Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
F		2204351

Interstellar: A Global Equity Evaluation Model and Its Application on Asteroid Mining

Summary

"We use math to describe the vastness of space, the shape of time, the weight and worth of a human soul."

—Foundation

The development of space resources is on the schedule of many countries. Resources acquired from various celestial bodies can have a profound impact in all walks of life. However, due to the disparity between countries in technology and economy, many countries may lose the opportunity of getting those resources. A global equity evaluation model should be built and applied on asteroid mining in order to promote global equity.

To begin with, we provide our definition of global equity. **Global Equity** stands for: All countries have the ability to provide its people with sufficient **Protection**, **Education** and **Economic Resources** during their development.

Then, we establish our **Global Equity Evaluation Model** based on **Optimized Cline Function**. The function covered the three aspects we described in our definition. It aims to calculate **Country Ability Index** which reflects each country's ability to provide these resources to its people. We selected 11 inferior indicators for the three aspects and uses **Entropy Weight Method** to determine the weight of each indicator. Among all the indicators, the weight of **Energy** is rising sharply over time which emphasizes the importance of space resources. After determining the weight of each indicator, we apply the **TOPSIS Method** to grade each section and use Optimized Cline Function to calculate the country ability index. We get the score of 74 countries with USA scoring 0.247 topping the list while Philippines scoring 0.033 ranks at the bottom.

Next, we use the country ability index to determine a **Standard Line**. Countries beneath the standard line are considered not capable of providing enough protection, education and economic resources to its people. We create the **CAID Function** to calculate the **Global Equity Index**. The idea behind this function is to calculate the sum of the distances between the below-line countries and the standard line. We find out that the global equity index is growing slowly from 0.48 to 0.59 in the last 20 years.

After that, we propose the **Asteroid Mining Model** to describe and justify our proposed future of asteroid mining. In our model, the **Asteroid Mining Union** will do the mining , all the countries can fund. We combine the country ability index in the global equity distribution to determine the **Benefit Distribution Method** and quantify its **Impact** on global equity.

Finally, we analyze the possible **Changes** in our proposed future by using **The Game Matrix**. We also propose **Policies** targeted for **Different Time Period**. Sensitivity analysis, the strengths and weaknesses of the models are discussed at the end of the paper.

Keywords: Optimized Cline Function, Country Ability Index, Global Equity Index, CAID Function, Asteroid Mining Model, Entropy Weight Method

Contents

1 Introduction

1.1 Background

According to the United Nations,[1] the exploration and use of outer space shall be carried out in the interests of all countries and shall be the province of all mankind. The emerging asteroid mining industry has extremely ambitious intentions. It is within the realm of possibility that their work may usher in a change in global economics as profound as the Industrial Revolution[2] .

However, the world is suffering great disparity between countries in terms of economic and scientific development. Many people in developed countries can enjoy sufficient living resources and the convenience brought by cutting-edged technologies. Nevertheless, marginalized communities continue to face disproportionate harm from environmental pollution, hazardous workplace conditions, industrial activities, a lack of access to health care, and many other threats[3] .

Due to the belief that the space is a treasure for all humans, and humans' pursuit of **Global Equity**, we decide to build a model to measure global equity and analyze the **Impact** of mining asteroids. Finally, we can design a suite of policies to protect equity both on Earth and in the Space.

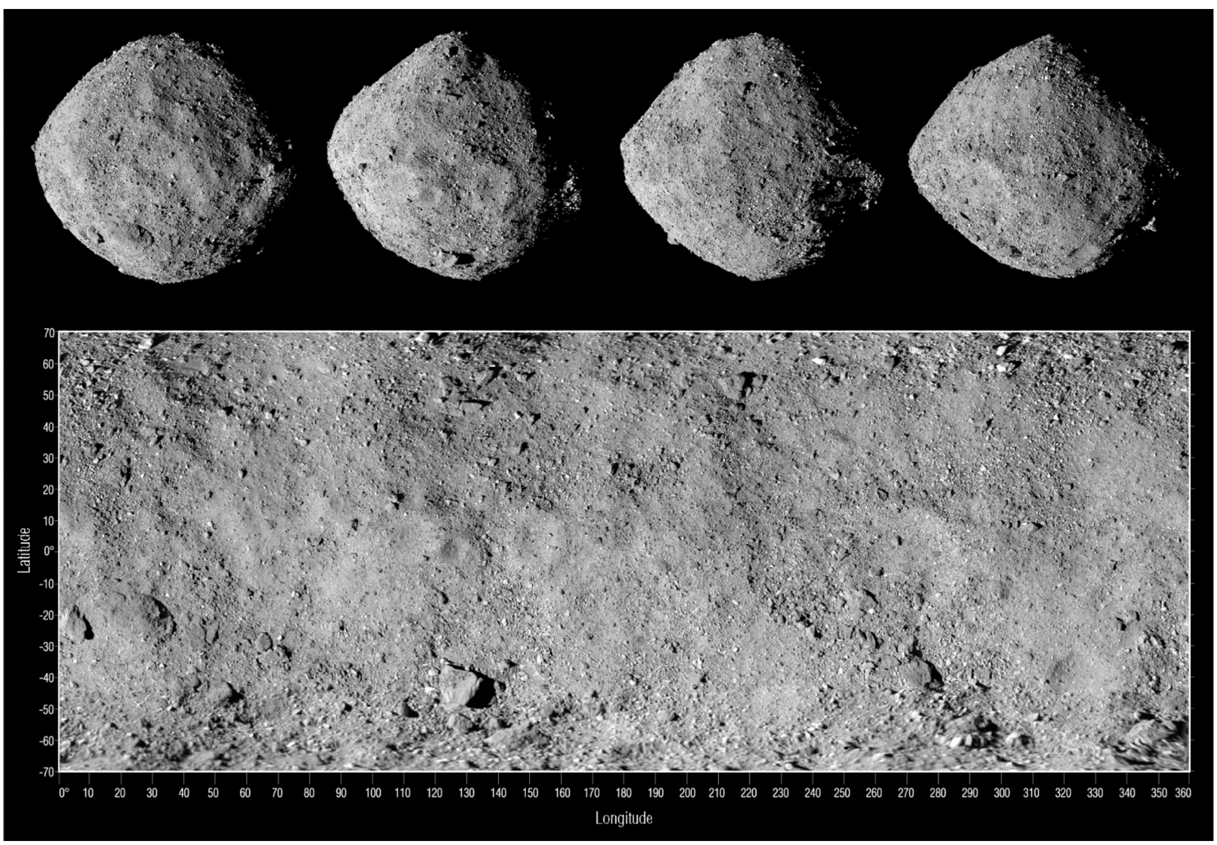


Figure 1: Asteroids

1.2 Our Works

For illustration, we draw a flow chart to represent our approach.

We begin by establishing our Global Equity Evaluation Model. The model substantialize the abstract ability of each country to provide resources and we use it to calculate and measure global equity. We validate the model by using regional and historical analysis.

We predict and justify the future of asteroid mining by using the Asteroid Mining model. Then we analyze the possible impacts the asteroid mining section have on global equity. Changes in the model is analyzed.

Finally, we propose policies according to the results we get.

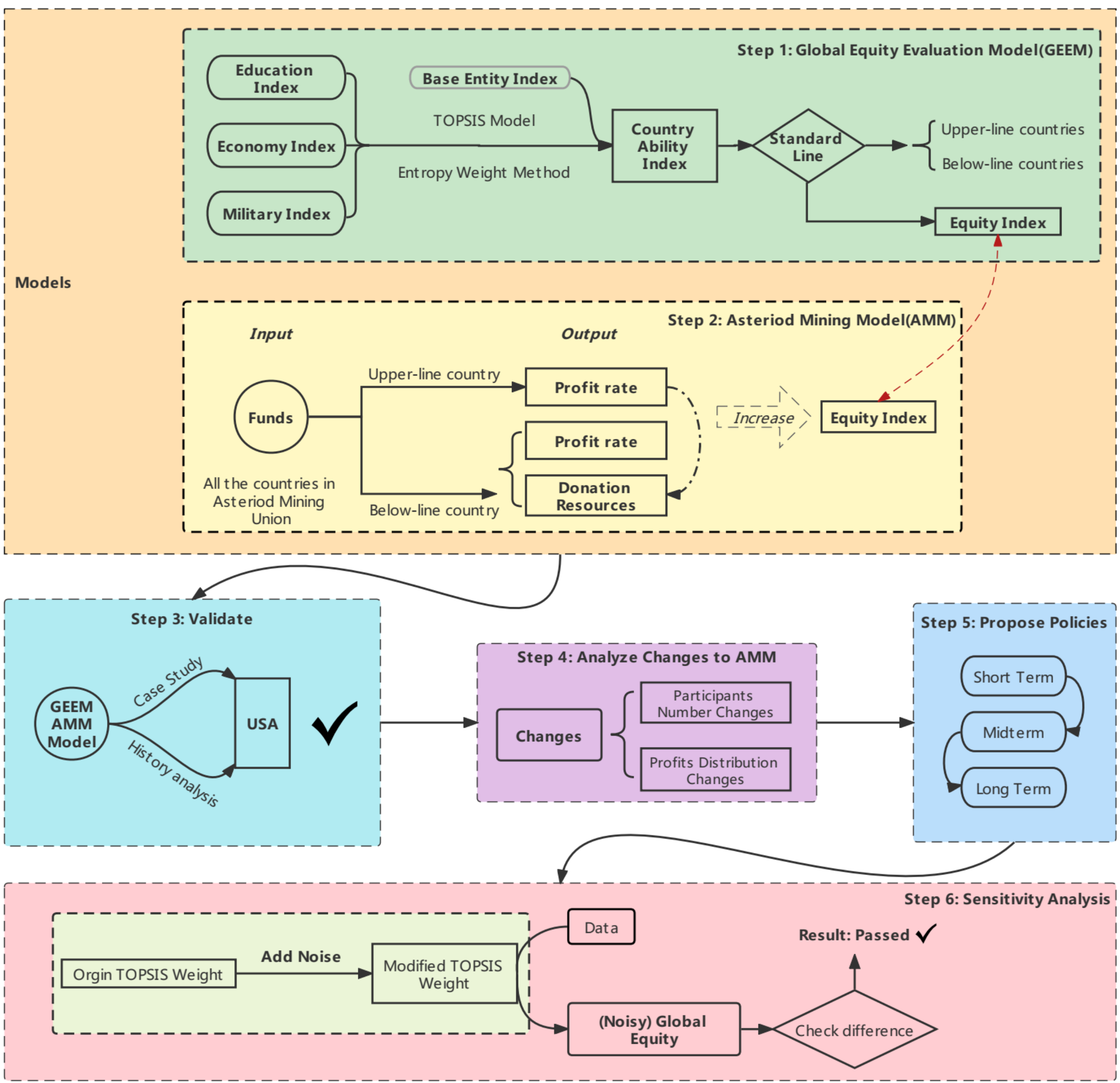


Figure 2: The Flow Chart of Our Work

2 Assumptions and Justifications

Aiming to realize the evaluation of ecosystem services, we conduct comprehensive consideration which needs appropriate assumptions to better address the problem. The assumptions are as follows.

Assumption 1: Statistics we collected from the websites are actual and reliable.

Explanation: The data we collected are mostly from authoritative websites, therefore we can consider it as trustworthy.

Assumption 2: We assume that the indicators we choose do not have endogeneity.

Explanation: When choosing the indicators, we choose the indicators that is not directly related to each other. That is to say, the endogeneity of the indicators can be ignored.

Assumption 3: We assume that asteroid mining directly influences the economy and military, but it does not influence education.

Explanation: Asteroid materials can promote the development of military, and bring about economic profits, but asteroid mining does not directly link to education.

Assumption 4: In our first model, we only consider the consumption of oil, coal and natural gas when determining energy consumption.

Explanation: People use various kinds of energy. However, nowadays oil coal and natural gas combined still contribute to most of the energy people consume. So, we use the three energies to simplify our calculation.

Assumption 5: We assume that the standard line we define to measure Country Ability Index remains constant in a short period of time.

Explanation: We make this assumption due to the fact that according to the data and the result we get, the standard line has little variation over the last twenty years.

3 Notations

Table 1: Notations

Symbols	Description
λ_{CR}	The Index of Each Country's Ability to Provide Resources
Ψ_s	The Value of Standard Line
ϕ_{GE}	The Index of Global Equity
μ_i	The Profit Index of Each Country Participate in Asteroid Mining
CNP	Comprehensive National Power
BE	Basic Entity, Combination of Population and Surface Area
ECO	Economic Power
MIL	Military Power
EDU	Education Power

W_j	The Entropy Weight of Each Indicator
S_i	The Final Grade of Each Section
BLN	The Number of Countries Below the Standard Line
AN	The Number of All The Countries in the World
N_i	The i^{th} Country of All the Countries
c_k	The Money Each Country Fund before Each Operation
TAV	The Total Value of the Asteroid Resources after Each Operation
CM	Cost of the Mining Operation
w_d	Donation Index

4 Definition of Global Equity

Equity symbolizes one aspect of fairness. It pays attention to **reasonably allocating resources**, realizing the difference between each other and then help everyone achieve a similar goal. For example, equity means giving more apples to who are starving instead of putting exactly the same amount of apples into each basket.

As mentioned above, gaps exists between countries in multiple areas. The well- being of all people, no matter rich or poor, can not be ignored. That's why it is of great importance to define global equity and find a way to measure it. In our case, we define **Global Equity** as: All countries have the ability to provide its people with sufficient **Protection**, **Education** and **Economic Resources** during their development.

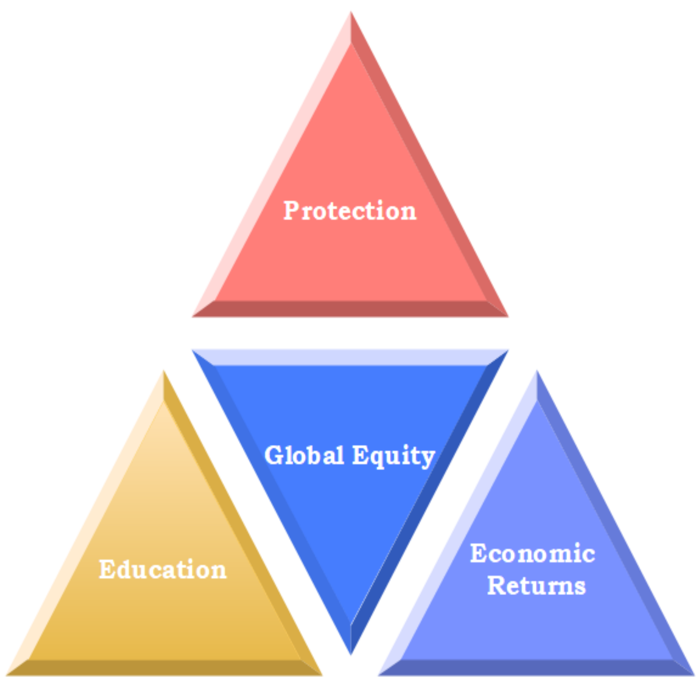


Figure 3: Global Equity

5 Global Equity Evaluation Model

5.1 Introduction

Global Equity is a worldwide issue, therefore directly setting up indicators to calculate it regardless of the differences and conditions of each country is a rough handling of the problem. In order to address the problem more accurately and effectively, instead of calculating global equity immediately, we first build a model to evaluate the ability of **Each Country** to provide resources for its people. The model covered **Protection**, **Economy**, **Education**. The ability index of each country is denoted as λ_{CR}. After that, we will combine the results we get to measure global equity.

5.2 Optimized Cline Function

To calculate λ_{CR}, we optimized the **Cline Function**. The Cline Function, proposed by Ray S.Cline,[4] who was the head of the CIA's Directorate of Intelligence, is used to estimate Comprehensive National Power (CNP). The function is written down as:

$$CNP = (BE + ECO + MIL) \times (STR + WIL) \tag{1}$$

In this function BE stands for **Base Entity** which consists of two variables: population and surface area. ECO and MIL represents **Economic and Military Power** respectively. STR is a index that reflects whether a country's strategy is on the right track while WIL stands for the will of the country.

Before using the formula, he selected indicators for each category and grade each indicator. After that, he ranked the countries by its final score.

The method he uses has its **advantages and disadvantages**. On one hand he uses a relatively intuitive function to describe CNP. On the other hand, the method is subjective in many aspects.

Firstly, sections like STR and WIL can not be measured in an objective way. Hardly any objective standards can be found to evaluate the process.

Secondly, he assume that all the indicators he chose share the same weight, which might not be the real case. Meanwhile, the grade he gave came directly from the statistics and experience little data processing.

Thirdly, important categories such as **Education Power** is ignored. Education not only represents a country's power at present but also cultivate the country's future. Therefore, it is a great contributor to the country's total asset.

Fourthly, CNP itself only represent the overall power of the nation. But overall does not consider the resources per capita.

In order to reduce the subjectivity and address the ability of each country to provide resources for its people more accurately, we first changed the function into:

$$\lambda_{CR} = \frac{EDU + ECO + MIL}{BE} \tag{2}$$

In the equation above, EDU stands for **Education Power** while the meanings of ECO, MIL and BE do not change. By using this equation we include three of the most important resources people can get from their country, which is **Protection, Education** and **Economic Returns** for a better living. Meanwhile, since we take **Basic Entity** into account, we are bringing not only the countries but also everyone in the country into the measurement.

After setting up the equation, we will select a number of indicators. All the indicators' weight will be determined by using the **Entropy Weight Method** . After determining the weight of each indicator, we use the **TOPSIS Method** to grade each index. Finally the function is used to calculate the ability index of each country.

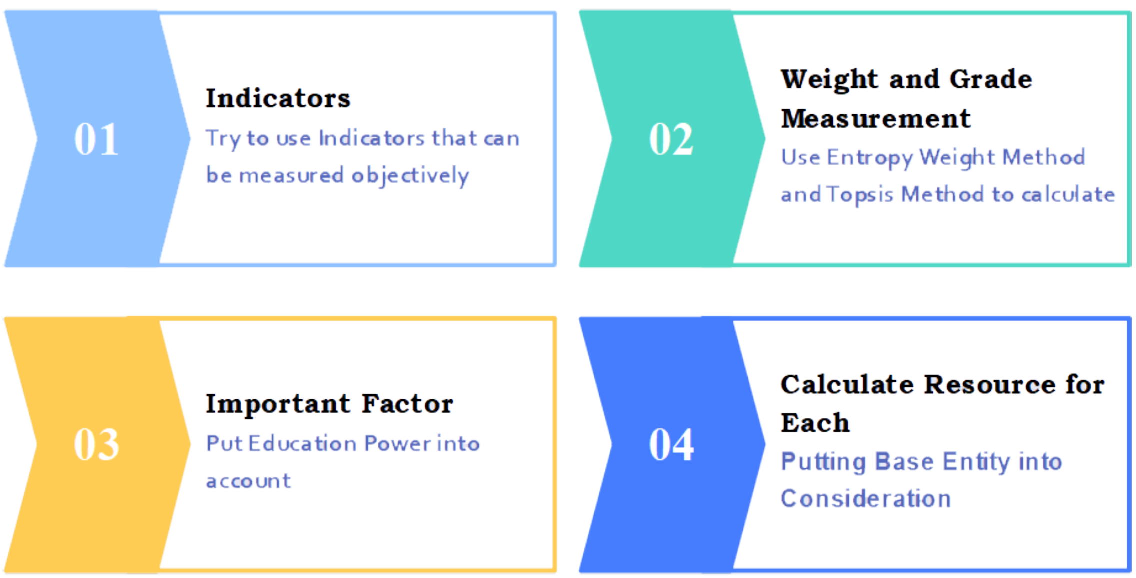


Figure 4: Optimization of The Cline Function

5.3 Selection of Indicators

In order to use the function and calculate, we have to select a number of indicators from each criteria. The indicators we chose are listed below:

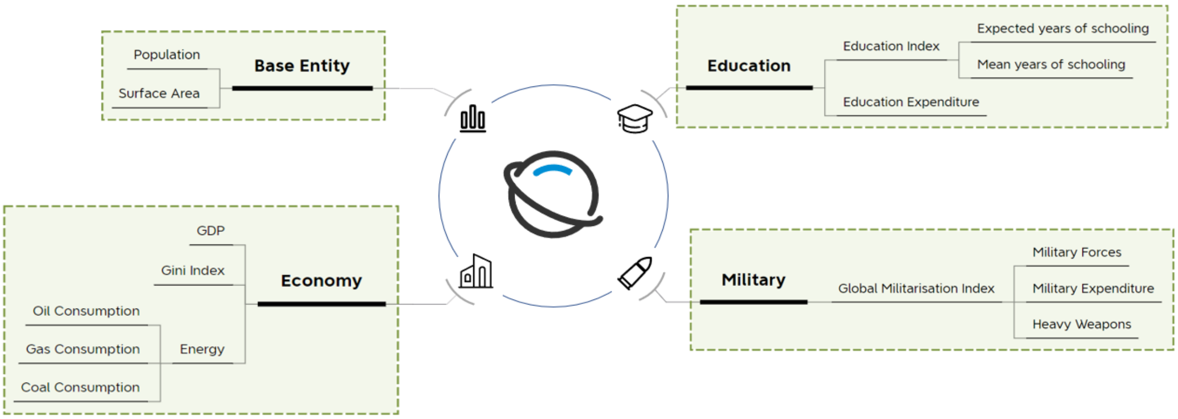


Figure 5: Indicators Selection

Some of the important indicators and why we choose them are listed below.

- **Base Entity**

  In order to measure the ability for the country to provide resources needed for everyone in the country. We selected two indicators which are **Population** and **Surface Area**.

  Population

  Population is the most direct indicator for Base Entity. When considering popularity, many "strong" countries may fail since their resource is brought by the accumulation of population.

  Surface Area

  Using Surface Area as an indicator can further makes it more fair for smaller countries. Since it is inequitable to ask smaller countries to have the same resources as the big countries in areas like energy resources. Adding surface area makes our model more reasonable.

- **Economy**

  In order to measure a country's economic power, we selected three economic indicators.**GDP**, **Gini Index**,**Energy** are indicators that can effectively represent a country's economic power.

  GDP

  In order to measure a country's Economy Power, GDP is what comes to the table first. The GDP is the sum total of all monetary transactions of households, businesses and governments in the economy – the total money value of goods and services exchanged and consumed. The GDP is a good measure of monetary wealth and financial well-being[5] .

Gini Index

The Gini index can measure the income gap between residents of the country. The income gap will lead to the instability of the economy of a country. The Gini coefficient is a popular and widely used index for measuring inequality[6] .

Energy

Energy plays the fundamental role in daily activities. People have to live with all kinds of energies. There are different kinds of energy resources. To make the problem less complicated, we choose oil, coal and natural gas consumption as our indicators. These energies are what people consume the most.

- **Military**

  Global Military Index

  Every year, BICC's Global Military Index (GMI) presents the relative weight and importance of a country's military apparatus in relation to its society as a whole[7] . By using this Index, how much protection resource can be shared for everyone in the country can be calculated.

- **Education**

  Education Index

  Education index is calculated by two statistics. Mean Years of Schooling Index ($MYSI$) and Expected Years of Schooling Index ($EYSI$). The calculation method is as follows:

$$EI = \frac{\sqrt{MYSI \times EYSI}}{0.951} \tag{3}$$

  Of a number of indexes and abstracts, the Education Index is the most valuable single source or guide to periodic literature in education[8] .

5.4 Entropy Weight Method and TOPSIS Method

After selecting the indicators, we have to determine the weight of each indicator. This is because each indicator plays a different role in the sectors we choose.

Due to the subjectivity of Analytic Hierarchy Process and the sufficient data we have, we choose to use **Entropy Weight Method** (**EWM**) to calculate the weight of our indicators. It is found that the Entropy Weight can enhance the function of the attribute with the highest diversity of attribute data (DAD) as well as weaken the function of the attributes with a low DAD in decision-making or evaluation[9] .

The theory of EWM is to look at **the degree of variation** of the indicators. The more varied of the indicators, the more information they convey. The calculation process of entropy weight is shown in Figure 6.

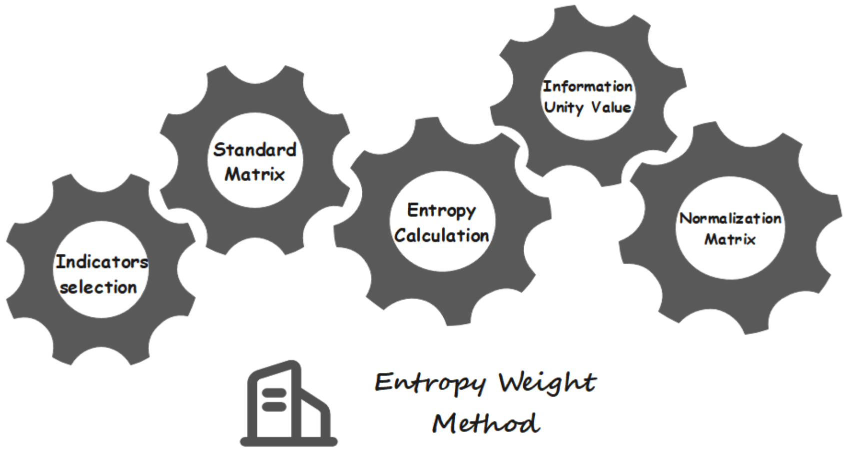


Figure 6: Process of Calculating Entropy Weight

Suppose we have n countries and m indicators, we create the matrix:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \tag{4}$$

Before calculating, we standardize the data we have. For the i^{th} country and its j^{th} indicator, we standardize the data and create the standardized matrix.

$$\tilde{z}_{ij} := \frac{x_{ij}}{\sqrt{\sum\limits_{k=1}^{n} x_{kj}^2}} \tag{5}$$

Next, we calculate the probability matrix. Each of the element in the standardized matrix is transformed in to the element in the probability matrix.

$$p_{ij} := \frac{\tilde{z}_{ij}}{\sum\limits_{k=1}^{n} \tilde{z}_{kj}} \tag{6}$$

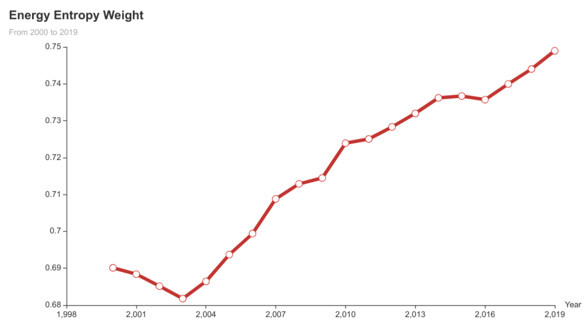
Finally, we can calculate the entropy Information and the entropy weight of each indicator.

$$e_j := -\frac{1}{\ln n} \cdot \sum_{i=1}^{n} p_{ij} \ln p_{ij} \quad W_j = \frac{1 - e_j}{\sum\limits_{i=1}^{m} (1 - e_j)} \tag{7}$$

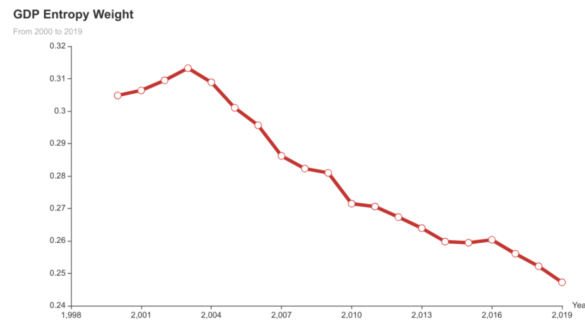
W_j is the **Entropy Weight** we want to get for each indicator.

Since we have the data for each indicator for 20 years, we can calculate the entropy weight every year and we find some **trends** worth noticing. The Entropy Weight of each indicator and the trend over the past few years are listed in the following graphs.

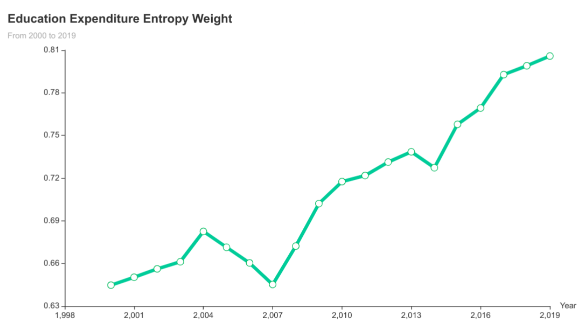
From Figure 7a and Figure 7b, we can find out that the weight of Energy Consumption is gradually increasing and the weight of GDP is gradually decreasing. This conveys that **Energy** is playing an **increasingly Important role** in representing the country's economic power. Figure 7c and Figure 7d above show that the weight of the Education Index is decreasing while the weight of education expenditure is increasing.



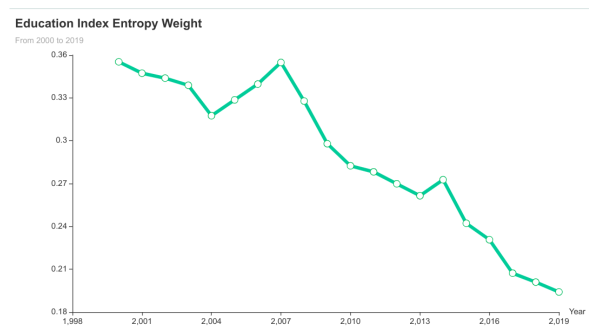
(a) Energy



(b) GDP



(c) Education Index



(d) Education Expenditure

Figure 7: Entropy weight of Each Indicator

After measuring the weight of every indicator, we have to determine a fixed weight of each indicator to simplify the grade calculation process when we use the **TOPSIS Method**.

We use the **average entropy weight** of the last five years to be the weight we use when using the TOPSIS method to grade each section. The weight we use is shown in the table below.

Sector	Indicator	Effect	**Entropy weight**(Approximation average)
Economy	GDP	+	0.26086
	Gini's Index	-	0.02354
	Energy	+	0.70559
Education	Education Index	+	0.27955
	Education Expenditure	+	0.71045

Table 2: The Weight Used In the TOPSIS Method

After finding the data of each indicator and determining the weight. We are about to grade every sector by using the **TOPSIS Method**. After that we put the grades into the **Optimized Cline Function** to calculate the ability index of every country.

The central idea of the TOPSIS Method is **locating the best solution and the worst solution**. Then, measure the **distance** between your evaluation target and both solutions. If the target is closer to the best solution, the grade is higher, vice versa.

Since we have already experienced the data standardization part while determining the weight, we now have to normalize the data. Different indicators use different methods to normalize. In our case, we only have two types of indicators, benefit type and cost type.

For benefit type indicators, the normalization is:

$$z_i = \frac{z_i - z_{\min}}{z_{\max} - z_{\min}} \tag{8}$$

For cost type indicators, the normalization is:

$$z_i = \frac{z_{\max} - z_i}{z_{\max} - z_{\min}} \tag{9}$$

After normalization, we have to define the best solution and the worst solution.

$$Z^+ := \left(\max_{1\le k\le n}\{z_{k1}\}, \cdots, \max_{1\le k\le n}\{z_{km}\}\right), Z^- := \left(\min_{1\le k\le n}\{z_{k1}\}, \cdots, \min_{1\le k\le n}\{z_{km}\}\right) \tag{10}$$

Z^+ and Z^- stands for the best and worst solution in the matrix. Then we calculate the distance between our target and the two solutions. The calculation formula is as follows:

$$D_i^+ = \sqrt{\sum_{k=1}^{m}\left(Z_k^+ - z_{ik}\right)^2}, D_i^- = \sqrt{\sum_{k=1}^{m}\left(Z_k^- - z_{ik}\right)^2} \tag{11}$$

Finally, we can calculate the score of each category. The score reflects how close you are to the best or worst solutions.

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{12}$$

Now we have the **final grade** S_i of each section, then we plug the grades into the optimized Cline Function and get the result of the **Country Ability Index** λ_{CR}.

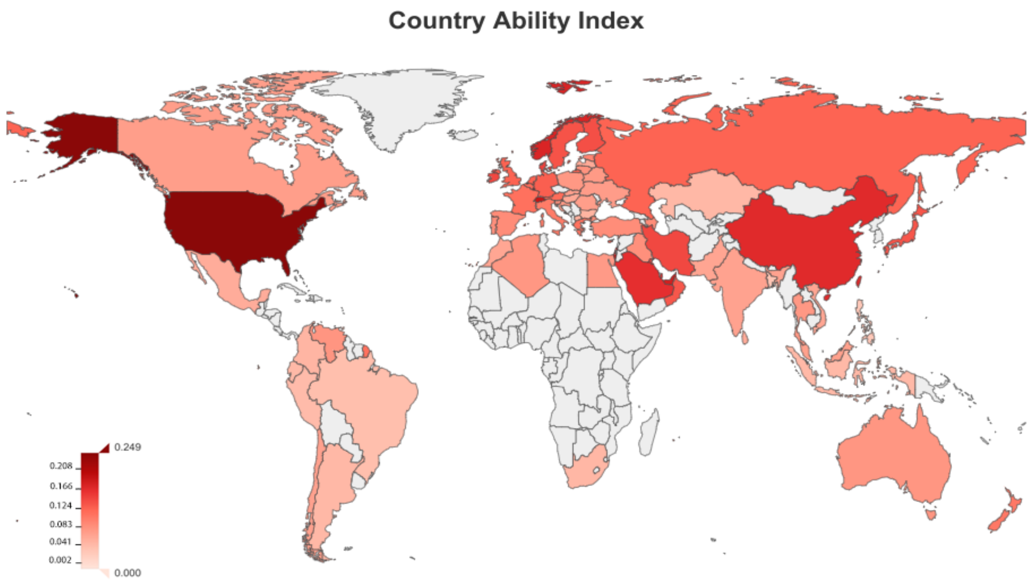


Figure 8: Country Ability Index, 2019

5.5 Calculation of the Global Equity Index: CAID Function

Now we have the ability index of all the countries to measure their ability to provide protection, education and economic resources to their people. Assume that when $k > BLN$ (BLN is the number of the countries below the standard line), the country N_k is beyond the standard line, and when $k \leq BLN$, the country N_k is beneath the standard line.

In order to measure **Global Equity**, we first need to find out how many countries are capable of providing sufficient resources to their citizens. This needs to be measured by setting up a **Standard Line**, and we denote its value by Ψ_s.

Then we use the value of standard line Ψ_s, the Country Ability Index of all the countries below the standard line and the number of all the countries in the world to calculate the Global Equity. Finally, we can get the **Global Equity Index** (ϕ_{GE}) we have always longed for. The **Country Ability Index Distance Function** is written as:

$$\phi_{GE} = \left(1 - \frac{\sum_{i=1}^{BLN} \frac{|\lambda_{CR}^{(i)} - \Psi_s|}{\Psi_s}}{AN} \right)^3 \tag{13}$$

Where $\lambda_{CR}^{(i)}$ and AN stands for the Country Ability Index of N_i and the number of all the countries in the world respectively.

$|\lambda_{CR}^{(i)} - \Psi_s|$ means the **distance** from the current country ability to the standard line. Note that $\lambda_{CR}^{(i)} < \Psi_s$ as we only consider below line countries in this function. We standardize the distance and calculate the sum of all the distances. We use the sum of the distance to divide the total number of countries to determine to which extent the global inequity is. We use 1 minus global inequity index to normalize the index. In order to make the index vary remarkably, we apply cube function and get **Global Equity Index**. We achieve global equity when the Index **grows to 1**.

Since the definition of a developed country refers to a country who has a high quality of life, developed economy and advanced technological infrastructure compared to other less industrialized nations[10] . Most of these countries should have the ability to provide the resources we discussed to their people. So this makes them perfect to be the standard of setting up the ability line. We take thirty of the developed country's statistics and analyzed the past five years. We took away five of the highest scores and five of the lowest scores each year. Then we get the minimum score of the rest of the twenty developed countries. We calculate the mean of this value over the past five years and take it as our standard line

We set the mean of the minimum of the 20 developed countries left to be the standard line. And the value of the **Standard Line** Ψ_s is **0.1**. This means that if a country's ability index is greater than 0.1, it is capable of giving its people the related resources needed for their well-being. The line will be modified after a period of time to ensure its effectiveness.

Finally, we calculated the **Global Equity** Index of the past 20 years by using equation (13).

6 Validation of the Model

By using the model we proposed, we determine the **Country Ability Index** first and then calculate the **Global Equity Index**.

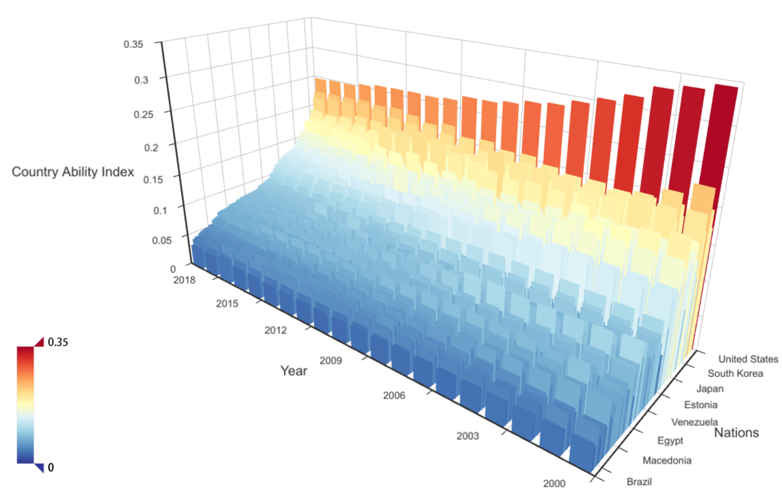


Figure 9: Country Ability Index, 2000-2019, 74 countries

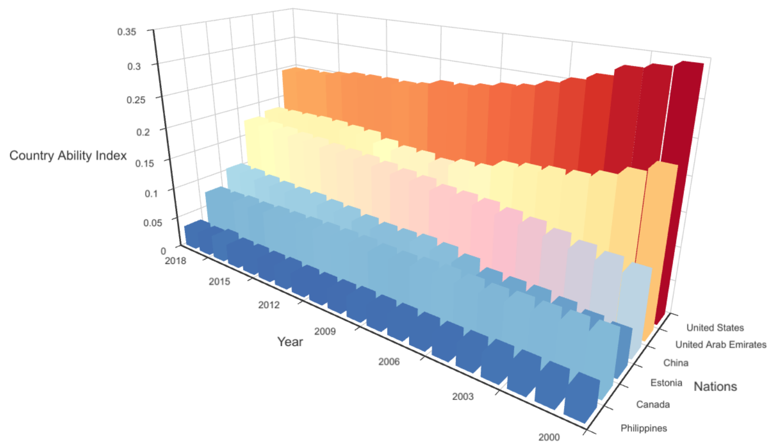


Figure 10: Country Ability Index, 2000-2019, 6 Symbolizing Countries

Figure 9 describes the Country Ability Index of 74 countries from 2000 to 2019 while Figure 10 chooses 6 countries to represent different trends.

By using this method, we can find out which **country** or which **region** does not satisfy the demand of global equity. Meanwhile, it can also dig into **historical issues**. Since we have collected statistics for 20 years, we can find out when the ability of a nation start to increase or decrease. When we pay attention to that specific time point, there is a high possibility that we can find out why the ability changes.

6.1 Regional Analysis: The USA

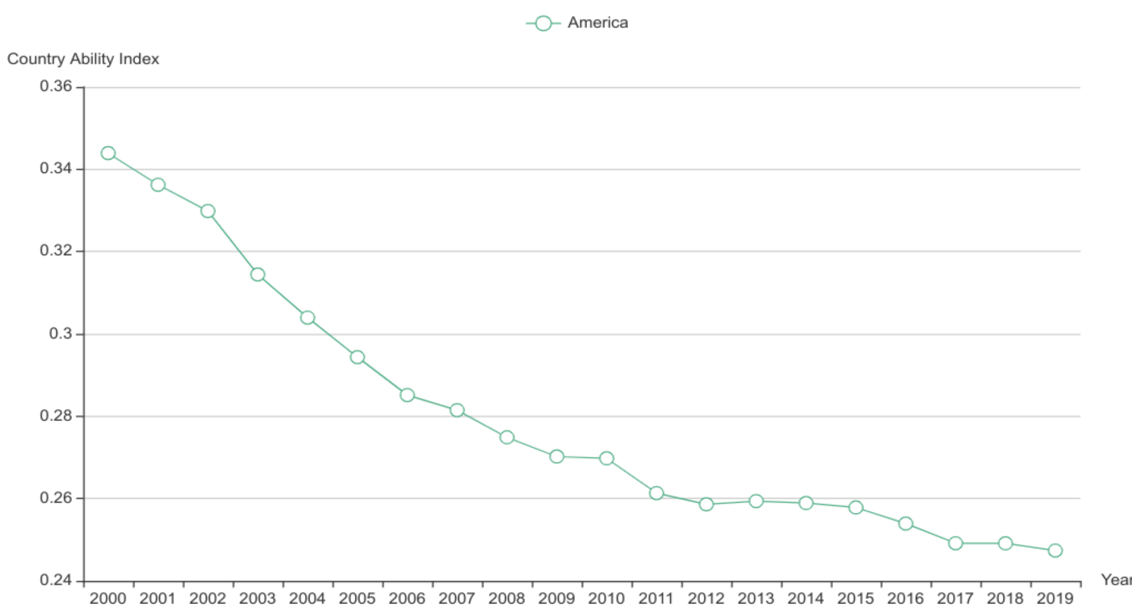


Figure 11: The Country Ability Index of the USA, 2000-2019

Take United States as an example, though it has been topping the list since the beginning of our data, its Country Ability Index has fallen dramatically in 20 years. The numbers on each resource is still optimistic but its growing speed on each section is decreasing. Since the grading method TOPSIS is based on the logic of comparing distance, the reason why United States' Country Ability Index is decreasing has a strong connection with the rapid development of developing countries such as China. When more people are starting to compete for more resources, the growing speed of the United States prevent it from coming back to its peak in the past.

6.2 Global Equity Index and Historical Analysis

After determining Country Ability Index, we used the index and the standard line we proposed to calculate the Global Equity Index. The result is shown in Figure 12.

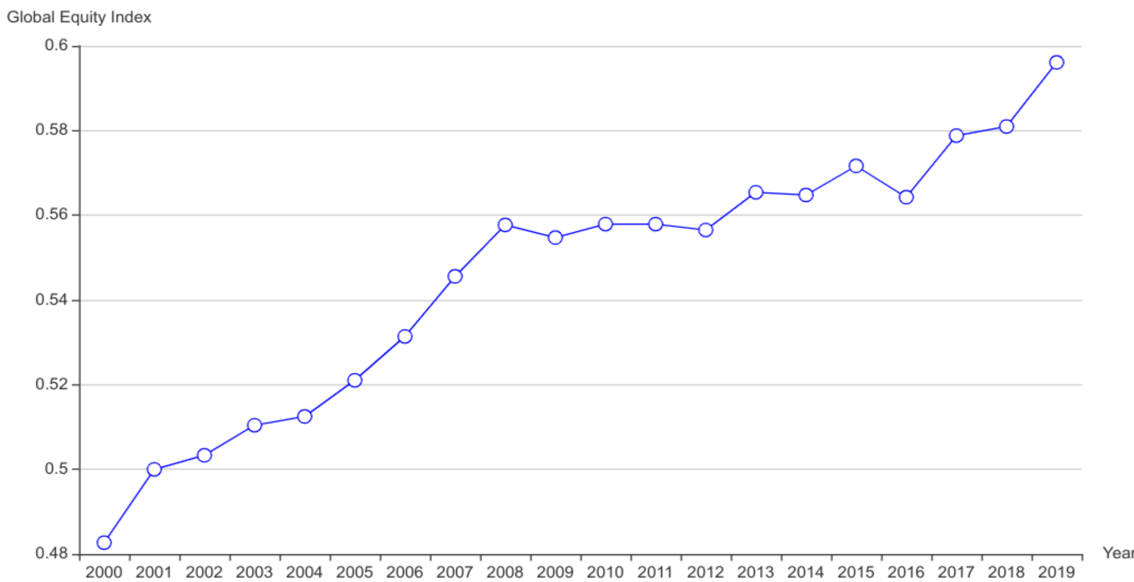


Figure 12: Global Equity Index, 2000-2019

From the figure, we know that the Global Equity Index is **slowly increasing**. It grows from 0.48 to 0.59. That is still far away from our ultimate goal of letting all countries reach the standard. The ultimate goal of ours is to let this index become 1. From the graph, we can find out that the Global Equity was indeed improving, but we also have to admit that increasing Global Equity is time consuming and the countries below the standard needs proper guidance to step out of the predicament.

7 Asteroid Mining Model

7.1 Future Description

To realize global equity, it is necessary all the countries collaborate with each other. **Asteroid Mining Union (AMU)** should be established, with every country that joins in the journey of asteroid mining participating in. Elite scientists and astronauts from all over the world, regardless of their nationality, will work together and do the mining, fighting for the prosperity of global equity.

The Asteroid Mining Union will be funded by **all the countries** who want to get asteroid resources, how much money each country fund can be freely decided by themselves.

Every country is entitled to the benefits of asteroid mining. But it is reasonable that those who fund more can get more benefits. The distribution of benefits should also meet the goal of global equity and cater to every country's interests.

Figure 13: Future Asteroid Mining

7.2 Asteroid Mining Model: Justification for the Future

Suppose the total number of the countries in the world is AN, the Country Ability Index of each nation is defined as $\lambda_{CR}^{(1)}, \lambda_{CR}^{(2)}, \cdots, \lambda_{CR}^{(AN)}$. Assume that when $k > BLN$, country N_k is beyond the standard line, and when $k \leq BLN$, country N_k is beneath the standard line.

Before each asteroid mining operation, the Asteroid Mining Union calls for funding and open its funding passageway for all the countries.

Denote the fund each country put in before each operation as:$c_1, c_2, \cdots, c_N$ and the total asteroid resource value after each operation as TAV.

A reminder is that the cost of the mining operation CM is shared by the ratio of each country's Country Ability Index. So if the country wants to successfully participate in the operation. c_i must be greater than the shared cost.

Firstly, The Asteroid Mining Union sets up a donation index w_d. Before letting each country take their fair share of the asteroid resources after the operation, the union preserve a certain proportion of resources and donate them evenly to the countries beneath the standard line. So the overall donation resource preserved for countries under the standard line equals to $TAV \cdot w_d$ (residual profits).

Then we define the profit index μ_i, using this index to multiply c_i (the input of the country) is the total return each can get. In order to simplify the problem, we assume all the profit index is greater than 1, which means every country can gain profit after the mining process. But this does not mean that countries should input too much of their money due to the profitability of the mining project because the mining project has a relatively long development period, and the returns will take a long time to get.

By applying the rules above, we get:

$$c_1\mu_1 + c_2\mu_2 + \cdots + c_{AN}\mu_{AN} = TAV(1 - w_d) \tag{14}$$

In this case how to define μ_i is the soul of this model. We want to balance the resources to help weaker countries as well as bringing profits to satisfy every country participated. μ_i should decrease with the rise of λ_{CR} and should vary slowly to protect the interest of every country.

After careful consideration, we use the following formula to calculate the profit index:

$$f_{FIX}(x) = \exp(-x) + 1 \tag{15}$$

$$\mu_i = \frac{TAV(1 - w_d)}{\sum\limits_{i=1}^{AN} c_i f_{FIX}(\lambda_{CR}^{(i)})}(f_{FIX}(\lambda_{CR}^{(i)})) \tag{16}$$

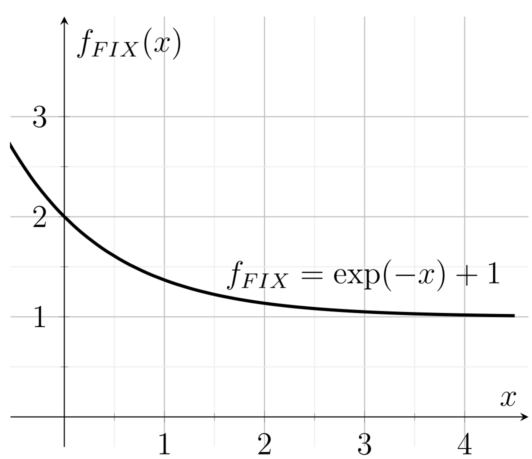


Figure 14: The Function Fixing Profit Index

The function above perfectly satisfy our expectation. So we use it as a fixing function to help calculate profit index.

7.3 Impact on Global Equity

On a whole, there are two aspects of global equity asteroid mining directly impact on - **Protection** and **Economy**.

Asteroids represent an extraordinary source of minerals which can be exploited for the increasing necessities of our civilization[11] . The rare minerals can not only become the source of energy but also be built into powerful weapons to strengthen national security.

Since energy is one of the indicators we choose to represent economy and military is considered protection resource in our first model, asteroid mining has a very strong impact on global equity.

We first measure the **Impact** our asteroid mining resource have on the Country Ability Index. To simplify our calculation, we assume that the impact asteroid mining resource have on λ_{CR} is linear and the coefficient is α.

Then we can get the following equations:

$$\lambda_{CR}^{(i)\prime} = \lambda_{CR}^{(i)} + \alpha(c_i(\mu_i - 1)), i > BLN \tag{17}$$

$$\lambda_{CR}^{(i)\prime} = \lambda_{CR}^{(i)} + \alpha(c_i(\mu_i - 1) + \frac{TAV \cdot w_d}{BLN}), i \leq BLN \tag{18}$$

The difference between the two equations is that countries below the standard line of Country Ability Index will receive donation from the Asteroid Mining Union. By the help from the union, it is more likely for those countries to reach the line.

If there exists some $i \leq BLN$ such that $\lambda_{CR}^{(i)\prime} > \lambda_{CR}^{(i)}$ then $|\max\{\Psi_s - \lambda_{CR}^{(i)\prime}, 0\}| < |\Psi_s - \lambda_{CR}^{(i)}|$, after measuring all the countries, the impact formula can be written as:

$$\Delta\phi_{GE} = \left(1 - \frac{\sum_{i=1}^{BLN} \frac{|\lambda_{CR}^{(i)\prime} - \Psi_s|}{\Psi_s}}{AN}\right)^3 - \left(1 - \frac{\sum_{i=1}^{BLN} \frac{|\lambda_{CR}^{(i)} - \Psi_s|}{\Psi_s}}{AN}\right)^3 > 0 \tag{19}$$

With more and more countries improving their country ability, stepping toward and surpassing the standard line, by our calculation in the Global Equity Evaluation Model, the global equity index will gradually increase.

That is why the construction and vision of our model benefits mankind and increase global equity.

8 Changes in the Asteroid Mining Model

8.1 Change in Members

In the Asteroid Mining Model, we assume that all countries participate in the union and the members of the union remains unchanged. But this might not be the case. Countries join and leave all kinds of organizations due to their own interest and development strategies. Though we would like all the countries to work together to achieve the same goal, the decision of each country is beyond our control. Therefore we have to measure the impact changes in participation have on global equity.

We know that the cost of the operation CM is shared by every country participating. If some of the countries cease to participate, the cost they once took responsibility of will be transferred to other countries who are still participating.

There are several possible results for this, we create the **Game Matrix** as follows:

Country / **Union**	Actively cooperate	Negatively cooperate	Do not cooperate
Actively cooperate	X_1/Y_1	X_2/Y_2	impossible
Negatively cooperate	impossible	X_3/Y_3	impossible
Do not cooperate	impossible	impossible	X_4/Y_4

Table 3: The Game Matrix between the Union and a Country

The above game matrix table shows different kinds of relationships between a country and the Asteroid Mining Union. X_1,X_2,X_3,X_4 and Y_1,Y_2,Y_3,Y_4 are the total return the union and the country get respectively. The impossible blocks means the situation will not exist or have no meaning under our assumption.

If the country participates actively with the union, the union will get the best return among all the situations. So X_1 is greater than $X2$ and X_3. The country participated will get the return of Y_1.

If the country participates negatively with the union, but the union still actively cooperates as usual, the benefits of both the country and the union will slightly decrease. Since the influence of the decrease of a single country's fund will be shared by other countries, the decrease in the return of the Union will be smaller than that of the country. This indicates that $X_1 - X_2 < Y_1 - Y_2$.

In the third version, the negative participation of the union means that the union will decrease the scale of the operation due to decreased funds. Since the scale cannot be decreased continuously, it will decrease level by level, so in this case $X_1 - X_3 > Y_1 - Y_3$.

In the fourth version, the country and the union do not participate at all. Then X_4 will be far smaller than X_1,X_2,X_3. We admit that the country may get more resources and benefit more by mining alone, but it will also shoulder the cost of failure by itself.

Therefore we assume Y_4 as a random variable which obey the normal distribution from $-2Y_1$ to $2Y_1$.

After comparing and calculating the game matrix, we draw the conclusion that actively participating with each other is the **best strategy** for both the union and the country.

All the other options will result in the **decrease of global equity**. The three other situations all take away the help and benefits aiming to help countries beneath the standard line. Under this circumstance, more and more countries will cease to develop and may even be threatened due to the loss of energy and protection.

8.2 Change in Benefits

Benefits mainly contains two part, the overall benefit and the benefit distribution. In our case, the change of benefit distribution in the long term has a great impact on global equity.

In the Asteroid Mining Model, we design a benefit distribution that can benefit all countries while helping countries beneath the line to achieve global equity.

As time proceeds, because of the benefit distribution, more countries are going to acquire the ability to provide sufficient resources to its people. Meanwhile, they will gradually start to share part of their profit to help the countries below the standard line. In the long run, there will be more countries beyond the line and less country beneath the line.

This means that the **rise** of the Global Equity Index will be **accelerated** because of the change in benefit distribution since more countries are lending their helping hand and the benefits increases for those countries under the standard line.

9 Policies and Analysis

There are many policies that could be implemented to encourage the asteroid mining sector to advance. Our ultimate goal is to raise the global equity index and global equity. We use the results of our analyses to make justified policy recommendations in different timelines to ensure the policies will be taken effectively and benefit mankind.

9.1 Short Term Policy

Short term policies are needed to put everyone on the table and get things started. It is also a fundamental step of achieving global equity.

- **Encouraging Participation**

  Appeal to the upper-line countries to join in the AMU and sign up the treaty. The AMU will promise a profit rate according to the initial fund each country invests in.

  The reason to propose this policy is to encourage participation. Stepping into the space is a big project and we need cohesion to achieve global equity. Moreover, it will decrease the competition of fighting for asteroid resources. We have already analyzed and found out that less participation will lead to the decrease in global equity. The policy not only encourages countries to participate and also guarantees a promising future.

- **International Collaboration Rule**

  Any country in the union should not dominate space resources alone. All the countries in the Asteroid Mining Union (AMU) should negotiate about the investment and the distribution in the union.

  This policy sets up the foundation of the Asteroid Mining Union. By actively communicate and participate, countries will become more united and go hand in hand to achieve the same outcome. This not only applies to asteroid mining but all sections in human activities.

9.2 Midterm Policy

Midterm policies aims at leading countries and the world to reach satisfying achievements in a period of time. The midterm policy is key to the functioning of the future we anticipated.

- **Targeted Poverty Alleviation**

  Countries that have been below-line for 5 consecutive years and rank lower can apply to increase the profit rate.

  This is the policy we made in order to help those countries who have severe difficulties. This policy represents the humanitarian concern and bring more opportunities for those countries. This policy is a giant leap to achieve global equity.

- **Roles Changing Responsibilities and Benefits**

  Within 3 years, when a below-line country becomes an upper-line country, it can apply for an increase in the profit index. But the country needs to fulfill the obligation as an upper-line country to help below-line countries.

  Every time the role of the country transforms from below-line country to an upper line country, AMU should treat it carefully. Since the below-line country receive help from the upper-line country, they have the obligation and motivation to help the below-line country when they themselves become upper-line countries. The policy aims at stimulating this motivation and form a virtuous circle. This policy accelerates the speed of achieving global equity.

9.3 Long Term Policy

Long term policies not only focus on the profits and benefits of each country but also the future of the generations coming afterwards. Since global equity cannot be achieved in a day, the situation requires time to improve. We are Hari Seldons this time.

- **The Next Generation**

  The name of the policy comes from the *Star Trek* movie. Our long term policy aims to benefit the generation in the future.

  The global equity scores within each asteroid mining group following "The Next Generation" plan are roughly equal on average.

  Step 1: Form Groups in the Union

  Each upper-line country joins a 3~5 year "asteroid mining group" with 1~2 below-line countries. Each upper-line country can not only give out equally allocated residual profits, but also the upper-line country can work out the asteroid mining plan themselves within the "asteroid mining group" to help below-line countries.

  Step 2: Lay Emphasis on Specific Countries

  Emphasis should be put on the 10 below-line countries that rank high. As the number of below-line countries reduce, the weight of the residual profits can be decreased, and instead increase the profit index of below-line countries.

  Step 3: Reduce all the below-line Countries

  Update the "Next Generation" plan: 6~7 upper-line countries join a 3~5 year asteroid mining group with one below-line country.

  Cancel the allocation of residual profits and instead increase the profit rate of the below-line countries.

The **"Next Generation"** plan aims to divide the complex global system into small groups of several countries, so that we can improve the cohesion of upper-line and below-line countries, and our help towards below-line countries can be more targeted and effective. This is a plan that can truly benefit future generations.

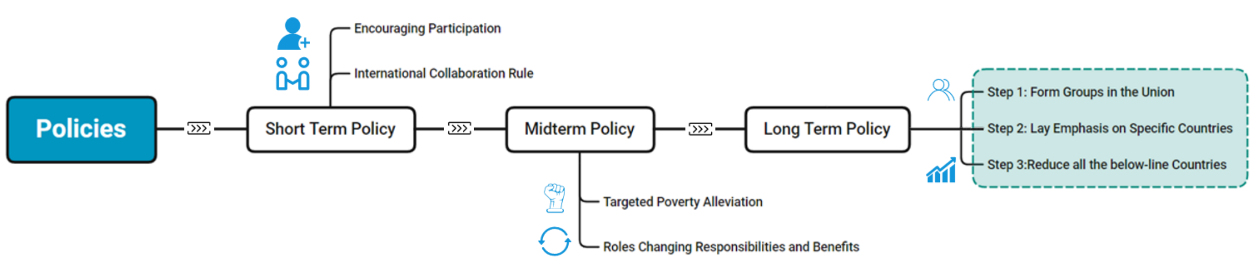


Figure 15: Policies for Future Asteroid Mining

10 Sensitivity Analysis

In the Global Equity Evaluation Model, we used entropy weight method to calculate the weight of the indicators we choose. We slightly change the entropy weights W_j of different indicators we choose in the Entropy Weight Method. We do the changes for four times and plot the result of the global equity index. The result is shown in the figure below.

Figure 16: Sensitivity Analysis of Global Equity Index

From Figure 16, we know that the overall curve and the trend of the Global Equity Index are stable, which suggests the **robustness** of our model.

11 Strengths and Weaknesses

11.1 Strengths

1. Our model can substantialize the abstract ability of each country to provide resources and we also select a great number of indicators. The model can reasonably quantify each country's ability and then measure the global equity.

2. Our model feature a great number of indexes of totally 74 countries, within 20 years. Therefore, we can reasonably validate our model by historical and regional analysis.

3. We provide different kinds of data visualization, so that the data is figurative and can meet people's intuitive understanding.

4. We offer a detailed future of the asteroid mining section by using math models and propose effective policies followed by the results of our model.

11.2 Weaknesses

1. In our model, parameters such as the Profit Index and Funded Money cannot be determined quantificationally. Therefore, our model has its limit to quantify.

2. In our model, we allocate the donation resources (residual profits) evenly to each below-line country. Though it is also a kind of method to achieve global equity, but this distribution method overlooks the disparity between the below-line countries, so we expect a more reasonable way of distribution of donation resources to meet the goal of equity.

3. We cannot accurately predict the time for each below-line countries to become upper-line countries and the accurate needed time for policies to implement. Our model has its limit to accurate prediction.

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