Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
F		2213532

2030: Space Gold Rush

Summary

From the first lunar landing of the *Apollo program* in 1969 to the triumphant return of China's Chang'e 5 in 2020, the space power of various countries has been increasing and human exploration in the universe has been deepening.How to allocate space-based resources while maintaining equity has become a problem. The mineral resources on the Earth are decreasing, and they are increasingly difficult to mine and in demand, as opposed to the asteroids, which are rich in mineral resources and rare metals. While *Arthur C. Clarke*'s *CometCowboy* is still in people's imagination, a Space Gold Rush is likely to come soon.

First, we define global equity and build a model for global equity **Global Equity Model (GEM)** based on it. In the model, we define two main measures-The number of opportunities and resources allocated and Contribution to humanity, and assign weights to their sub-indicators by **AHP**. To measure global equity,we build two submodels, Region-Global Equity Model (R-GEM) and History-Global Equity Model (H-GEM). For R-GEM, we adjust the calculation of the **Gini coefficient** to make it more consistent with the definition of global equity, and the adjustment process can be clearly seen in **Figure 7**; finally, we obtained the improved Gini coefficient as **0.192**. For H-GEM, we use Analysis of Variance and solve it with **SPSS**. Finally, we validate the model.

Second, we select an asteroid named 1943 Anteros for mining. The three main bases for selection are the mining cycle, the physical properties , the planet and the benefits. In addition, we develop a **Sphere Model** for asteroid exploitation. Using the value estimation and profit estimation for this asteroid, we obtain the variation of workforce, capital investment and revenue required for asteroid mining by simplified assumptions.

Third, we discuss our vision: the impact of asteroid mining on global equity when international collaboration is undertaken. We analyzed the task division and profited distribution of mining for selected countries, and then analyzed the impact of asteroid mining on global equity based on R-GEM and H-GEM respectively. We find that the improved Gini coefficient decreases to **0.150** in period 1 of mining (see **Figure 14**), indicating that asteroid mining contributes to global equity.

Fourth, to identify the factors that affect asteroid mining, we introduce the critical factor of private companies into the model analysis, and we discuss the impact of monopoly , free competition and venture capital on the asteroid mining industry and global equity. We used Lingo's nonlinear programming solver and Monte Carlo simulations to solve the problem, respectively. We concluded that monopolies would be fatal to the industry and global equity, and that venture capital-backed asteroid mining is unstable.

Fifth, we proposed some policy recommendations for asteroid mining and named them "**The Asteroid Cowboy Rule**" ,which coveres planetary mineral extraction, utilization, and distribution issues. It was hoped that these recommendations would promote global equity and made asteroid mining truly beneficial to humanity.

Sixth, we perform a sensitivity analysis and a strengths and weaknesses analysis of the above model. The adaptability of the model is studied by modifying the parameters of the log normal distribution curve. Furthermore, we pass a sensitivity analysis about the relevant models in practical applications, which is consistent with our predicted results and reflect an excellent practical application.

Contents

1 Introduction

1.1 Problem Background

Since the signing of the Outer Space Treaty in 1967, nations have continued to develop spaceflight, which has made it possible for us to explore space and access its resources. However, as the gap in space power between nations continues to grow, it is uncertain whether nations will still be able to comply with the fair commitments made more than half a century ago. Moreover, even if all States Parties comply with the Outer Space Treaty, there are still qualitative differences in the extent to which countries have gone into space due to the disparity in their technological prowess. For example, Russia, the United States, and China have successfully sampled the moon, but many countries have not successfully launched rockets. Given the high mineral content of a single asteroid and the large number of small and medium-sized planets in space, about 1500 near-Earth asteroids could be our main target stars for space mining [1]. Rich space resources make the definition of global equity the focus. Also, asteroid mining needs some policies from the United Nations to guarantee the equitable development of this business.

Figure 1: Imaginary map of asteroid mining
Space Station Steampunk Airships - Free image on Pixabay. Retrieved from: https://pixabay.com/illustrations/space-station-steampunk-airships-6229942/

1.2 Our work

Our work can be clearly seen in the Figure 2.

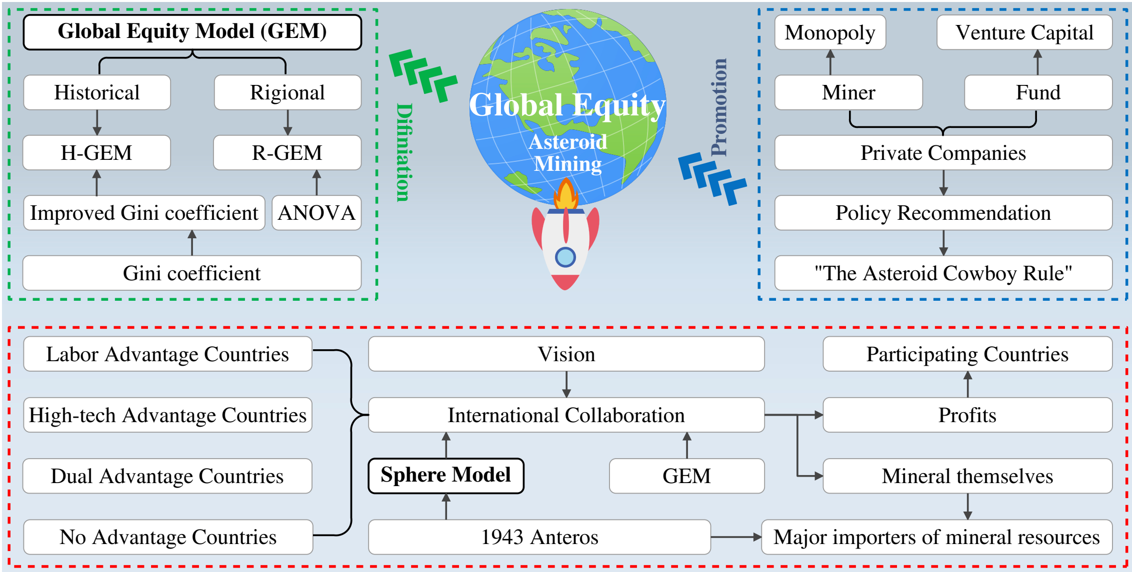

Figure 2: Overview diagram of our work

2 Assumptions and Notations

2.1 Assumptions and Justifications

1.**We assume that all our data are accurate and reliable and that the errors in the data are within reasonable limits.** Our data are all from authoritative websites and the process of data acquisition is relatively scientific.

2.**We assume that intra-country differences are not significant relative to inter-country differences in the measurement of global equity.** When considered from a global perspective, the first thing we see are the large differences between regions. For example, the gap between the richest and poorest regions is much larger than the gap between rich and poor in any one place.

3.**We assume that the countries and regions we are discussing actively cooperate with the assignment of tasks.** In the future of asteroid mining, countries will continue the current trend of globalization to maximize the use of asteroid resources through an international division of labor.

4.**We assume that peace in the world will continue and that there will be no major changes in the global political and economic situation.** Countless international organizations are contributing to world peace, and countries are cooperating intensively in the pursuit of development.

2.2 Notations

The key mathematical notations used in this paper are listed in Table1.

Table 1: Notations used in this paper

Symbol	Description	Unit
OR	The number of opportunities and resources allocated	/
C	Contribution to humanity	/
WP	Working Population	/
Gini	Gini coefficient	/
$Gini_{improved}$	Improved Gini coefficient	/
t	Number of periods	2y
v	Mining Speed	m/s
h_t	Mining Depth	m
SWP_t	Number of people conducting asteroid mining	/
β	Scientific and technical input per period	USD
SHE_t	Funds mainly for the development of high technology	USD
MR_t	Mineral Revenue	USD
TP	Total Profits	USD

3 Data Acquisition and Pre-processing

We obtained the required data through authoritative websites [3]-[9]. We selected data for countries or regions as shown in Figure 3 to represent most of the world.

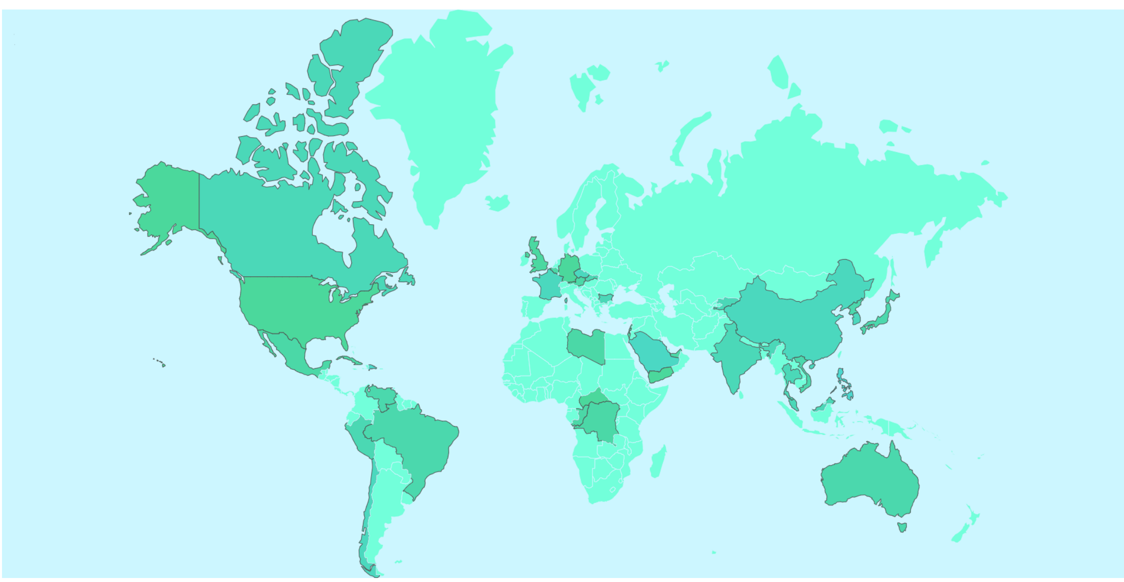

Figure 3: The countries we choose

However, the lack of completeness of the data is a big problem. For the missing data for each country, we must fill in the data with existing data after reasonable calculations; otherwise, some critical information is bound to be lost, thus causing a significant error. We consider the following cases:

- Missing data for a year

  We fill in the data using cubic spline interpolation. This method maintains the smoothness and continuity of the data and effectively preserves the information of the original data.

- Missing data for a country or region

  Considering the actual situation of this country or region, we use other similar data of this country or region for parallel filling.

4 Model 1:Global Equity Model (GEM)1

4.1 Preparation of the Model

4.1.1 Definition of Global Equity

To measure global equity, we must define global equity. Before giving this definition, we avoid two extreme cases. First, the equity should not be equal, i.e., it is not conducive to global development to expect each individual to pay an equal cost while receiving a commensurate amount in return. In fact, the realization of equity needs to go through the process of common distribution of resources and opportunities. Second, the equity should not result from initial distribution either. Facts have proved that when equity reaches the best, efficiency often cannot reach the best.

In summary, we get the definition of global equity. Each human being is allocated the appropriate amount of resources and opportunities according to his or her contribution to the global human race, and appropriate assistance is given to those in need. Resources here are those resources that are not owned and belong to all human beings; opportunities are the opportunities for each individual to develop and realize his or her values.

4.1.2 Section of Indicators

Based on our definition, we chose a set of indicators to quantify The number of opportunities and resources allocated (OR) and Contribution to humanity (C). In selecting the indicators, we considered the following aspects.

- The number of opportunities and resources allocated (*OR*)

  For resources, we chose energy use and material footprint as indicators, where material footprint refers to the global distribution of waste raw materials extracted to the final demand of the economy. For opportunity, according to the notion of "equity of opportunity" in Egalitarian Theory of Equity [2], we should focus on equality of opportunity and acknowledge inequality of outcomes, so we choose the population with higher education as an indicator. In an ideal global equity system, each individual would have similar access to education.

- Contribution to humanity (C)

  Measuring this indicator is complex. On the one hand, it is necessary to consider the achievements brought by each human field, and on the other hand, the preliminary investment is essential. Because the difficulty of each input field varies, some fields are at the frontier of development and seem to achieve only very little now but may have excellent prospects in the future. In terms of input, we have taken into account that high-tech industries can benefit humanity and that many frontier technologies are not yet able to achieve returns, and therefore we have chosen High-technology Exports as a relevant indicator to measure. We also consider that many countries do not yet have sufficient scientific and technological strength, but their sufficient labor force population has made significant contributions to human development. Therefore, we have also selected the labor force as an indicator. It is calculated as follows.

$$WP = Employment_{15+} \times (Population - Population_{15-}) \tag{1}$$

Where $Employment_{15+}$ denotes the employment rate of the population over 15 years old, $Population$ denotes the total population, and $Population_{15-}$ denotes the population aged 0 to 14 years. Achievement is expressed as the product of the HDI and the number of people. The HDI is proposed by the United Nations and is highly authoritative. A mind map of our selected indicators is shown in Figure 4.

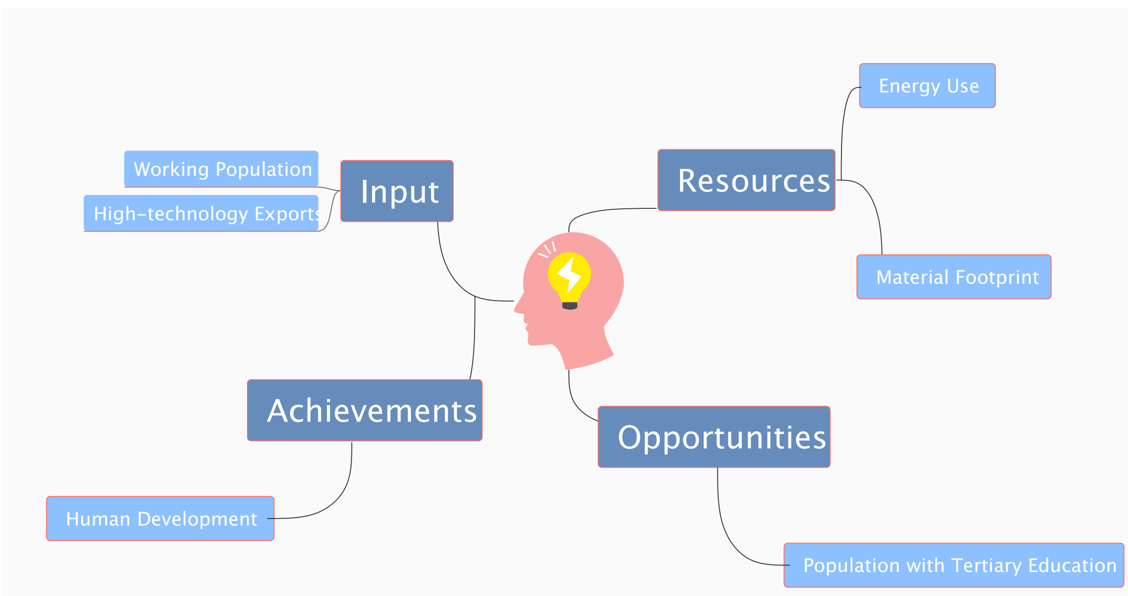

Figure 4: Mind map of our indicators

4.1.3 Data Normalization

For different indicators, they have different magnitudes. In order to be able to calculate them better, we use the following equation for the treatment.

$$z_i = \frac{r_i - \min}{\max - \min} \tag{2}$$

4.1.4 Determination of Weights

We use the Analytic Hierarchy Process to determine the weights. Its flow chart is shown in Figure 5.

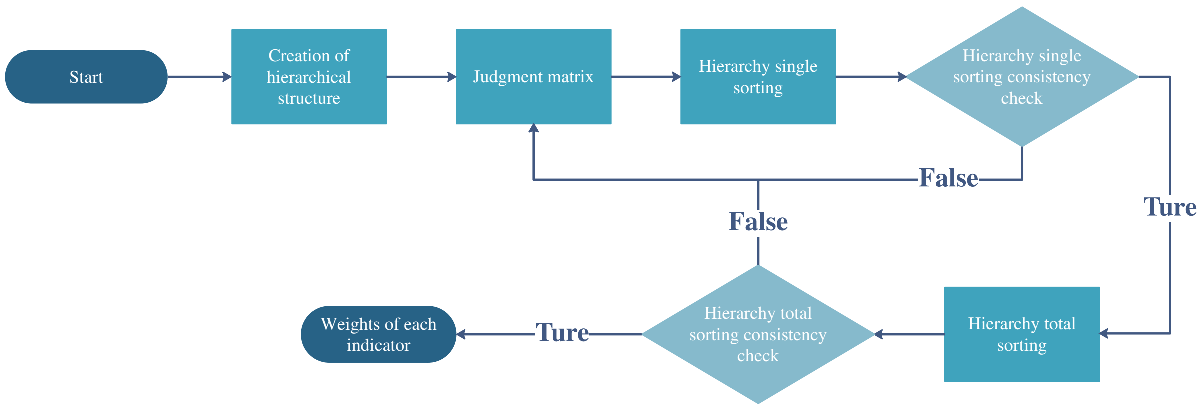

Figure 5: Flowchart of AHP

We used the arithmetic mean, geometric mean, and eigenvalue methods to determine the weights separately to ensure the robustness of the results. Because the results of a single method may differ significantly from the actual situation. The consistency tests all passed. Finally, we obtained the weights of each index as shown in Figure 6.

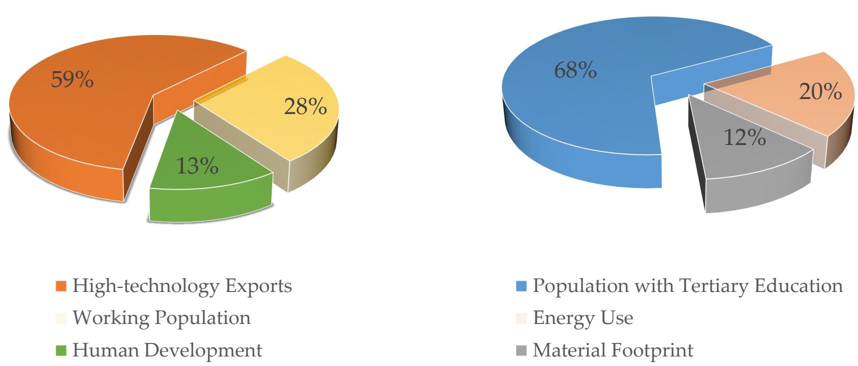

Figure 6: Weights of each indicator

The normalized metrics were weighted and summed, and we obtained *OR* and *C*.

4.2 Sub-model 1: Region-Global Equity Model (R-GEM)

- Introduction of the Gini coefficient

  The Gini coefficient is an indicator proposed by Hirschman to judge the degree of distributional equality based on the Lorenz curve. It visually indicates whether the distribution is equal by comparing the Lorenz curve with the absolute equality curve. The more curved the Lorenz curve, the smaller the Gini coefficient, the distribution is equal, and vice versa, the distribution is not equal. Because of the intuitive nature of the Gini coefficient, we chose to judge the distributional equity through the Gini coefficient. We selected countries as the unit of analysis and ranked them from smallest to largest by resources and opportunities per capita. After that, the cumulative OR of the top i countries as a proportion of the total is denoted as Y_i, and the cumulative population as the sum of their populations is denoted as X_i, so we obtain Y(X),the Lorenz curve. Assuming a total of n countries, the expression for the Gini coefficient is as follows.

$$Gini = 1 - 2\sum_{i=1}^{n} X_i Y_i \tag{3}$$

- Improved Gini coefficient

  In the original calculation of the Gini coefficient, the best-case scenario is that every individual has the same resources, which represents equality. However, such a situation does not exist in reality. In addition, according to the equity theory, each individual will compare the ratio of their reward to their input with others. If it is not equal, they will lose their motivation to work. So we constructed $Y^{(1)}$ based on C for each cell, country. This represents that each individual receives a reward corresponding to his or her contribution. However, countries that are lagging, should be given some help for humanitarian reasons. In short, the international community redistributes based on the initial distribution of resources and opportunities, rather than just pursuing efficiency. Therefore, we define $Y^{(2)}$.

$$Y^{(2)} = \frac{X + Y^{(1)}}{2} \tag{4}$$

  We assume that there are n countries and the adjusted Gini coefficient is still calculated as the ratio of the area between the two curves to the total area, as follows.

$$Gini_{improved} = \frac{\sum_{i=1}^{n} X_i (Y_i^{(2)} - Y_i)}{\sum_{i=1}^{n} X_i Y_i^{(2)}} \tag{5}$$

- Solution

  By calculation, we obtained the Lorentz curve. And the equality line, $Y^{(1)}(X)$, $Y^{(2)}(X)$ were calculated. As shown in Figure 7.

  The final improved Gini coefficient obtained is 0.192, and the results indicate that the current regional distribution of opportunities and resources of global resources is more reasonable, but there is still room for improvement.

4.3 Sub-model 2: Construction of History-Global Equity Model (H-GEM)

- Overview

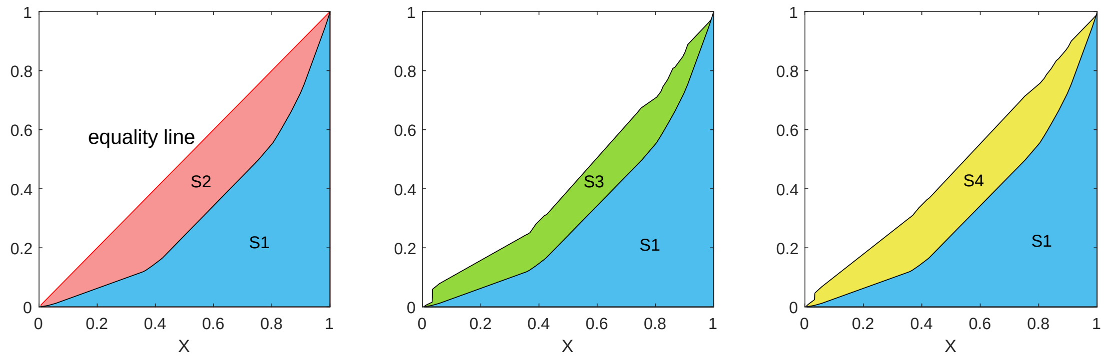

Figure 7: Adjustments to the Gini coefficient

According to **Equity Theory**, each individual will compare the ratio of their past rewards to their inputs. If the present is not as good as the past, they may do more work, but they will think that such treatment is deserved over time. Therefore, we believe that the returns in the present cannot be significantly different from those in history. First, we made a box line plot of the OR to C ratio for each year. As shown in Figure 8.

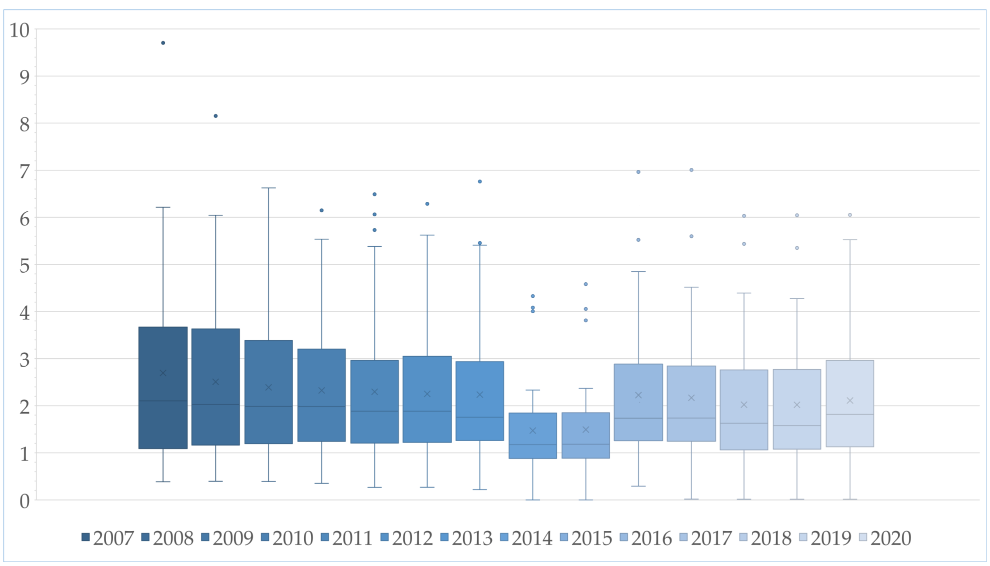

Figure 8: Box line diagram

As can be seen from the graph, the values of OR/C produced a significant difference between 2014 and 2015 compared to the other years, indicating that for some reason, a significant decrease in fairness was produced in these two years.

- Introduction of the ANOVA

  The ANOVA requires certain conditions to be met.

  1.Consider the data for a given country as a sample of capacity 14 obtained in the aggregate.
  2.Samples drawn from different aggregates are independent of each other.

The assumptions of the ANOVA are given in the following equation.

$$H_0 : \mu_1 = \mu_2 = \cdots = \mu_s = \mu \tag{6}$$

This means that in our original hypothesis, the mean value of the ratio of OR to C is equal in each year.

- Model Solution and Validation

  We solved the H-GEM using SPSS. First, we performed a homogeneity of variance test $p = 0.034$, which considered the homogeneity not satisfied at the 95% confidence interval. Also, we obtained that the original hypothesis did not hold at the 95% confidence interval ($p = 0.045$), and for different years the difference in the means of the OR to C ratio was statistically significant. Because the homogeneity was not satisfied, we used the Tamhane T2 test and obtained that the mean values of 2007 were significantly different from 2014 and 2015 at the 95% confidence interval. So we further obtain that the global equity status is poor from the historical perspective.

  In order to verify the plausibility of the model, we reviewed relevant information and found significant economic fluctuations around 2014 to 2015 in various countries around the world. For example, the WTI oil price plunged in October 2014, and the 10-year US Treasury bond yield fell below 2% in the same year. Meanwhile, the impact of the refugee crisis and terrorism crisis also began to intensify in these two years. These instabilities have taken a big bite out of global equity. Combined with the historical analysis, it can be concluded that the establishment of our model is well justified.

5 Model 2: Sphere Model

5.1 Asteroid Selection

Once we have developed a level of technology that allows asteroid mining, we have the power of choice in space. There are many asteroids in space, and about 1500 near-Earth asteroids can be our main target stars for space mining [12], however, among these 1500 planets, we selected one of the most suitable asteroids, 1943 Anteros, after excluding difficulties such as low economic efficiency and difficulty of mining. we selected it for three main factors.

- A closer distance to Earth results in a relatively short mining cycle. No matter how close a planet is to Earth, the time cost and economic cost of transportation cannot be ignored, and a shorter mining cycle will undoubtedly improve the economic efficiency and transportation efficiency, and better relieve the pressure of resource shortage on Earth. The mining cycle of 1943 Anteros is only 2.408 years [10], and such a short mining cycle makes it it an excellent mining potential. Moreover, according to **Tsiolkovsky rocket equation**

  $$v_f = v_i + v_e \log\left(\frac{m_i}{m_f}\right) \tag{7}$$

  The velocity increment Δv required to transfer the spacecraft between orbits is moderate, which allows the propellant to require less propellant, carry more material for return, and lower economic cost of exploitation, increasing the revenue.

- The physical properties of the planets are moderate. 1943 Anteros has an orbital period of only 1.71 years which is also rich in magnesium silicate, aluminum, and iron silicate making it highly valuable [11]. In addition to having enough volume and mass so that it can generate enough economic benefits to offset the large input costs and even make huge gains. In addition, its physical state and chemical composition; the asteroid's magnetic field, magnetosphere, and the solar wind interacting with the planet are relatively suitable to reduce the impact of extraneous factors on mining.
- The gains are large and the returns are significant. According to studies, it can generate an economic value of about US$5,570 billion, while the net profit reaches US$1,250 billion [13], in which the rich aluminum resources can alleviate the raw material demand of aluminum-poor countries to a certain extent, thus promoting **Global Equity**. Such a huge gain makes it a very stimulating effect on the world economy, which will undoubtedly accelerate the progress and development of all humanity.

5.2 Construction of Sphere Model

On our selected asteroid 1943 Anteros, there are mineral resources distributed that can be collected. First, the mineral resources can be considered uniformly distributed. In addition, the size of 1943 Anteros is 2.38 ± 0.72 km, which is similar to a sphere, and we regard it as a perfect sphere. The countries and regions we have chosen as participants in the gold rush have become asteroid cowboys, and we want to discuss a specific mining process.

The asteroid is closest to the Earth every 2.408 years, so for simplicity, we consider 2 years as a period and set 2030 as the start of the collection.

$$t = \frac{Time - 2028}{2} \tag{8}$$

$Time$ is the year. We assume that an equal depth can be extracted each year.

$$h_t = vt \tag{9}$$

We assume that the astronauts are uniformly distributed on the surface of the sphere since a reasonable density is necessary to ensure sufficient efficiency. The number of astronauts satisfies the following equation.

$$SWP_t = 4\alpha\pi\left(r_0 - h_t\right)^2 \tag{10}$$

α is a constant. To realize the exploitation of asteroids, a large amount of funding must be obtained. The funding can be divided into Upfront Cost (UC) and the input in the mining process. Only if countries raise this funding, high tech power can be developed and asteroids can be developed.

$$SHE_t = \begin{cases} UC & t = 0 \\ \beta & t = 1,2,3\cdots \end{cases} \tag{11}$$

The mined fraction per period is a spherical shell and the Mineral Revenue (MR) obtained is proportional to the volume of the spherical shell. The total value of the asteroid we set to Value Estimation (VE).

$$MR_t = \frac{V_{t-1} - V_t}{V_0} VE = \frac{(r_0 - h_{t-1})^3 - (r_0 - h_t)^3}{r_0^3} VE \tag{12}$$

We have set a 20-year horizon for mission completion, which is 10 periods. We already know the Value Estimation (VE) and Profit Estimation (PE), so we can get the cost of mining. The cost includes the investment in science and technology, as well as the money used to train the astronauts. Astronauts need to be trained enough to master the technology, and many measures are needed to ensure the safety of the astronauts. In addition, as workers in an industry with a high-risk factor, these astronauts should receive an extremely high income. We set u to the cost of training astronauts, and we get

$$VE - PE = \sum_{t=0}^{10} SHE_t + u \sum_{t=1}^{10} SWP_t \tag{13}$$

The mining process can be seen in the Figure 9

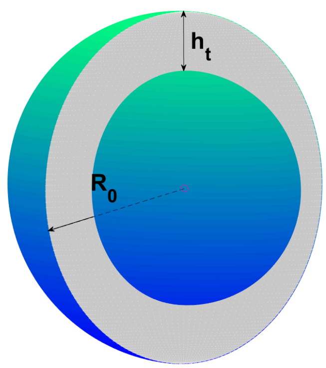

Figure 9: Schematic diagram of the sphere model

We calculate the change in the cumulative sum of SHE_t, MR_t, and MR_t over time. As shown in the Figure 10, it can be seen that the high initial cost can be offset by the huge profit by 2032.

6 Case Study 1: Our Vision - International Cooperation

6.1 Assignment of Tasks

The countries and regions we have selected each have strengths in different areas, some with strong scientific and technological capabilities and others with sufficient labor resources. They must divide the labor to accomplish the task of asteroid mining. This is because if the strengths of each country are not utilized, the efficiency will be greatly reduced.

- First, we rank the countries in order of their working populations and take the countries with the largest working populations, which account for 80% of the total population of these

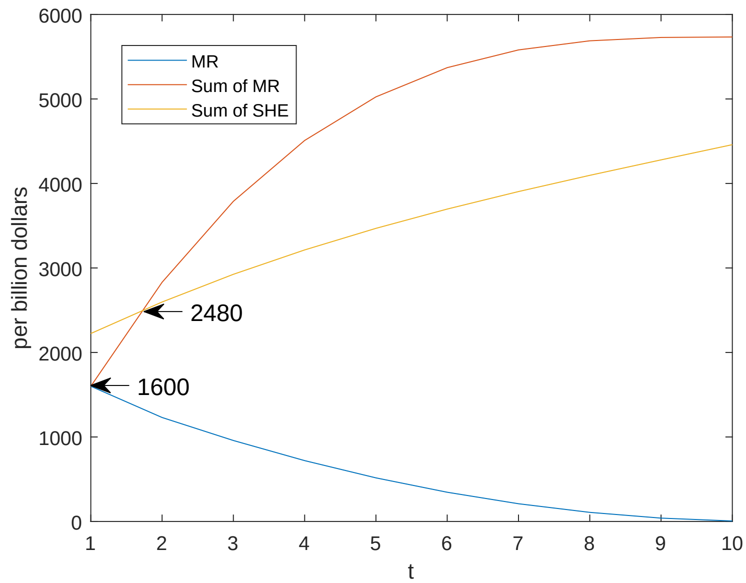

Figure 10: MR, $\sum MR_t$, and $\sum SHE_t$ over time

countries and regions, and we call them **Labor Advantage Countries**. these countries will be primarily responsible for mining and training astronauts for space operations.

- Second, we ranked the countries according to their high-tech exports, and we selected the top 18 countries and called them **High-tech Advantage Countries**, which will be primarily responsible for providing the funding to develop the technology needed for mining.

- Third, if a country has both identities, we call it **Dual Advantage Countries**.They have an obligation to invest in the two areas.

- Fourth, if a country is not yet considered, it is called **No Advantage Countries**. to include these countries, we have these countries work on hardware manufacturing, extraction and processing of asteroid material, and logistics. When distributing the benefits, we treat these countries the same as Labor Advantage Countries because their work is so important.

In the input chain, SWP_t will be borne by Labor Advantage Countries and No Advantage Countries in proportion to their labor force, and SHE_t will be borne by High-tech advantage countries in proportion to their high-tech exports. In the output chain, we must allocate the profits obtained according to the contribution of each country. For the sth country, in period t, we define

$$WOR_t^{(s)} = \gamma_W SWP_t^{(s)} MR_t \tag{14}$$

$$HOR_t^{(s)} = \gamma_H SHE_t^{(s)} MR_t \tag{15}$$

Here $WOR^{(s)}$ and $HOR^{(s)}$ denote the resources and opportunities gained by Labor Advantage Countries and High-tech advantage countries through their mining ventures, respectively. In this way, each participating country receives a corresponding profit. However, we consider that for those countries with high demand for ore resources, they need the ore itself rather than the profit. In 1943

Anteros, the reserves of aluminum are very rich and, in addition, the economic value of aluminum obtained after processing is very high, based on which we have selected the top 20 countries in the world in terms of aluminum ore imports. These countries buy ore from other countries in addition to the ore allocated to them. Although the final harvest for these countries will be less than the initial allocation due to market forces, they do get the resources they need, which still positively affects on Global equity.

$$\Delta OR_t^{(s)} = \lambda \left(HOR_t^{(s)} + WOR_t^{(s)} \right), \lambda = \begin{cases} 1, & if\ s\ is\ not\ major\ importers\ of\ aluminum\ ore \\ 0.8, & if\ s\ is\ major\ importers\ of\ aluminum\ ore \end{cases} \tag{16}$$

The identity of each country and region can be seen in Figure 11.

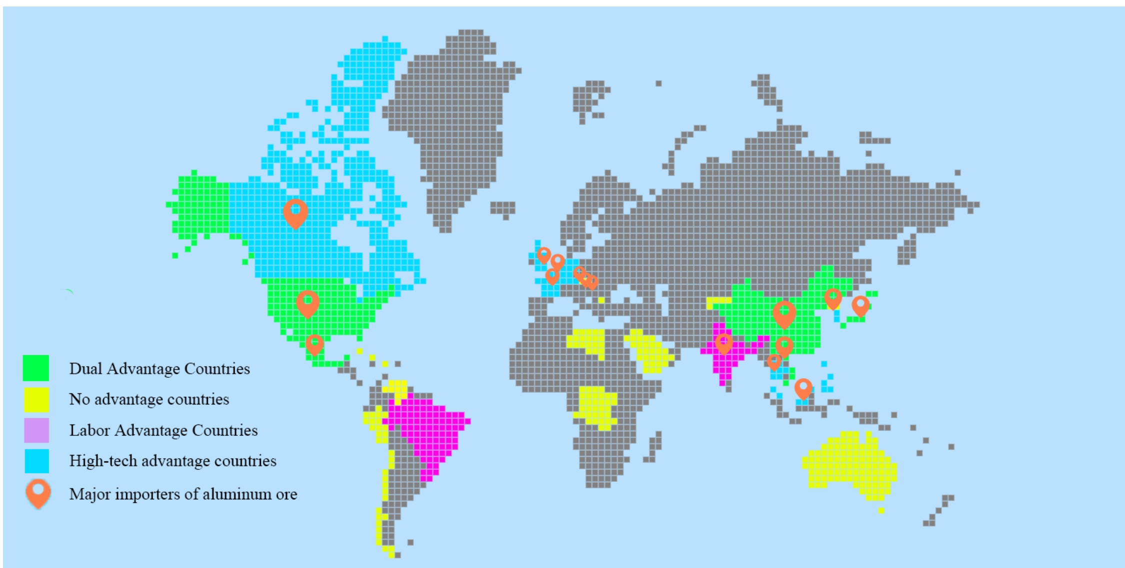

Figure 11: Identity of each country and region

The final jobs and benefits assigned to each country are shown in Figure 12.

From Figure 11, we can conclude that **Dual Advantage Countries** are mainly distributed in Asia and North America, **High-tech advantage countries** are concentrated in Europe and Southeast Asia, **Labor Advantage Countries** are mainly distributed in South America and South Asia, and **No Advantage Countries** are mainly distributed in Africa and South America. Whether analyzed from the historical perspective or the geographical perspective, the distribution of these countries has certain reasonableness, which provides some help for our planning. In addition, the countries lacking aluminum ore are mainly distributed in North America, Asia and Europe, and the demand for ore in the countries and regions involved will still maintain a rising trend in the future.

6.2 Application of R-GEM

We combine the **Region-Global Equity Model (R-GEM)** to calculate the trend of the Lorenz curve and $Y^{(2)}(X)$ within the next 10 years, as shown in Figure 13. The graph shows that the

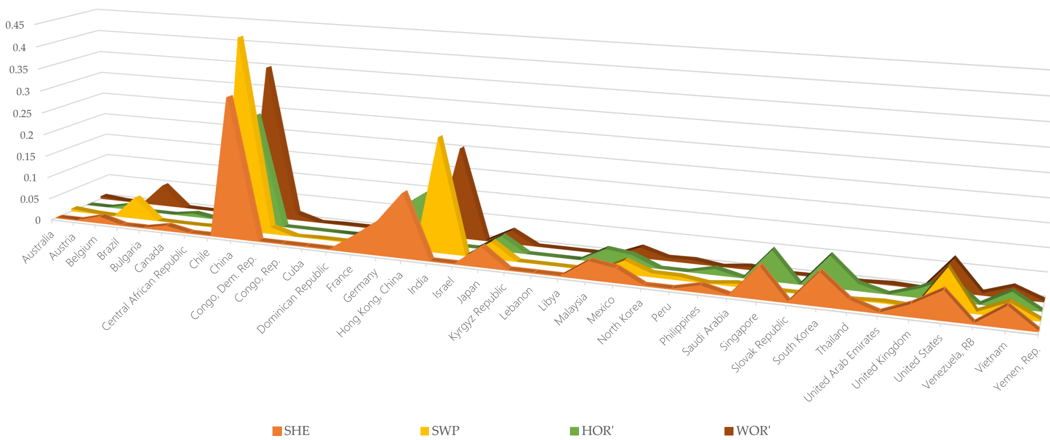

Figure 12: Countries that contribute more will gain more.

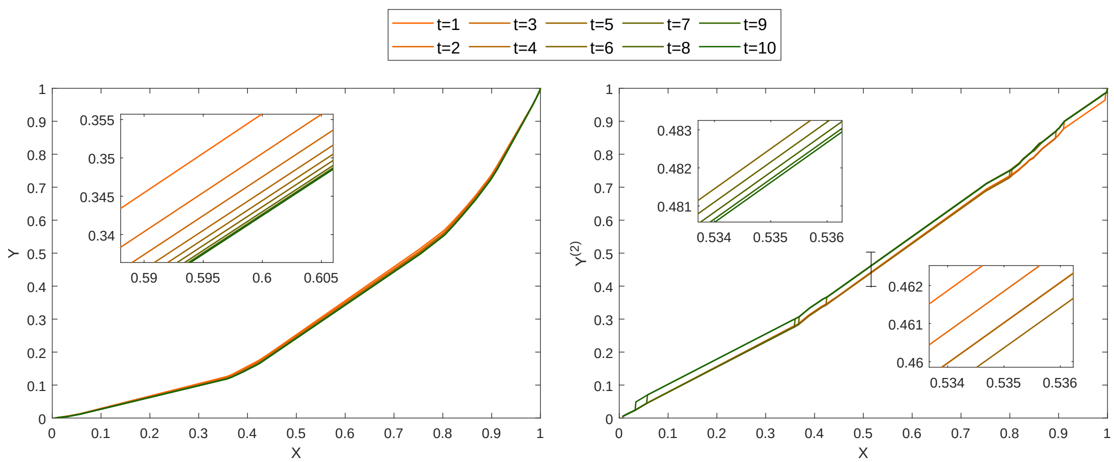

Figure 13: Lorenz curve and $Y^{(2)}(X)$ over time

Lorentz curve Y become progressively more curved as mining proceeds. This indicates that in the actual mining process:

- In the beginning phase the planetary resource reserves are abundant and bring great value to humanity, which in turn allocates more resources in the initial distribution, and each country is rewarded accordingly, reflecting good Equity, making the improved Gini coefficient significantly lower compared to the level in 2020.
- As resources continue to be utilized, the amount of resources available to each country decreases, affecting the distribution of resources. At the same time, due to redistribution, especially for the export of aluminum ore utilization, secondary benefits are generated in return, neutralizing the impact of reduced resources.
- When asteroid mining is complete, the supply of ore is interrupted and the value of the profits from it flows to individual countries after multiple distributions, with a stabilizing effect on global equity.

To be more accurate and intuitive, we calculated the improved Gini coefficient, as shown in Figure 14:

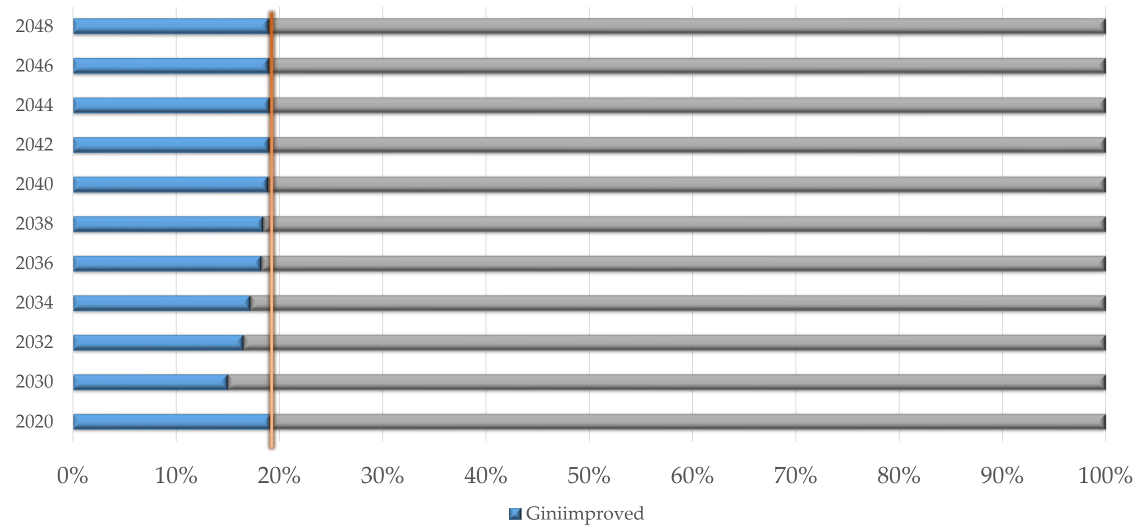

Figure 14: Improved Gini coefficient over time

From combining Figure 13 and 14, it is known that asteroid mining has a positive impact on global equity, and the more abundant the prior period, the greater the positive impact.

6.3 Application of H-GEM

Next, for the years in which mining took place, we calculated the ratio of OR to C.The change in the mean value of the ratio for each country over time is shown in Figure 15.

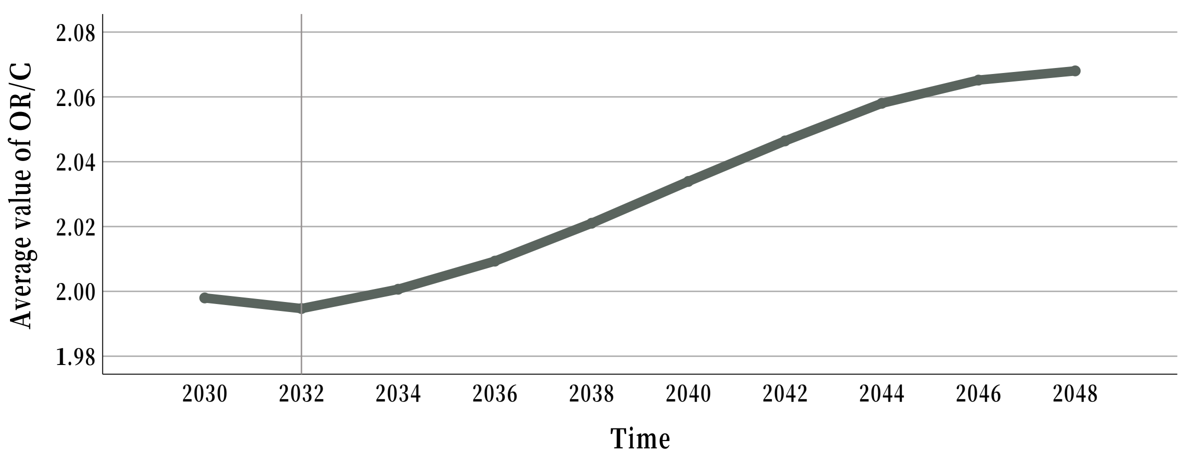

Figure 15: Compared to pre-mining, mining did not cause dramatic fluctuations in the OR/C of countries over time.

Next, we performed an **ANOVA** and obtained $p = 1.000$, which indicates that the original hypothesis holds and that there is no significant difference between the means of each year. This indicates that the global equity state is good from a historical perspective after the start of asteroid mining.

7 Case Study 2: Private Companies

In our vision, governments cooperate. Each country's treasury bears the funds, and the government sends personnel for mining, dividing the obligations according to the advantages. Accordingly, the harvest is distributed among countries according to the size of their contribution. Such behavior is relatively stable due to institutional constraints. We now bring private companies into the analysis and determine whether they affect the global equity impact of asteroid mining.

7.1 Impact of Monopoly

Let us consider the case of a private company that is solely responsible for the extraction of 1943 Anteros. We assume that this private company still draws labor from Labor Advantage Countries and No Advantage Countries and still receives technical support equal to that from High-tech advantage countries. This company would distribute the harvested revenues in the same way. However, the private company has no competition and it has complete control over the progress of extraction. According to the basic assumptions of economics, the firm's decisions are rational , and the firm seeks to maximize profits. So we use nonlinear programming to obtain:

$$\begin{aligned} &\max\ TP = \sum MR_t - \sum SHE_t - u \sum SWP_t \\ &s.t. \begin{cases} \sum MR_t = \frac{r_0^3-(r_0-vt)^3}{r_0^3} VE \\ \sum SWP_t = \frac{3t^3v^2}{2} + t\left(r_0{}^2 + \frac{v^2}{3} - v\right) - t^2\left(2\,r_0\,v - v + \frac{5\,v^2}{6}\right) \\ \sum SHE_t = UC + \beta t \\ 0 \leqslant t \leqslant 10, t \in Z \end{cases} \end{aligned} \tag{17}$$

Where TP stands for Total Profits. we use Lingo to solve it and get the optimal solution of \$1802.081 billion,the maximum profit the firm can earn. Also, $t^* = 6$, which means that the private company stops mining at period 6, because it believes that continuing does not allow it to make greater profits. The effect of this is simple, as the positive impact of the original asteroid mining on global equity will disappear because of the stagnation of the asteroid mining industry, and global equity will regress to its original level. At the same time, the total amount of resources available to humanity will decrease and humanity may be caught in a future of resource depletion.

7.2 Impact of Free Competition and Venture Capital

Since the state needs to guarantee its credit, the various financial expenditures and revenues of the national government are relatively stable. Private companies, on the other hand, are unlikely to have stable revenues. In fact, many companies working on asteroid resource utilization are under economic pressure because they currently have few returns; for example, Planetary Resources made significant layoffs when it was unable to complete a funding round. And venture capital is an important economic source for these companies; in 2015, venture capital firms invested more dollars in space companies than in the past 15 years combined. [14]

Let us consider a situation where many companies compete to mine an asteroid. If one stops, the other companies will mine more ore to make more profit. So, the process of mining ore will not stop voluntarily. Instead, in order to win the competition, we assume that they will use all the investments they get for this undertaking. Due to the large number of these companies, the national government cannot afford to finance each one of them. Because of the dangers of mining minerals, we assume that these companies are mainly financed each of them. It is assumed that the funding received by these companies in each period follows a lognormal distribution.

$$lnX \sim N\left(\mu, \sigma^2\right) \tag{18}$$

Mining can only take place if there is enough money for one extraction. If the funds are sufficient, the competition of firms will lead to two mining sessions. We assume that $\mu = ln2000, \sigma = 1$. Let the number of periods for which asteroid mining is completed be T. Next, we performed 100,000 times of Monte Carlo simulation and obtained $\bar{T} = 9.3791$, indicating that the task is completed faster than the state on average. We plotted Figure 16 based on t and mining progress for each mining session.

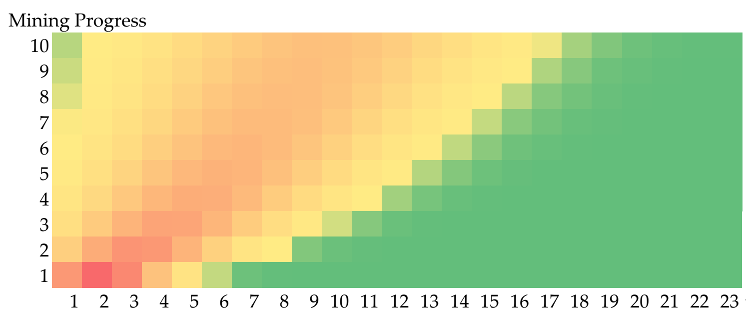

Figure 16: Heat map reflecting the probability of completing the progress at time t

Some conclusions can be drawn from Figure 16. Although likely mining will not begin until Phase 2, there is an extremely high probability that the task will be completed within Phase 10. However, there is also a very small probability that the work will be in arrears until after Phase 15.

The introduction of free competition and venture capital can bring uncertainty to global equity. On one hand, it is possible that the mining industry is doing well and investors see its prospects for increased investment, making the positive impact of mining on global equity greater. On the other hand, it is possible that the asteroid mining industry will experience a change in fortune and have limited access to capital, bringing global equity back to its original level.

8 Our Policy Recommendation: "The Asteroid Cowboy Rule"

As we move forward with asteroid mining in the future, it is important to be clear about what is driving this industry and what responsibilities and obligations each country has. Today's State Party

continues to explore outer space under the guidance of the Outer Space Treaty. This exploration and research is changing the perception of deep space and stimulating the development of related industries. We cannot deny the enormous commercial value behind this, but we need to develop some new programs and guidelines to avoid some of the disputes that can occur when mining asteroids, and ultimately achieve the vision of global equity that we desire.
The Asteroid Cowboy Rule:

1. The United Nations Asteroid Mining Cooperation Organization (UNAMCO) was established to promote international cooperation and equal distribution of space-based resources and utilize minerals' commercial and social production value to reduce the economic power gap between countries. At the same time, UNAMCO will also protect the interests and rights of each country in the exploration of resources so that outer space exploration becomes more fair and efficient.

2. Each State Party must identify the risks and rewards of asteroid mining and voluntarily assume the consequences. UNAMCO will review and evaluate each plan and call for cooperation to increase the benefits and reduce the risks of loss.

3. According to our analysis, unhealthy competition from private companies may lead to stagnation in developing the asteroid mining industry. The dynamism of private companies may promote the development of the industry as a whole, but the instability of their funding sources may slow down the development of the industry. Therefore, the mining program must be state-oriented, and private enterprises are prohibited from mining planetary resources without UNAMCO's permission. However, after authorization, private investment enterprises can invest in planetary mining and bear the corresponding investment risks. Each State Party shall provide the necessary economic support to its private enterprises.

4. It is prohibited for any country to station military bases on asteroids or conduct military research. It is forbidden to use mining as a reason for military occupation or to impede the conduct of mining. Not only would this not promote global equity, but it would also lead to a global security crisis. However, in concert with other scientific and technical personnel, military personnel are allowed to engage in activities for non-mining purposes.

5. Each State Party should provide support and assistance to other countries at the technology research and development level and promote the exchange of technology.

6. According to our analysis, international cooperation with a division of labor promotes global equity. Therefore, before mining begins, each country must define its own mission and identity, and negotiate the ownership and distribution of resources in the context of its own development. UNAMCO has the right to decide and revise the results of these negotiations to make the best use of the ore resources and promote global equity.

7. Ore resources must be preserved and processed in the areas designated by UNAMCO, and any country or organization is prohibited from enjoying the ore resources privately for illegal trading. At the same time, each State Party has the right to monitor the behavior of other countries to create an open and transparent environment.

8. To avoid monopoly, UNAMCO Anti-Monopoly Office is established. Any State Party and authorized enterprise shall have the right to develop and utilize known asteroid resources, and

no Contracting State and authorized enterprise shall interfere with such right; otherwise, any State and authorized enterprise shall have the right to apply to the Office for the investigation to defend such right.

9 Sensitivity Analysis

In Case Study 2: Private Companies, we derive the uncertainty that free competition and venture capital bring to global equity by studying the impact of private companies mining asteroids on global equity. To better describe and analyze this change, we vary the probability distribution of funds provided by venture capital firms, i.e., we vary μ and σ for sensitivity analysis, respectively. The results of the analysis are shown in Figure17:

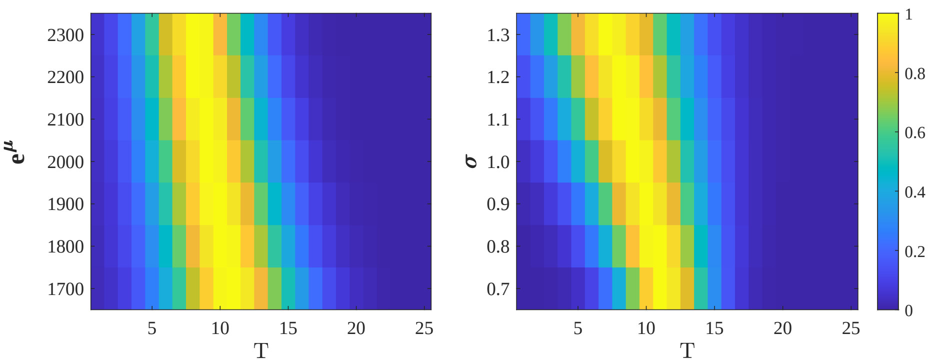

Figure 17: Sensitivity Analysis

From Figure 17, it can be concluded that the change in funding has a significant effect on private company mining, as μ increases, the expectation of the number of periods needed to mine asteroids is decreasing, and the motivation as well as the efficiency of private company mining is increasing. And as σ rises, there is more uncertainty about the time to complete mining. It indicates that the model is more sensitive to μ and σ, and the model is consistent with the uncertainty of mining by private companies as well as the riskiness of investment.

10 Model Evaluation

10.1 Strengths

1. In the **Global Equity Model**, we select two important indicators, OR and C, to quantitatively describe the global equity, which improves the rationality of the model. At the same time, we use **Region-Global Equity Model** and **History-Global Equity Model** to describe and analyze global equity from two dimensions to ensure the accuracy of the model in the process of measuring global equity.

2.In Case Study 1, we classify the selected countries and regions according to own conditions, and assign these countries the corresponding tasks and reasonable returns after mining. A suitable asteroid was also analyzed and selected for mining. Using our equity model, we can conclude that the scenario we have developed has good applicability and can bring positive impact on global equity.

3.In Case Study 2, we develop a relevant model based on rational decision theory and make predictions through **Monte-Carlo simulation** to analyze the impact of asteroid mining on global equity under a private firm-led scenario, and finally, we pass a sensitivity analysis to show that the model is well adapted.

10.2 Weakness

1.Since we selected multiple indicators for analysis and prediction, unnecessary errors were inevitable in the process of data collection and processing.

2. In the process of analyzing the equity model, to have a good focus and relevance, we obtain information from objective data without taking into account factors such as geopolitics.

11 Conclusion

Through the above models, we analyze the possible impact of global equity and asteroid mining on global equity. The analysis shows that there is still room for improvement in global equity today and that inequities still exist in some areas. But we should also maintain an optimistic attitude. When all countries can cooperate, develop together and bridge the gap between each other, it will make a great contribution to the development of all humanity. Just like our vision, each country bears the corresponding responsibility to jointly complete the great cause of asteroid mining. Only in this way can each country get the corresponding return, realize its development, and then promote the development of global equity.

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Appendix

Introduction: Monte Carlo simulation using Matlab. m language

```
clc;clear
%Set parameters and get datas
sigma=1;
u=log(2000);
year_chengben=swp_t.*1.2+SHE_t;
count=zeros(10,1000000);
Num=100000;
K=zeros(1,Num);
%Monte Carlo Solution
for i=1:Num
    X=0;
    Y=1;

    for T=1:1000000
        %Generate random numbers with lognormal distribution
        Shui=lognrnd(u,sigma);
        X=X+Shui;

        while X≥year_chengben(1,Y)
            X = X - year_chengben(1,Y);
            count(Y,T)=count(Y,T)+1;
            Y=Y+1;

            if Y==11
                break;
            end
        end

        if Y==11
            break;
        end

    end
    K(1,i)=K(1,i)+T;
end

average_K=sum(K)/Num;
disp(average_K);
figure('DefaultAxesFontSize', 12)
im=count([1:10],[1:24]);
imagesc(im)
c = colorbar;
axis xy;
```

Introduction: Solving nonlinear programming with Lingo

```
model:
max=mr-she-1.2*swp;
mr=(1000^3-(1000-100*t)^3)/1000^3*55700;
she=18000+1800*t;
swp=(1.5*100^2*t^3+(100-2*1000*100-5/6*100^2)*t^2+(1000^2+10000/3-100)*t)
*3.14*4*0.0002;
t<10;
@gin(t);
end
```