The United Nations also needs to formulate relevant international space treaty to support countries without independent asteroid mining capabilities, legitimize mining by companies and international partners, and encourage individuals and small organizations to invest in asteroid mining, etc.

7. Summary

(1) Global equity refers to economic equity, environmental equity, educational equity, social equity, and health equity. We establish a comprehensive evaluation system of global equity to analyze regional equity.

(2) Asteroid mining is mainly participated in by countries with high equity index in the embryonic stage featuring the immature technology and limited scale. In the development periods, countries with medium equity level gradually joined asteroid mining, leading to the equity index growing rapidly. Then countries with low equity level and the public are encouraged to participate in asteroid mining in the mature stage where the obtained benefits are shared by all investors and distributed scientifically according to the type and proportion of investment, thus improving the equity index has steadily.

(3) We analyze the impact of mining on global equity in views of the countries' type. For inequitable countries, significant impact indicators are GDP per capita, current health spending, and compulsory education time in a descending order. For fairer countries, those are service sector employment, GDP per capita, consumption expenditure per capita. For equitable countries, those are current health spending, probability of death for children, compulsory education time ranked from highest to lowest.

References

- [1] Zhang Kefei, Li Huaizhan, Wang Yunjia, Deng Kazhong, Li Changgui, Wang Qianxin, Liu Xinhua, Xie Yaoshe, Duan Yabo, Yang Yang. Current Situation, Opportunities and Challenges of Space Mining Development [J]. Journal of China University of Mining and Technology, 2020, 49(06) :1025-1034.
- [2] The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies, of 27 January 1967, United Nations RES 2222 (XXI).
- [3] Wu Yu. Research on Xi Jinping's Thought on Building a Community of Shared Future for Human Beings [D]. Hebei Normal University, 2019.
- [4] Wang Quanhai. Leading the reform of the global governance system with the concept of equity and justice [J]. Reference for Middle School Politics Teaching, 2020(37):86-87.
- [5] Hein A M, Matheson R, Fries D. A techno-economic analysis of asteroid mining[J]. Acta Astronautica, 2020, 168: 104-115.
- [6] Sonter M. Asteroid mining: key to space economy[J]. Retrieved on August, 2006, 6: 2009.
- [7] Deng Li, Peng Zhengmei. Ensuring equity of the 'starting line'--Based on the comparison of preschool education opportunity indicators between OECD countries and China [J]. Journal of Nanjing Normal University (Social Science Edition), 2020(06):62-74.