Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
F		2200721

Under the same sky.

Summary

In this question we are asked to define the concept of **global equity** and to develop a global equity assessment and asteroid mining management standards model to maximize global equity.

First, we define the concept of global equity: we use the **global happiness index** to reflect the level of satisfaction of people in different countries with their current life, and then use the variance of the global happiness index to express the degree of difference in the evaluation of current life among people in different countries, finally using this as the global equity judging criteria. To this end, we collected 16 kinds of data related to GDP, science and technology, environmental quality, carbon dioxide emissions, etc. in 47 countries.

Second, We take subjective condition and objective condition as two primary indicators and existing data were divided as secondary indicators. Then we define the weight matrix corresponding to the first and second conditions respectively according to the algorithm structure of the **secondary fuzzy comprehensive evaluation**. Then, we set up **our own happiness index model** with unhappy, relatively happy and very happy as the evaluation set, and verified the model with the actual data.

Third, after obtaining the happiness index, we made assumptions about the possible situation of the asteroid mining industry in the future. We then calculated weights based on countries' economic, technical data and various data that could affect **asteroid mining**. After applying it to the original data, the happiness index is calculated again. Finally, through the comparison of the variance of the two happiness indexes before and after, it is found that asteroid mining will have a **huge impact** on global equity.

What's more, to find the impact on global equity of the changes of indictors caused by asteroid mining, we modify the previous assumption that the cost-ability is **linearly** related to its benefits achieved. After that we explore the effects of increasing or decreasing caused by the **rate of gains** as participation increases on world equity. We also tried to modify the **economic** and **technological weighting** in calculating **cost-abilities** to see which of the two indicators will determine mining capacity in the future. And we calculate the influence of asteroid mining on world equity when the weights between them change. Finally, we make a systematic explanation of the correlation between **cost-ability** and the **impact of happiness indictors**. And we as analysis the influence that will be brought when the rations between technology and economy indicators changes.

Finally, based on the above analysis with the **World equity model** and in the light of the UN Outer Space Treaty, we propose reasonable suggestions on how to promote asteroid mining activities, maintain global equity issues, and sustainable development of space mineral exploitation.

Keywords: Secondary Fuzzy Comprehensive Evaluation; Global Equity; Asteroid Mining.

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February 22, 2022

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Contents

1 Introduction

1.1 Problem Background

The United Nations(UN) aims to promote global peace and reduce inequities. 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. But if humankind looks to harvesting space-based resources, maybe we need new laws to ensure equity. Our goal is to find:

1. What is global equity, and how might we measure it?
2. What might asteroid mining look like in the future, and how might asteroid mining impact global equity?
3. How do changes in the conditions that you selected in defining a vision for the future of asteroid mining impact global equity?
4. What policies could be implemented to encourage the asteroid mining sector to advance in a way that promotes more global equity?

1.2 Our Work

In this paper we break our work into sections as follows:

1. Data collection and preprocessing.
2. Use secondary fuzzy comprehensive evaluation to build a model of global equity based on the happiness indicators of countries, which includes objective and subjective factors.
3. Establish a model to analyze the impacts of asteroid mining, and get the degree of global equity after asteroid mining.
4. Change the models and parameters of the impact of asteroid mining, compare the degree of the global equity.
5. Come up with policies of asteroid mining for more global equity.

2 Preparation of the Models

2.1 Assumptions

To develop a definition of global equity, the first thing is to explicit what is equity. Due to the differences between researchers on the judgment of fair value, the value judgment may even be affected by national interests, and the so-called debate on fairness may only be a debate on national interests in essence.[1] However, most studies focus on philosophical speculation, political disputes and value discussion of fairness, and empirical studies on subjective evaluation of fairness are still relatively few.[2]

To include as many factors as possible, and make the model more reasonable, we regard the **happiness of people** in each country as the indicator of equity. And we regard the **variance** of happiness indicators as the degree of global equity. In other words, the **lower** the variance of happiness indicators is, the more it says it is **fair**. To achieve global equity, differences in happiness indicators between countries need to be reduced.

2.2 Notations

Table 1: SUMMARY OF NOTATIONS

$Notation$	Definition
$\mathcal{K}_n$	Happiness indicator of each country
$\mathcal{N}$	The degree of world equity
N	The number of countries.
m	The number of secondary indicators corresponding to each first-degree indicator
E	Cost-ability, which means the ability of Asteroid Mining
α	The initial value of the influence factor
β	The weights of asteroids mining influenced on secondary indicators
γ	Weight of benefit distribution
δ	The increment of the secondary indicators

2.3 Data Acquisition and Preprocessing

2.3.1 Data Acquisition

The happiness indicators are related to **subjective** and **objective** factors. The subjective factors come from **surveys of people**, while the objective factors from the **figure for the nation's report**. The datas' specific indicators and sources are shown in Table 2 and 3.

(1) **Objective** Data.

The data of objective factors is mainly from the World Bank.

Objective data includes financial condition, air quality, carbon dioxide emissions, educational level, medical level, poverty ratio, unemployment ratio, scientific and technological strength and healthy life expectancy at birth.

(2) **Subjective** Data.

The data of subjective factors is mainly from the World Happiness Reports[1], whose the most important source has always been the Gallup World Poll. The Gallup World Poll is unique in the range and comparability of its global series of annual surveys.

Subjective data includes people's evaluation of social support, freedom to make life choices, generosity, perceptions of corruption, positive affect and negative affect.

Table 2: Factors Affecting Happiness Indicators

First-degree Indicators	Secondary Indicators
Objective Factors	Financial condition
	Air quality
	Carbon dioxide emissions
	Educational level
	Medical level
	Poverty ratio
	Unmployment ratio
	Scientific and technological strength
	Healthy life expectancy at birth
Subjective Factors	Social support
	Freedom to make life choices
	Generosity
	Perceptions of corruption
	Positive affect
	Negative affect

2.3.2 Data Preprocessing

Delete the invalid data. Find the countries missing data from the table and delete them.

Put the data of all the factors for each country together in the same format.

3 Model Construction

In order to get the model of the world equity, we use **Secondary fuzzy comprehensive evaluation** to evaluate the happiness indicator of people in each country.

3.1 Model of equity of a single country

Fuzzy comprehensive evaluation is a kind of comprehensive evaluation method based on fuzzy mathematics.The comprehensive evaluation method transforms qualitative evaluation into quantitative evaluation according to the membership degree theory of fuzzy mathematics, that is, fuzzy mathematics makes an overall evaluation of things or objects restricted by many factors.[3]

3.1.1 Establish the factor sets of first-degree indicators

$$E = [e_1, e_2, \cdots, e_m] \tag{1}$$

Where $e_1, e_2, \cdots, e_m$ means the secondary indicators corresponding to the first-degree indicators respectively. And m refers to the number of secondary indicators corresponding to each first-degree indicator.

Factors that affect the happiness indicator include subjective and objective factors as shown in Table 2.

Table 3: Secondary Indicators' Weights and Sources

Secondary Indicators	Weight	Specific Indicators and Data Sources
Financial condition	0.2	Log GDP per capita, From the Happiness Reports[5] mainly based on WHR 2017.
Air quality	0.1	PM2.5 air pollution, population exposed to levels exceeding WHO guideline value (% of total), from Poverty and Equity | DataBank (worldbank.org)[6]
Carbon dioxide emissions	0.1	CO2 emissions (metric tons per capita), from Poverty and Equity | DataBank (worldbank.org)
Educational level	0.1	Government expenditure on education, total (% of GDP), from Poverty and Equity | DataBank (worldbank.org)
Medical level	0.1	Domestic general government health expenditure (% of GDP), from Poverty and Equity | DataBank (worldbank.org)
Poverty ratio	0.1	Poverty headcount ratio at national poverty lines (% of population), from Poverty and Equity | DataBank (worldbank.org)
Unmployment ratio	0.1	Unmployment population (% of population), from Poverty and Equity | DataBank (worldbank.org)
Scientific and technological strength	0.1	Patent applications, from Poverty and Equity | DataBank (worldbank.org)
Healthy life expectancy at birth	0.1	From the Happiness Reports mainly based on WHR 2017.
Social support	0.15	From the Happiness Reports based on the Gallup World Poll.
Freedom to make life choices	0.2	From the Happiness Reports based on the Gallup World Poll.
Generosity	0.15	From the Happiness Reports based on the Gallup World Poll.
Perceptions of corruption	0.15	From the Happiness Reports based on the Gallup World Poll.
Positive affect	0.2	From the Happiness Reports based on the Gallup World Poll.
Negative affect	0.15	From the Happiness Reports based on the Gallup World Poll.

3.1.2 Establish the evaluation set of secondary indicators

$$V = \{v_1, v_2, v_3\} \tag{2}$$

Where v_1 is "low", v_2 is "medium" and v_3 is "high".

3.1.3 Determine the membership function of the factor

Use $Kaufmann$ trapezoidal distribution in Figure 1 to represent the grade distribution and scoring range of five fuzzy language variables in 3.1.2.

3.1.4 Establish a single factor evaluation matrix

$$R_i = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ \vdots & & \\ r_{m1} & r_{m2} & r_{m3} \end{bmatrix} \tag{3}$$

3.1.5 First-degree fuzzy comprehensive evaluation

Establish the weight distribution set A_i, and assign different weights to each secondary indicator according to their influence on the first-degree indicator.

$$A_i = (a_{i1}, a_{i2}, \cdots, a_{im}) \tag{4}$$

In the equation, $a_1' + a_2' + a_3' = 1$.

It should be noted that the measuring process of happiness indicator is a subjective process at first. Therefore, there is inevitable correlation between the secondary indicators of various factors. The weight of each secondary indicator is shown in Table 3.

After that, carry out the first-degree fuzzy comprehensive evaluation to obtain the comprehensive evaluation of each indicator B_i.

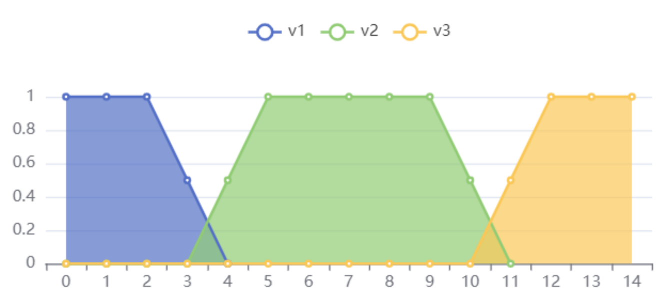


Figure 1: Grade distribution and scoring range of fuzzy language variables

$$B_i = A_i \cdot R_i = (a_{i1}, a_{i2}, \cdots, a_{im}) \cdot \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ \vdots \\ r_{m1} & r_{m2} & r_{m3} \end{bmatrix} \tag{5}$$

3.1.6 Secondary fuzzy comprehensive evaluation

Establish the single factor evaluation matrix R of first-degree indicators to happiness indicator.

$$R = [B_1, B_2]^T \tag{6}$$

Establish the weight distribution set A, and assign different weights to each first-degree indicator according to their influence on the happiness indicator.

$$A = (a_1, a_2) \tag{7}$$

Carry on secondary fuzzy comprehensive evaluation to get the matrix of comprehensive evaluation of happiness indicator B. [4]

$$B = A \cdot R \tag{8}$$

Mutiple B with $[3, 6, 9]$ to obtain the comprehensive evaluation of happiness indicator $\mathcal{K}$.

$$\mathcal{K} = B \cdot \begin{bmatrix} 3 & 6 & 9 \end{bmatrix} \tag{9}$$

3.1.7 Conclusion

This evaluation model can be directly used to evaluate the happiness indicator of people in a single country, which represent the degree of equity in this country.

3.2 Model of global equity

To ensure the equity of the whole world, the differences of the happiness indicators between countries should be as small as possible. Therefore, we regard **Variance** of happiness indicators across all countries as the degree of global equity.

$$\mathcal{N} = \sigma^2(\mathcal{K}) = \frac{\sum_{n=1}^{N} (\mathcal{K}_n - \mu)^2}{N} \tag{10}$$

In the equation, N is the number of countries. And $\mathcal{N}$ is the degree of global equity. If increase $\mathcal{N}$, the world would becomes more unequal. On the contrary, if decrease $\mathcal{N}$, the world would becomes more equal.

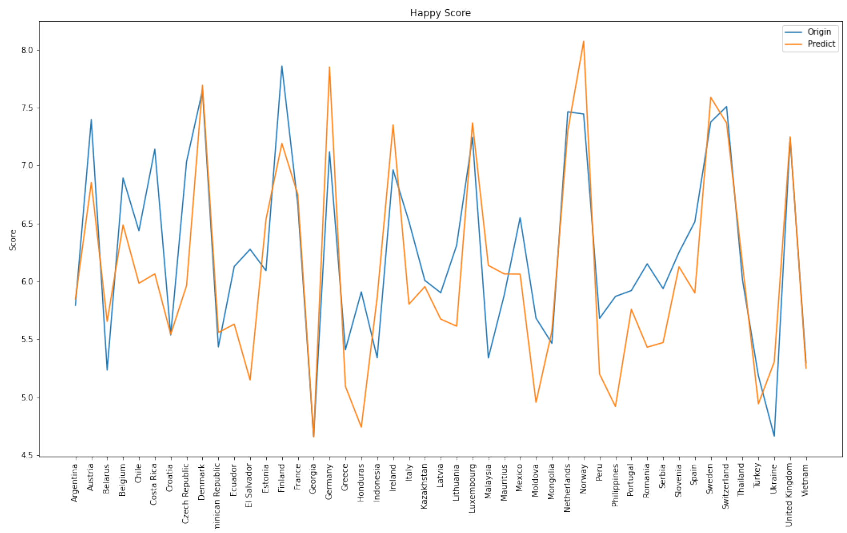


Figure 2: Comparation Between Scores in Happiness Report and Our Model

3.3 Model validation

As shown in Figure 2, our model is roughly the same as the results in the Happiness Report, which can verify that our model is basically correct.

4 Apply to The Real Data

The above model is our preliminary analysis of the data set, in order to solve the problem raised by ICM, we will refine the model or further analysis based on the problem.

4.1 Qustion 1: Definition of global equity

Plug the data mentioned in 2.3 into the model of global equity described in 3.2, we can get the degree of global equity, which can be used to assess global equity under different influencing factors.

In Figure 3, the study subjects are countries filled with blue. The darker the color, the higher the scores of these countries are, the higher the happiness indicators are. Figure 4 is the happiness indicators of 47 countries.

We regard **Variance** of happiness indicators across all countries as the degree of global equity. The degree of global equity in 2018 is **0.4185**. (We choose the data in 2018 to avoid the influence of COVID-19, in order to ensure the adaptability of the model without COVID-19 in the future.)

4.2 Qustion 2: Asteroid Mining in the Future

From the existing technology, the distance of the planet, the value of mineral resources, economic benefits and other comprehensive factors, mineral deposits on asteroids are necessary and feasible for mining.

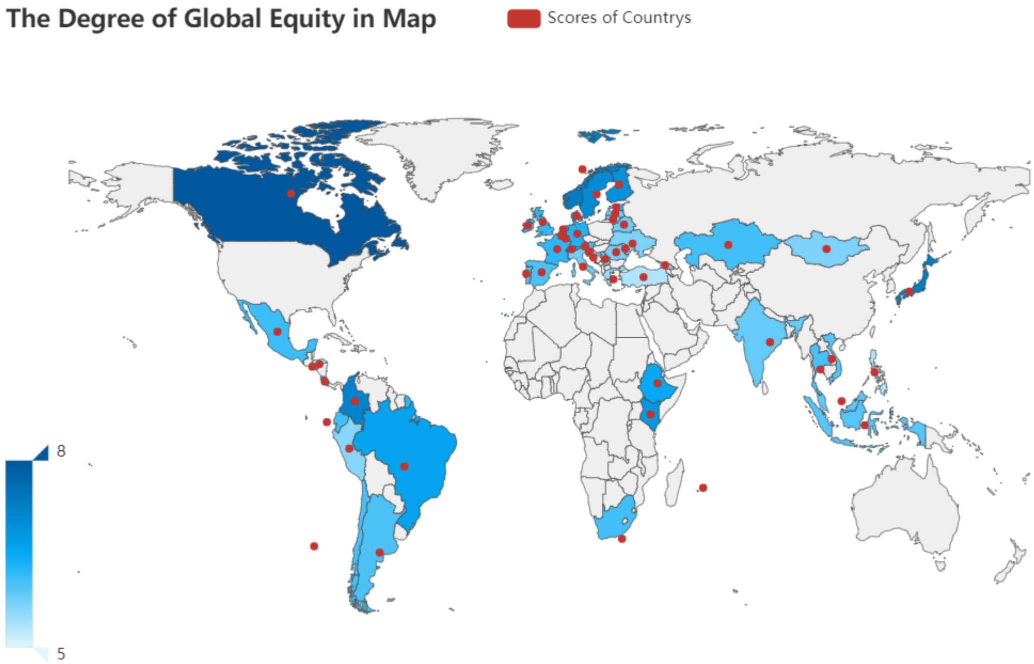


Figure 3: The Degree of Global Equity in Map

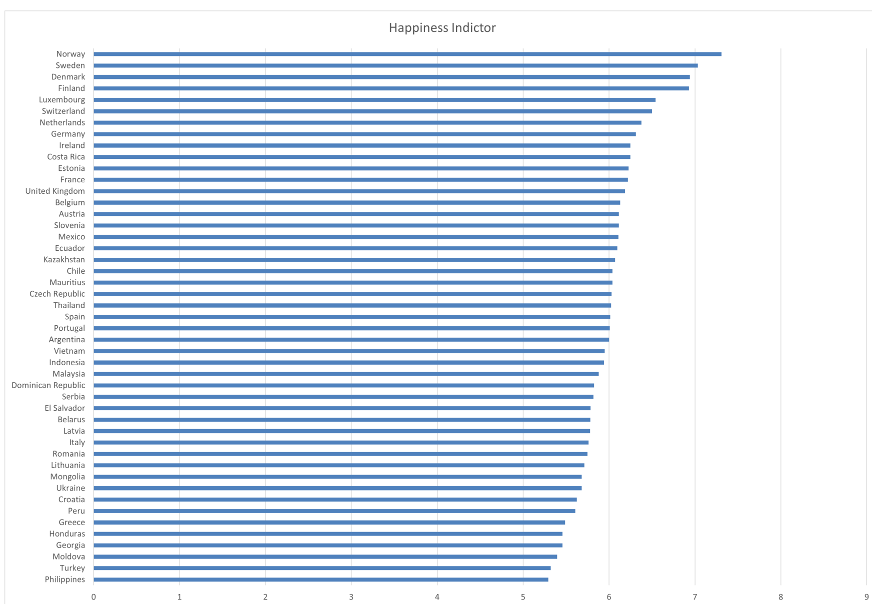


Figure 4: Happiness Indictor

4.2.1 Possible Scenarios for Asteroid Mining

(1) Who is Going to Mining the Asteroid.

From the mining unit, it may be the enterprises, countries, international cooperations and other forms of organizations.

(2) The Cost of Asteroid Mining.

Asteroid Mining needs certain economic and technical support. We can judge the economic capacity of an organization by the indicator of financial condition and the scientific and technological capacity of by the number of published patents. (The number of patents used to assess the organization's scientific and technological capabilities comes from a wide range of technologies, including basic science, materials science, physics, energy, control and computer science.) The more capable these two abilities of the organizations are, the better able they are to mine asteroids. Add the two datas in a certain proportion and call it cost-ability E, which means the ability of Asteroid Mining.

(a) Take the country as the unit.

If a country is taken as the unit, we can directly regard the sum of GDP and technology indicator in 3.1 after normalization as the measurement of cost-ability. (Equation 11 to 13)

$$f_i' = \frac{f_i - f_{min}}{f_{max} - f_{min}} \tag{11}$$

$$t_i' = \frac{t_i - t_{min}}{t_{max} - t_{min}} \tag{12}$$

$$E_i = f_i' \cdot k_f + t_i' \cdot k_t \tag{13}$$

Where

f_i represents the i'th GDP indicator. t_i represents the i'th technology indicator.

f_i' represents the i'th GDP indicator after normalization.

t_i' represents the i'th technology indicator after normalization.

E_i is the i'th cost-ability, which represents the the ability of Asteroid Mining.

${}_{min}$ represents the minimum of the indicator. ${}_{max}$ represents the maximum of the indicator.

k_f represents the proportion of financial condition.

k_t represents the proportion of technology indicator.

For example, in Table 4, the financial indicator of Chile is 0.1458, while Philippines is 0.1301. The science and technology indicators are 0.0397 and 0.0551 in Chile and Philippines respectively.

Table 4: Example of the Cost-abilities Based on Countries

Country	Financial indicator	Science and Technology indicator	Cost-ability
Chile	0.1458	0.0397	0.1855
Philippines	0.1302	0.0551	0.1853

When the ratio of k_f and k_t is 1:1, both of these two countries' cost-ability are around 0.185. Thus, the two countries are thought to have the same cost capacity, which means the same ability to mine asteroids.

(b) Take the enterprise as the unit.

Similarly, if an enterprise is taken as a unit, its economic and technological indicators can be taken according to its GDP index and the charges for the use of intellectual property receipts/payments. The cost-ability of the enterprise can be obtained by adding the two after normalization.

(c) Take the international cooperations as the unit.

If the international cooperation organization is taken as the unit, the sum of the cost-abilities of its constituent units is taken as the cost-abilitiy of the organization.

For instance, in Table 5, the cost-abilities are 0.3612, 0.1815 and 0.1797 in France, Ukraine and Switzerland respectively. If Ukraine and Switzerland work together to form international cooperation organization named C, the cost-ability if C is the sum of Ukraine and Switzerland. We can see that both of the cost-abilities of France and C are 0.3612. Thus, France and C are thought to have the same cost capacity, which means the same ability to mine asteroids.

(3) Distribution of influence.

Successful mining from asteroids comes at some influences. These influences will affect the indicators mentioned in 3.1, and then affect the happiness indicator of each country. We build a model to measure the impact of different countries.

(a) Weight based on cost.

Table 5: Example of the Cost-abilities Based on International Cooperations

Organizations	Members	Cost-ability respectively	Cost-ability
France	France	0.3612	0.3612
C	Ukraine	0.1815	0.3612
	Switzerland	0.1797	

Impact of Asteroid Mining can be considered as the influence on the secondary indicators of the model in 3.1. The input cost directly corresponds to the impact distribution, in other words, the input percentage of the cost should be responsible for the percentage of the impact. So we can directly regard the cost-ability E as its weight of impact, which is written by γ. Here, we take the ratio of financial condition to technology indicator as 6:4.

$$\gamma_i = E_i \tag{14}$$

(b) Weights of different indicators.

The influence is weighted differently among different secondary indicators. To model the different weights among indicators, we made the following assumptions:

We believe that the indicators directly impacted by asteroid mining mainly include the improvement of financial condition and the technological strength.

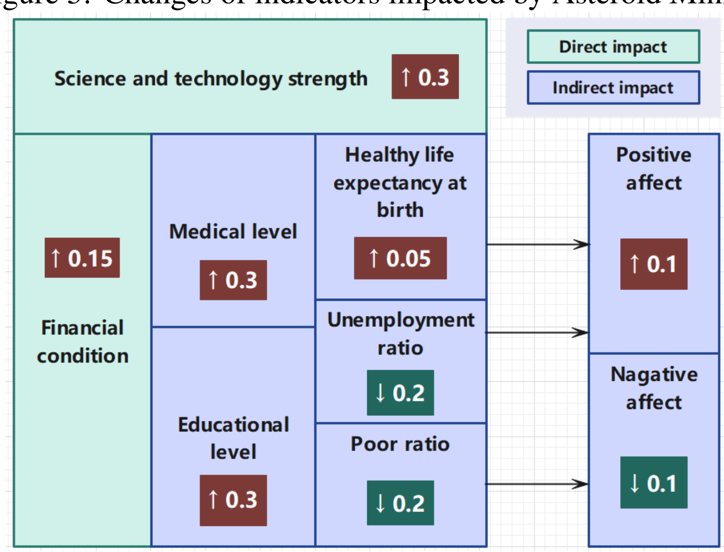
i) Direct impact.

In terms of the improvement of **technological strength**. The precious metal minerals obtained from asteroid mining and the technical difficulties overcome in the mining process can directly bring about significant technological progress.

It is foreseeable that the technological breakthroughs brought by asteroid mining will be huge such as space transportation technology and ultra-low gravity mining. Here we assume that asteroid mining will greatly improve the technological strength of participating countries, and we assumed the Proportion increase of **0.3**.

In terms of the improvement of **financial condition**.

Figure 5: Changes of indicators impacted by Asteroid Mining



Combined with the current heavy-duty launch vehicles with high carrying capacity, such as the US Mars 5 (Carrying capacity 140 metric tons)[7], We assume that when technology has reached a very advanced level, asteroid mining made possible, and the cost problem is solved : the rocket at this time has a carrying capacity of up to 500 metric tons. In order to maximize returns when mining, we assume that the ores collected are mainly rare metals. A metric ton of gold is known to be worth $65.43 million, and a metric ton of silver is about $839,000[8]. To be conservative, we take the average value of $33.13 million for a metric ton of rare metals. So the rare metal obtained by one launch is worth 16.567 billion. Assuming that the launch and collection technology is not yet mature, the cost of obtaining metal consumption is still as high as 70% of the metal value. Therefore, the revenue per asteroid mining is as high as 4.9701 billion. So we conservatively estimate that a country launches 20 launch vehicles with a 500-ton equivalent a year, whose direct income will be as high as 99.402 billion. The average GDP of the top 20 countries in terms of GDP in 2018 was 6.62 trillion[6] (We believe that countries with higher GDP have the ability to launch super-heavy launch vehicles). So we assume a **15%** increase in GDP from asteroid mining (0.99402/6.62 = 0.15).

ii) Indirect impact.

For **education** and **medical condition**, we believe that it is equal to the proportion of technological improvement, which is set to **0.3**.

The **average life expectancy** has increased due to the improvement of medical technology. We assume that it increases by **0.05**.

Both the **poor population** and the **unemployment rate** decreased by **0.2**.

At the same time, **positive emotions** for asteroid mining will increase, and **negative emotions** will decrease, we assume that they are both **0.1**.

The impact of space launches on the **environment** is negligible.[5]

This process can be illustrated in Figure 5. It shows the changes of indicators impacted by Asteroid Mining, which are written by β.

$$\alpha_{ij} \cdot \beta_j \cdot \gamma_i = \delta_{ij} \tag{15}$$

Figure 5 shows the changes of indicators impacted by Asteroid Mining, which are written by β.

In Equation 15,

i represents the data of the i'th country. j represents the data of the j'th secondary indicator.

α represents the initial value of the influence factor.

β represents the weights of asteroids mining influenced on secondary indicators.

γ represents the weight of benefit distribution.

δ represents the variation of the secondary indicators.

Figure 6: Happiness Indictor After Asteroid Mining

Then, we can get the variation of the secondary indicators δ. After that, plug δ into Equation 16, and we can get the value of the influence factor after asteroid mining which is written by p.

$$p_{ij} = \alpha_{ij} + \delta_{ij} \tag{16}$$

Then, use the model in 3.1, we can get the happiness indicator of each country after asteroid mining which is written by $\mathcal{K}$.

Figure 6 is the happiness indicators after asteroid mining of 47 countries.

4.2.2 Impact of Asteroid Mining on Global Equity

In 4.2.1(3) we can get the happiness indicator of each country after asteroid mining which is written by $\mathcal{K}$.

Then use the model in 3.2, we can get the degree of global equity after asteroid mining. The degree of global equity after asteroid mining is **0.8020**. The whole process is shown in Figure 7.

4.2.3 Conclusion

The original degree of global equity is **0.4185**. After asteroid mining, the figure for global equity sharply increase to **0.8020**. It suggests that asteroid mining would exacerbate global **inequity**.

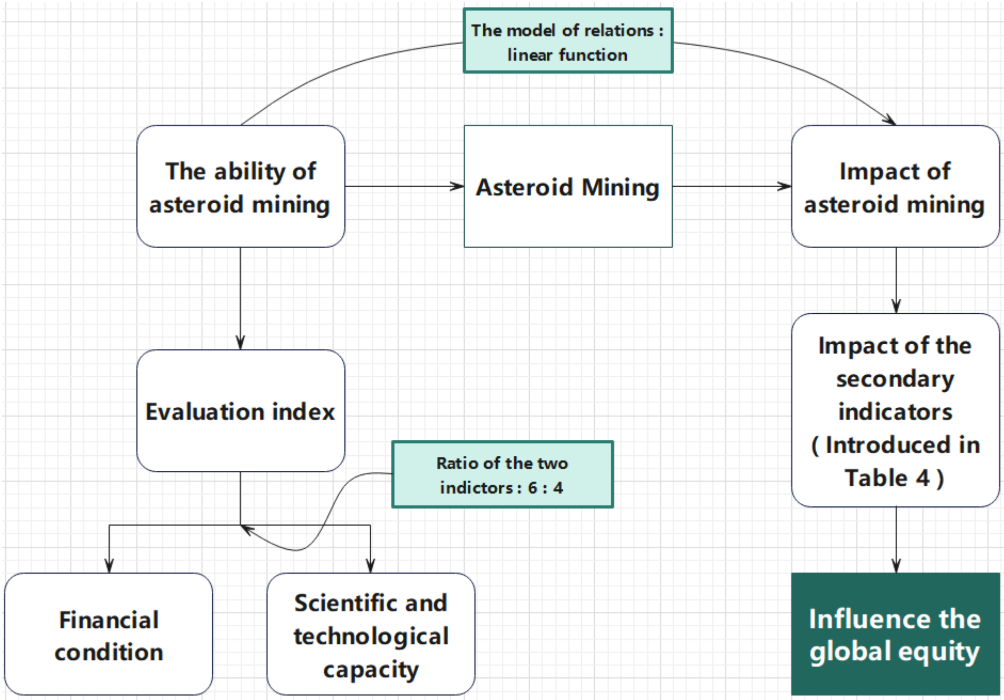


Figure 7: Impact of Asteroid Mining on Global Equity

4.3 Qustion 3: Changes of Global Equity for Different Asteroid Mining Conditions

4.3.1 Change the model of relations between cost-ability and impact of indicators

The original model of relations between cost-ability and impact of indicators presented in Equation 15 is linear model. In our model, the weight of impact distribution is directly related to the cost-ability, which is the sum of financial condition and technological Strength in a certain proportion.

But it is possible that the richer you are, the more you pay, the more you get, which will aggravate the global inequity.

To test this assumption, we change the model of relations between cost-ability and impact of indicators. Then compare the global equity of these models.

(1) Exponential model.

$$\alpha_{ij} \cdot \beta_j \cdot (e^{\gamma_i} - 1) = \delta_{ij} \tag{17}$$

In this model, with the increasing of the independent variable, the growth rate of the dependent variable is increasing. It means that those who give more get even more, who give less get even less. The global equity under this circumstance is **0.9320**, which is much higher than the origin one of **0.8020**.

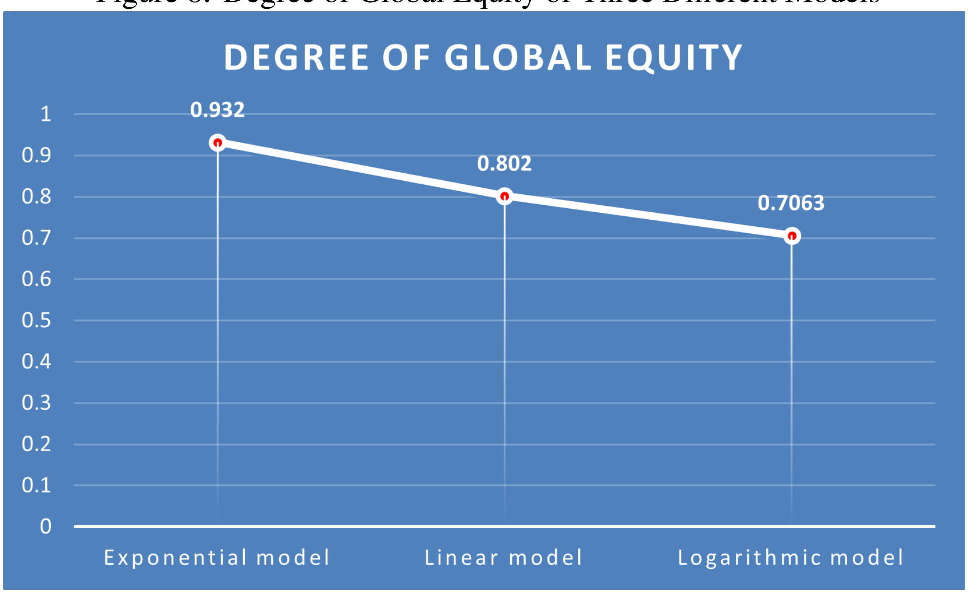
(2) Logarithmic model.

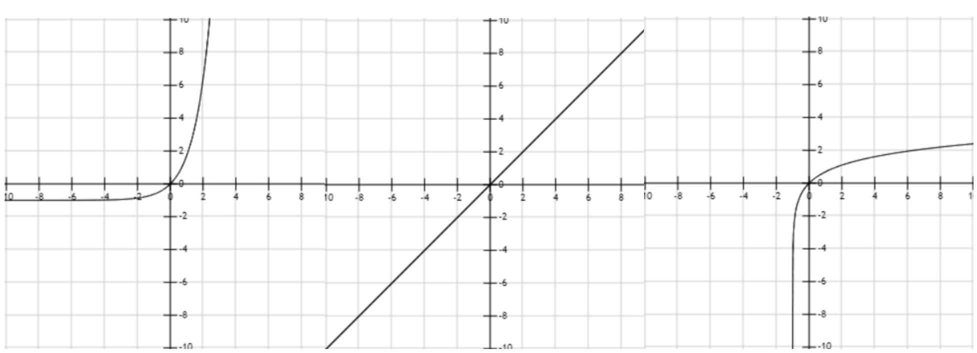
$$\alpha_{ij} \cdot \beta_j \cdot \ln\left(1+\gamma_i\right) = \delta_{ij} \tag{18}$$

In this model, with the increasing of the independent variable, the growth rate of the dependent variable is decreasing. Like a tax model, it means that those who give more gain a bit less, who give less get a bit more. The global equity under this circumstance is **0.7063**, which is lower than the origin one of **0.8020**.

Conclusion: As shown in Figure 8, the conjecture mentioned in limine of this subsection is correct. The richer you are, the more you pay, the more you get, which will aggravate the global inequity.

Figure 8: Degree of Global Equity of Three Different Models





(a) Exponential model (b) Linear model (c) Logarithmic model

4.3.2 Change the ratio of Scientific and Technological Strength to Financial Condition

In our model, financial condition and technological strength are considered to be the cost factors affecting the asteroid mining capacity. Is it possible that in the future, financial condition is less limited, and technological strength is the main factor constraining the efficiency of asteroid mining? Or vice versa, is financial condition the main limiting factor?

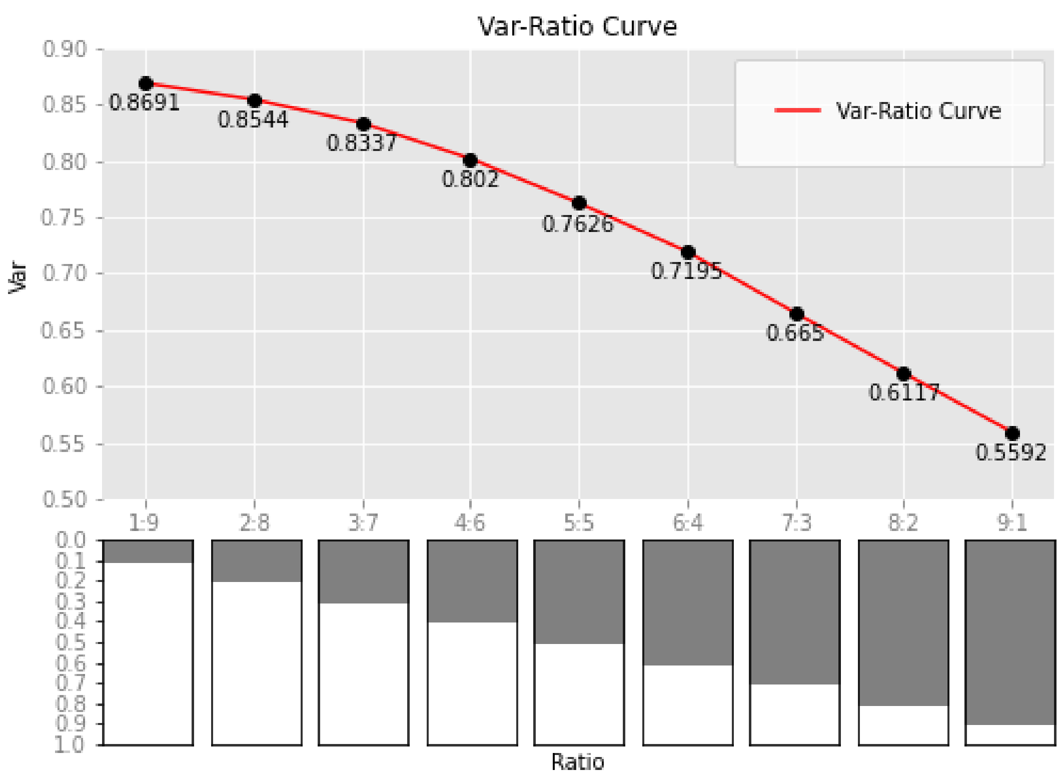
In the model mentioned in 4.2, we take the ratio of technological strength to financial condition as 6:4.

To explore the question mentioned above, we change the ratio of technological strength to financial condition. Then compare the global equity of these conditions.

Figure 9 shows the degree of global equity of different ratio of technological strength to financial condition. The ratio changes from 1:9 to 9:1, corresponding to the degree of global equity of 0.8691, 0.8544, 0.8337, **0.8020**, 0.7626, 0.7195, 0.6650, 0.6117, 0.5592 respectively.

Conclusion: The higher the proportion of technological strength is, the lower the degree of global equity is, the fairer the world is. It means that the technological strength is the main limiting factor in asteroid mining.

Figure 9: Global Equity of different ratios of Technological Strength to Financial Condition



4.4 Qustion 4: Policies of Asteroid Mining for more Global Equity

4.4.1 Incentives

1) Set up prospecting rights and mining rights for asteroid mining to provide legal protection for the mining of asteroid mining.

2) Countries, individuals and enterprises can apply for the exploration right of asteroids according to the law, and stipulate that the holder of the exploration right pays a certain fee every year during the period of the exploration right. Otherwise, anyone can use the intellectual achievements for free.

3) Prospecting costs are borne by individuals, and their exploration rights and discovered minerals are protected by the United Nations, and no one is allowed to mine privately.

4) Prospectors can enjoy the construction of corresponding in-situ processing plants and spaceship supply facilities on mineral planets.

5) The resources obtained from prospecting are public resources. According to the assessment of mineral prices and the cost of prospecting, the price of the resources will be determined by the United Nations. The United Nations shall be responsible for the follow-up mining and maintenance of minerals.

6) The mineral is identified as the prospector's intellectual property within a certain period of time, and other people need to pay the property right fee for its use. All countries can buy according to the price.

7) Prospecting rights can be converted into mining rights under certain conditions. When the prospecting right holder conducts exploration within the validity period of the exploration license, and discovers minerals that meet the requirements of the stateâĂŹs regulations for simultaneous exploration and mining, or complex deposits, he or she could submit an application for trial mining to the United Nations. After approval, the trial mining can be conducted for one year; if it is necessary to extend the trial mining time, must go through the registration procedures.

4.4.2 To maintain global equity

1) At the same time, increasing taxes on mining countries in stages will increase the income of countries or enterprises with low mining volume and weak mining volume, and reduce the mining revenue of countries with high mining volume and strong asteroid mining capacity. So as to conform to the conclusion of the world fairness model: Appropriately reduce the high mining volume and the mining income of strong space-faring countries, while making up for the loss of space resources experienced by weak mining countries.

2) The prospector should disclose all the information of the mineral after discovering the mineral, including the type of mineral, geographical location, difficulty of exploration and other factors. This can prevent the excessive wealth gap, technology gap and social protection gap caused by private mining of unknown minerals from having a serious impact on global equality.

3) While the United Nations is responsible for economic activities such as taxation of ore mining, an asteroid security fund should be established. Economic assessment of the loss of space resources will be made to countries with no autonomous mining capability or low participation in planetary mining, and corresponding compensation will be given. Simultaneously provide it with an international cooperation platform for asteroid mining. This can improve the benefits of asteroid mining for countries with no autonomous mining capabilities or low participation in asteroid mining, which is in line with the assumptions of the global fairness model and promotes global fairness.

4.4.3 To achieve sustainable development

1) The United Nations will evaluate the data of mineable asteroids, and select the most suitable location for spacecraft landing based on factors such as the distance from the Earth and the ease of spacecraft landing. A mining park will be established near this location, and all mining countries/organizations can only build the factories needed for mining in this location.

2) All mining countries will be required to strictly control the disposal of slag during their operations and will not be allowed to discharge any slag into space or directly on the asteroid. Countries found to be doing this will be banned from mining for one year. Countries are encouraged to cooperate in mining clusters in mining areas. All cooperative countries should share mining factories and tools, and there should be certain division of labor and cooperation between cooperative countries. For all cooperative countries that meet the requirements, the United Nations will give certain subsidies according to the size of the cluster.

5 Strengths and Weaknesses

5.1 Strengths

- ★ We use **Secondary Fuzzy Comprehensive Evaluation** to merge the datas to build model of happiness indicator.
- ★ We considered both **subjective** and **objective** factors.
- ★ We **quantify** and **visualize** the level of global equity. And we considered a variety of models and parameters.
- ★ Our data are reliable, scientific and widely sourced.

5.2 Weaknesses

- ▶ We don't take into account the inflation and currency devaluation result from precious metals taken back to earth and flowing into the market.
- ▶ When caculate the weights of the secondary indicators after asteroid mining in 4.2.1(1), the weights of some subjective indicators lack data support.
- ▶ Less consideration has been given to the long-term effects of asteroid mining.

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Appendices

Main Python source:

```
# -*- coding: utf-8 -*-
import pandas as pd
import numpy as np
from functools import reduce

Happy2018 = pd.read_excel("data/2018Happy.xls")
Happy2018 = Happy2018[Happy2018.Year == 2018]
Happy2018 = Happy2018.dropna(axis=0).reset_index(drop=True)
Countrys2018 = list(Happy2018['Country name'].values)
# normalization

df2018 = pd.read_excel("data/2018_4conditions.xlsx")
df2018 = df2018.dropna(axis=0).reset_index(drop=True)
df2018 = df2018.loc[df2018['Country name']
                    .isin(Countrys2018)].reset_index(drop = True)
df2018['PM2.5'] = 1 - df2018['PM2.5']

Patent2018 = pd.read_excel("data/2018Patent.xlsx")
Patent2018 = Patent2018.dropna(axis=0).reset_index(drop=True)
```

```
Patent2018 = Patent2018.loc[Patent2018['Country name'].
                            isin(Countrys2018)].reset_index(drop = True)

Umployment2018 = pd.read_excel("data/2018Unemployment.xlsx")
Umployment2018 = Umployment2018.dropna(axis=0).reset_index(drop=True)
Umployment2018 = Umployment2018.loc[Umployment2018['Country name'].
                                    isin(Countrys2018)].
reset_index(drop = True)
Umployment2018['Unemployment Ratio'] /= 100
Umployment2018['Unemployment Ratio'] = 1-Umployment2018['Unemployment Ratio']

Social_dfs2018 = [Happy2018.iloc[:,[0,3,5]] ,
                  df2018.iloc[:,:] ,Patent2018.iloc[:,[0,3]] ,
                  Poor2018.iloc[:,[0,3]] ,Umployment2018.iloc[:,[0,1]]]
Social2018 = reduce(lambda x,
                    y: pd.merge(x, y, on="Country name"
                                , how="outer"), Social_dfs2018)
Social2018 = Social2018.dropna(axis=0).reset_index(drop = True)
Social_Countrys2018 = Social2018["Country name"].values
Private2018 = Happy2018.iloc[:,[0,4,6,7,8,9,10]]
Private2018 = Private2018[Private2018['Country name']
                          .isin(Social_Countrys2018)].reset_index(drop = True)

# parameters
w21 = np.array([0.2,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1])
w22 = np.array([0.2,0.15,0.15,0.2,0.15,0.15])
w = np.array([0.5,0.5])

# trapezoidal distribution
def Trape_Zoid_A1(a,b,x):
    Result = (b - x) / (b - a)
    return Result

def Trape_Zoid_A2(a,b,c,d,x,section):
    if section == 'Section1':
        Result = (x - a) / (b - a)
    if section == 'Section2':
        Result = (d - x) / (d - c)

    return Result

def Trape_Zoid_A3(c,d,x):
    Result = (x - c) / (d - c)
    return Result

# get membership (3)
def CaculateR(data,class_num,SectionData):
    data['R'] = np.NaN  # create a new empty 'array' column (filled with NaNs)
    data['R'] = data['R'].astype(object)  # convert it to an 'object' data type

    for country in data.index:
        MatrixR = np.zeros([data.shape[1] - 2,class_num])
        for num,column in enumerate(data.columns[0:-2]):
            Value = data.loc[country,column]
```

```
            Min = float(SectionData.loc['min',column])
            Max = float(SectionData.loc['max',column])
            Median = float(SectionData.loc['median',column])

            Section1 = Min + (Max - Min) / 3
            Section2 = Max - (Max - Min) / 3
            # get A1
            if Value < Min:
                A1 = 1
            elif (Value >= Min) & (Value < Section1):
                A1 = Trape_Zoid_A1(Min,Section1,Value)
            else:
                A1 = 0

            # get A2
            if Value < Min:
                A2 = 0
            elif (Value >= Min) & (Value < Section1):
                A2 = Trape_Zoid_A2(Min,Section1,Section2,Max,Value,"Section1")
            elif(Value >= Section1) & (Value < Section2):
                A2 = 1
            elif(Value >= Section2) & (Value < Max):
                A2 = Trape_Zoid_A2(Min,Section1,Section2,Max,Value,"Section2")
            else:
                A2 = 0

            # get A3
            if Value < Section2:
                A3 = 0
            elif (Value >= Section2) & (Value < Max):
                A3 = Trape_Zoid_A3(Section2,Max,Value)
            else:
                A3 = 1

            MatrixR[num,:] = np.array([A1,A2,A3])
        data.at[country,'R'] = MatrixR
    return data

# init beta
SocialEffect = [0.3,0.15,0.3,0.3,0.05,0.2,0.2]
PrivateEffect = [0.1,0.1]

# normalization
Social_Change.iloc[:,:-2] /= (Social_Change.iloc[:,:-2] ** 2).sum() ** 0.5
Private_Change.iloc[:,:-2] /= (Private_Change.iloc[:,:-2] ** 2).sum() ** 0.5

# new B
Social_Change['B'] = np.NaN
Social_Change['B'] = Social_Change['B'].astype(object)
Private_Change['B'] = np.NaN
Private_Change['B'] = Private_Change['B'].astype(object)
# subjective
SocialR_Change = CaculateR(Social_Change,3,Social2018)['R']
SocialR_Change.to_excel('SocialRChange.xlsx')
```

```
# objective
PrivateR_Change = CaculateR(Private_Change,3,Private2018)['R']
PrivateR_Change.to_excel('PrivateRChange.xlsx')

# get B
for country in Social_Change.index:
    b = np.dot(w21,Social_Change.loc[country,'R'])
    Social_Change.at[country,'B'] = b

for country in Private_Change.index:
    b = np.dot(w22,Private_Change.loc[country,'R'])
    Private_Change.at[country,'B'] = b

# get the score
# Output = Social[].copy(deep=True)
Output_Change = pd.DataFrame(Social_Countrys2018,columns=['country name'])
Output_Change['Score'] = np.NaN
Output_Change['Score'] = Output_Change['Score'].astype(object)
Output_Change['Evaluation Matrix'] = np.NaN
Output_Change['Evaluation Matrix'] = Output_Change['Evaluation Matrix'].astype(object)
# Output_Change['Origin Data'] = np.NaN
# Output_Change['Origin Data'] = Output_Change['Origin Data'].astype(object)
Output_Change = Output_Change.set_index(keys = 'country name')


for country in Output_Change.index:
    B = np.vstack([Social_Change.loc[country,'B'],Private_Change.loc[country,'B']] )
    Evaluation_Matrix_Change = np.dot(w,B)
    Score_Change = np.dot(np.array([3,6,9]),Evaluation_Matrix_Change)
    Output_Change.at[country,'Evaluation Matrix'] = Evaluation_Matrix_Change
    Output_Change.at[country,'Score'] = Score_Change

Output_Change.to_excel("Result2018_Change.xlsx")

print("origin",np.var(Output2018['Score']))
print("change",np.var(Output_Change['Score']))

# draw figures
import matplotlib.pyplot as plt
import seaborn as sns

Ratio_Curve = plt.figure(figsize=(8,6))
main_ax = plt.subplot(grid[:2,:]);
for i in range(9):
    ax = plt.subplot(grid[2,i]);
    ax.set_xlim((0,1))
    ax.set_ylim((1,0))
    ax.set_yticks([0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1])
    if i != 0:
        ax.set_yticks([])
    if i == 4:
        ax.set_xlabel("Ratio")
    for tick in ax.get_yticklabels():
        tick.set_color('gray')
```

```
    ax.set_xticks([])
    ax.fill_between([0,1],0,(i + 1) * 0.1,color = 'gray')

main_ax.patch.set_facecolor('#E6E6E6')
main_ax.set_axisbelow(True)

main_ax.grid(color='w', linestyle='solid')

for spine in main_ax.spines.values():
    spine.set_visible(False)

main_ax.xaxis.tick_bottom()
main_ax.yaxis.tick_left()

main_ax.tick_params(colors='gray', direction='out')
for tick in main_ax.get_xticklabels():
    tick.set_color('gray')
for tick in main_ax.get_yticklabels():
    tick.set_color('gray')


main_ax.figsize = (19,100)
main_ax.plot(Ratio[::-1],Var,'-',color = 'Red',label = 'Var-Ratio Curve')
main_ax.plot(Ratio[::-1],Var,'o',color = 'black')
main_ax.set_title("Var-Ratio Curve")
main_ax.set_xlabel("Ratio")
main_ax.set_ylabel("Var")
main_ax.legend(borderpad=2)
# main_ax.set_xticklabels(labels=Ratio, rotation=45);
main_ax.set_ylim((0.5,0.9))
for num,i in enumerate(Var):
    main_ax.text(Ratio[::-1][num],i - 0.025 ,i ,ha='center')

Ratio_Curve.savefig("Var-Ratio Curve")
```