Problem Chosen	2022	Team Control Number
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Mining Equity

Summary

In recent years, vital resources on Earth are showing signs of strain and scientists are casting sights on resources in space; this report imagine us to be in an era when asteroid mining is feasible. However, global equity is affected when certain countries can go into space and acquire resources from asteroids while others cannot, thus laying negative impact on world peace. The aim of this report is to build an equity evaluation model to quantitatively show the influence of asteroid mining on global equity. We are expected to predict the future of asteroid mining and provide policies for the United Nation to ensure global equity. To solve these, a Spatial and Temporal model as well as an Asteroid Mineral Transaction Market are established.

We use the Spatial and Temporal Model to calculate inequity. To get Spatial Equity Index, Theil's and Gini index are used to measure the inequity of variables with and without marginal utility respectively within a group; we also derive an index called Deviation Index and use it to measure the inequity among groups. After calculating all the index, Analytical Hierarchy Process is applied to assign weights to each variables so that we can get Spatial Equity Index. To get Temporal Equity Index, we use the method of Weighted Change Rate to predict the future value of a variable and map the resulting change rate onto the Sigmoid function so as to get a Temporal Equity index within the range of 0 to 1. To validate our model, data of three main aspects and twelve estimators are collected to evaluate current world's equity. Since all index are within 0 to 1, and the closer the index is to one, the less equal will be, we get the results that Spatial Equity Index is 0.4291, which is around average inequity, while Temporal Equity Index is 0.6210, which is quite unequal. Detailed results for each of the small estimators are in Table 3.

We build an Asteroid Mineral Transaction Market(AMTM) to illustrate our prediction on the future of asteroid mining. This market is based on the Efficient Market Hypothesis and the theory of Tragedy of Commons. In our market, state-owned companies and private ones can mine on asteroids and everyone can fund companies; what's more, since this is a free transaction market, people who needs minerals will get minerals, while people who sell minerals will get profits. We apply the ST model and get an result that spatial index will decreases, indicating this market can help reduce global inequity.

In addition, we are asked to predict how changes in AMTM will affect the global equity. We apply the analytical approach to break this question into four circumstances where changes may occur; then, we find which subject in AMTM contributes to this change; Thirdly, we find out other vulnerable subjects; at last, we list the estimators and get the results of the problem. We also listed five articles for the UN regarding how to regulate asteroid mining based on our model.

Eventually, we conduct sensitive analysis to AHP and get the results that our ST Model has good robustness.

Keywords: Asteroid mining; AHP ; Gini index ; Theil's index ; Sigmoid function

Contents

1 Introduction

1.1 Problem Background

Asteroids are small celestial bodies that orbit the sun; most of them are distributed in the Asteroid Belt between the orbits of Mars and Jupiter. Though small, asteroids are of great strategic importance for all human beings[1]; not only can they serve as radiation shields and centralizing hubs on our way to Mars and other distant planets, but they also contain huge amount of scarce elements, such as gold, nickle, iron, and those in the platinum group, which are precious on Earth. As Earth's vital resources are showing signs of strain, it's important for us to seek help from space.

Indeed, extracting metals from asteroids may sound difficult and unrealistic now, but the development of technology will soon bring us to a new era, where the outer space is the main 'battle field' among countries. Sixty years ago, the United Nation has released the Outer Space Treaty[2], which stipulates that nations should exploit the space only for the sake of all humans. Therefore, to avoid the circumstance where asteroids are solely claimed by a small portion of countries or private companies, it's necessary for us to start thinking about drafting policies that can make the asteroid mining industry head towards the path of global equity in the future.

1.2 Restatement of the Problem

- Provide the definition of global equity and build a model that can exam whether current world has achieved global equity or not; check the correctness of the model by applying it in a historical event.
- Predict the future of asteroid mining and declare the impact that asteroid mining may bring to the global equity.
- Develop an approach to address how changed condition will affect the model of global equity.
- Raise possible policies regarding asteroid mining to encourage global equity.

1.3 Our Approach

This topic requires us to build a model that can measure the level of equity of current world and provide several policies concerning a future industry, asteroid mining, that can help the world achieve global equity. Our work mainly includes the following:

- Establish a model to quantitatively evaluate global equity based on comprehensive estimators in both spatial and temporal scales.
- Ameliorate the structure of the commodity market and consider several well-known economy theories to construct the future system of asteroid mining, as well as describing and justifying the likely asteroid mining sector in the future.
- Apply the analytical approach to know how changes in condition of our predicted future Asteroid Mining Transaction Market affect global equity.

- Put forward reasonable policies to encourage the asteroid mining sector to advance in a way that promotes more global equity based on the theoretical foundation of the content mentioned above.

2 General Assumptions

To simplify the problem, we make the following basic assumptions.

- **Assumption 1:** The total amount of mineral resources will not change within the time period that we consider.
↪ **Justification:** The type of resources we consider are classified as non-renewable ones, which means it will take a long time for them to be generated again. Therefore, we assume that it will not change within the time we consider.
- **Assumption 2:** The Efficient Markets Hypothesis is valid.
↪ **Justification:** This hypothesis is consistent with the behavior of the market we predict.
- **Assumption 3:** Without constraints, people will maximize their own interests.
↪ **Justification:** Based on our context, it is the actual reflection of human nature.
- **Assumption 4:** The regulations proposed by international organizations are strongly binding.
↪ **Justification:** This is a prerequisite for our regulations to work.

3 Model Preparation

3.1 Notations

Important notations used in this paper are listed in Table 1.

Table 1: Notations

Symbol	Description	Unit
n	sample size	–
x	sample value	–
μ	sample mean value	–
T	Theil's index, an inequality estimator	–
G	Gini's index, an inequality estimator	–
DI	Deviation Index, deviation from the standard value	–
SEI	Spatial Equity Index	–
TEI	Temporal Equity Index	–

3.2 The Data

3.2.1 Data Collection

To validate our ST Model, we collect data from the following databases:

Table 2: Database collation

Database Names	Database URL	Data Type
BP World Energy Statistical Database	https://www.bp.com/	Resources
Our World in Data	https://ourworldindata.org/	Resources, Social
World Inequality Database	https://wid.world/	Resources, Social
World Bank Open Data	https://data.worldbank.org/	Economy
United States Geological Survey	https://www.usgs.gov/centers/	Resources

3.2.2 Data Processing

- When only a small amount of data are missing, considering that they have little impact on the global distribution, we just ignore them.
- When huge amount of data are missing, considering that lacking data may lead to incorrectness, we just give up using them and turn to use others.

4 Problem 1: ST Model and its Validation

We think global equity means the fairness in both spatial and temporal scales[3]. By fairness in spatial scale, we mean that different kinds of resources should be distributed according to the nation's needs, while special care should also be given to under-developed countries, so that the gap between the 'top' and the 'bottom' countries will not be unacceptably large; by fairness in temporal scale, we mean that our current behaviors should not damage the interest of the following generations.

To measure whether current world possess the equity that is consistent with our definition above, we build the ST model that can quantitatively evaluate equity from both the spatial and the temporal scales. What worth noticing is that when considering spatial factors, it is better for us to consider multiple aspects, so that we can evaluate the global equity more comprehensively. Following, we will introduce various methods, which can be fitted to handle different types of data. The following figure shows the summary of our model.

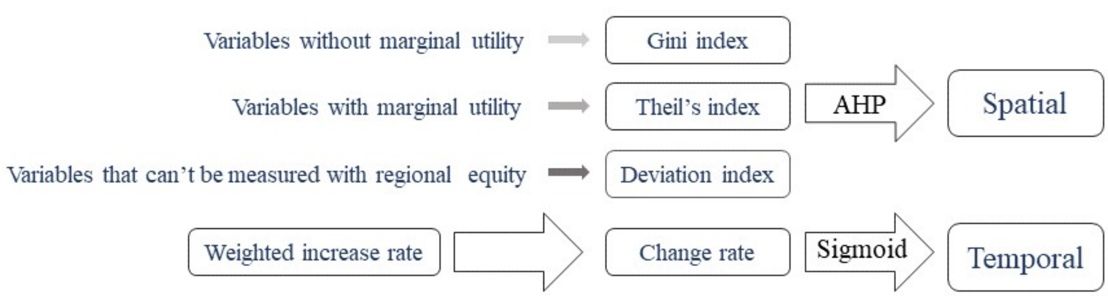

Figure 1: Summary of the type of variables and their corresponding method

4.1 Equity measurement in spacial scale

4.1.1 Theil's Index

According to Paul D. Allison, there are many kinds of measures for inequality[4]. However, after considering the criteria of scale invariance, only five measures, including the coefficient of variation V, the relative mean deviation D, the Gini index G, the Theil's index T and the variance of the logarithm L, remain available. Then, after the principle of transfers, only G, V and T stay available. Finally, after weighing the sensibility of transfers and the data we obtained, we narrow down our estimators into two choices: the Gini index and the Theil's index. Both of these two index can determine whether there are inequalities within a group, or in other words, whether the samples in a group has equity; however, there are slight differences between them and the further explanations are as follows.

Firstly, Theil's index can be used to measure the inequality of variables of interest that have diminishing marginal utility. Let's use income as an example to explain this. Suppose there are n people, each of which receives an annual income x_i with $i = 1, 2, ..., n$, and we use μ to denote the mean of incomes. Based on Information Theory, the Theil's entropy measure can be expressed as:

$$T = \frac{1}{n}\sum_{i=1}^{n}(\frac{x_i}{\mu})\log(\frac{x_i}{\mu}) \tag{1}$$

Since the calculated Theil's index T ranges within [0, $+\infty$), it's not convenient for us to assess it, therefore we use T^* in a range of 0 ~ 1 as the final Theil's value. Given that Theil's index has an upper bound of $logn$, T^* can be calculated in the following equation:

$$T^* = \frac{T}{\log n} \tag{2}$$

Then, suppose we transfer h dollars from a person with income x_i to another person with income x_j,where $x_i \geq x_j$; all other incomes remain the same. We use a limiting argument to get the expression for the effect of a transfer on Theil's measure T. As h goes to 0, we get

$$\Delta T = ch\log(x_j/x_i) \tag{3}$$

where c is positive and depends only on the mean and the number of observation. The change in T depends on the ratio of incomes; the lower the level of income, the more sensitive T is to transfer. We assume that income has diminishing marginal utility, then the transfer of income among low-income earners would be more consequential for them than a transfer of an equal amount of money among high-income earners. Theil's index T reflects such a difference, hence, we can use Theil's index to handle data that has marginal utility.

4.1.2 Gini index

When the variable of interest does not have diminishing marginal utility, the Theil's index is no longer suitable; therefore, based on the accessible data that we obtained, we consider the Gini's index as a sensible measure of equality. The following definition will clearly show that the Gini's index is a measure of dispersion divided by twice the mean:

$$G = \frac{\frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n}|x_i - x_j|}{2\mu} \tag{4}$$

Equation (5) is an equivalent formula that is convenient for individual-level data:

$$G = \frac{2}{\mu n^2}\sum_{i=1}^{n} i x_i - \frac{n+1}{n} \tag{5}$$

4.1.3 Deviation index

If we want to measure the inequity between groups that we already know what its equity should look like (remember that both Gini index and Theil's index can only be applied to exam equity **within** groups), we can construct our own index and see how the actual result deviate from the expected equity value. Let's consider an example where we want to measure whether the global employment ratio of men and women are equal. Firstly, according to the data from World Bank[], we know that the ratio of women and men is approximately 1. Then, we know that when the ratio of women and men in a workplace is also 1, then it means equity; therefore, assume the ratio of women and men in a country's workplace is r_c and the ratio in the world is r_w, use the equation:

$$d = 1 - \frac{r_c}{r_w} \tag{6}$$

to estimate the deviation of the actual value with the standard value. The closer the result of d is to 0, the more equal will the groups be.

4.1.4 Application Analytic Hierarchy Process

When all factors are measured using the above methods, we then need to apply Analytic Hierarchy Process (AHP) to assign weights to them. The following pseudo codes shows the AHP process.

Algorithm 1 Weighted assignment by AHP

Data: n indicators $c_i, i = 1, 2, \ldots, n$
Result: weight vector **w**
get the random consistency index of n indicators $RI(n)$;
while *not pass the consistency test* **do**
  construct discriminant matrix D;
  calculate the maximum eigenvalue λ_{max} of D;
  get the respective eigenvector **w** of λ_{max};
  consistency indicator $CI \leftarrow (\lambda_{max} - n)/(n-1)$;
  consistency ratio $CR \leftarrow CI/RI(n)$;
  if CR < *0.1* **then**
    pass the consistency test;
  else
    repeat this loop;
  end
end
return weight vector **w**;

4.2 Measure global equity in temporal scale

There are some kinds of factors, such as resources, that will have a relatively fixed amount of value; if people keep mining, few will be left for the following generations. Therefore, we need to develop method to measure the temporal impact of some factors to the global equity. In this part, we use the method of weighted increase rate.

4.2.1 Weighted increase rate

To calculate the temporal impact of one factor N, we will need a set of continuous N that changes with the time. Assume that the sample size is n, which also means that we have got n years of data, we need to firstly calculate the change rate of adjacent two years; then we assign weights to different years. Therefore, the total change rate will be the predicted number for the factor N. We can use the equation to calculate:

$$k = \sum_{j=1}^{n-1} j \cdot \frac{2}{n(n+1)} \cdot \frac{y_i - y_j}{y_j} \tag{7}$$

where k is the predicted tendency for what N will change to in the future.

4.2.2 Sigmoid mapping

Since we have considered a lot of factors to measure global equity, it's more convenient to assess them if we put them all in a range of $0 \sim 1$; therefore, a good way is to map the range of the change rate function to the domain of the Sigmoid function. This is because both of them are within a range of $(-\infty, +\infty)$. After mapping, the value of y-axis of the sigmoid function will be the predicted change rate of N. Based on the properties of Sigmoid function, if the future change rate is greater than 0.5, then the factor N will keep increasing in the future; if the result is smaller than 0.5, then it will have a decreasing tendency.

4.3 Validation and results

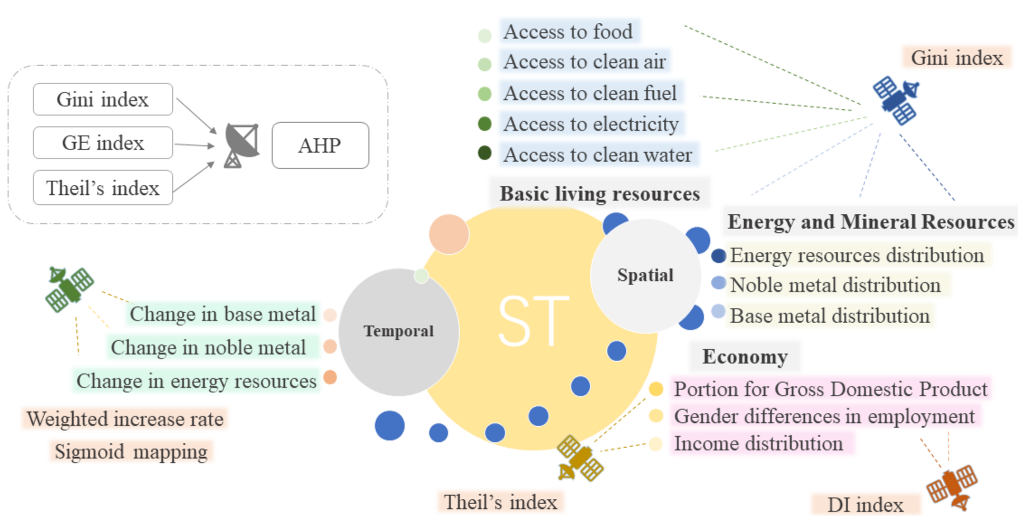

Figure 2: Structure of ST model

In terms of spatial scale, we consider three main aspects: Basic living resources (BLR), Energy and resources distribution (ERD)[5], Economy (Eco)[6]. Under each of them, we find several factors to quantify them. For BLR, we consider people's access to clean air, clean water, clean fuel, food and electricity; for ERD, we consider the distribution of energy resources, noble metals and base metals; for Eco, we consider people's income distribution, gender differences in employment, and portion of gross domestic product. In terms of temporal scale, since the amount of resources will be mostly affected by time, we consider the same three factors as in the ERD part here.

4.3.1 Spatial validation

- **Basic living resources**
  $\hookrightarrow$ Since all these data don't have marginal utility, we use the Gini index to measure them.
  Access to clean air

  We use the data of Global Death Rate from Air Pollution[7]. The data shows that low-income and middle-income countries have more burden than western developed countries on the air pollution issue.
  Access to clean water

  We used the data of Global Death Rate from Unsafe Water Sources[8]. Data shows that death rates are especially high in areas across the Sub-Saharan Africa and Asia.
  Access to healthy diet

  We use the data of the Share of Population that Can not Afford a Healthy Diet[9]. By 'healthy diet', we mean the lowest cost for the food that contain enough nutrients for human's basic well-being; by 'affordable', we stipulate that a household should spend less than 63% of their total income on food. As shown in Figure 2 (left), the global distribution of population without access to healthy diet is extremely uneven.
  Access to electricity

  We use the data of the Number of People Without Access to Electricity[10]. It shows that countries in the India Subcontinent suffer most electricity shortage, followed by countries in the middle Africa.
  Access to clean fuel

  We use the data of Share of the population with access to clean fuels for cooking[11]. Data shows that access to clean fuels are lowest in Sub-Saharan Africa,the situation of countries in South Asia and East Asia is less than encouraging either as shown in Figure 2 (right).

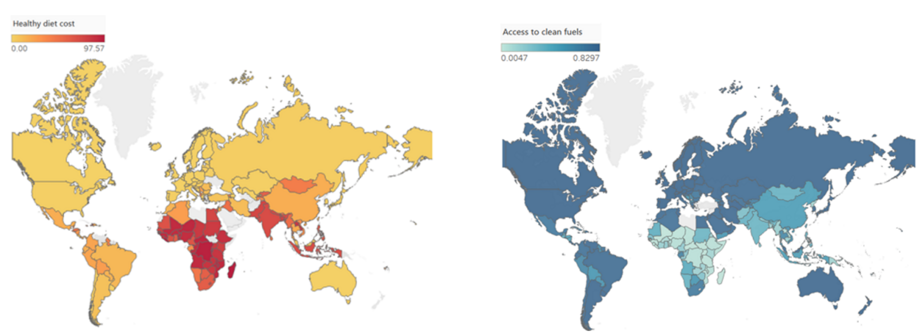

Figure 3: Share without access to healthy diet(left) and with access to clen fuel for cooking(right)

- **Economy**
  $\hookrightarrow$ Since it is necessary to consider the marginal utility of the data concerning income distribution and portion of GDP, we use the Theil's index. For gender differences in employment, for the reason that it's a comparison between countries, we use the Measure Deviation method.
  Portion for Gross Domestic Product

  We use the data of GDP per Capita[12].
  Gender differences in employment

  We use the data of Employment in Agriculture, Industry, Services, for both male and female[13, 14, 15, 16, 17, 18].
  Income distribution

  We use the data of Income Distribution (national)[19], and Income Distribution (global)[20]. From Figure 3, we can see that in South Africa, wealth are mostly concentrated in the richest 20% people, while the poorest 20% people hardly have income; therefore, we say that there are huge inequality of income distribution in South Africa.

- **Energy and Mineral Resources**
  $\hookrightarrow$ All these data don't have marginal utility.Therefore, we use the Gini's index to measure them. In our validation, we just select the most representative minerals for each factor. For energy resources, we choose petroleum, coal and natural gas; for noble metal, we choose gold, silver, platinum and palladium; for base metal, we choose copper, iron (pig iron, raw steel), zinc and aluminum.
  Energy resources distribution

  We use the data of each country's proven reserves of the three energy resources mentioned above[21]. As can be seen from Figure 3, the distribution of energy resources by continent or region is largely uneven.
  Nobel metal distribution and base metal distribution

  We use the data of the annual production of the metal resources of the major producer countries[22].

- **Weight assignment by AHP**
$\hookrightarrow$ We use Analytic Hierarchy Process(AHP) described by pseudo codes in Section 4.1.4 to determine the weight of indicators at the same level. For five indicators in Basic living resources(BLR), three indicators in Economy(Eco) and three aspects in terms of Spatial scale, discriminant matrix D_{BLR}, D_{Eco} and D_{Spa} are determined as follows:

$$D_{BLR} = \begin{bmatrix} 1 & 0.5 & 2 & 3 & 5 \\ 2 & 1 & 4 & 6 & 7 \\ 0.5 & 0.25 & 1 & 2 & 4 \\ 0.33 & 0.17 & 0.5 & 1 & 2 \\ 0.2 & 0.14 & 0.25 & 0.5 & 1 \end{bmatrix} D_{Eco} = \begin{bmatrix} 1 & 2 & 4 \\ 0.5 & 1 & 2 \\ 0.25 & 0.5 & 1 \end{bmatrix} D_{Spa} = \begin{bmatrix} 1 & 0.5 & 2 \\ 2 & 1 & 4 \\ 0.5 & 0.25 & 1 \end{bmatrix}$$

Weight vector w_{BLR}, w_{Eco} and w_{Spa} are as follows:

$$\mathbf{w_{BLR}} = (0.2504, 0.4724, 0.1475, 0.0819, 0.0478) \quad (8)$$
$$\mathbf{w_{Eco}} = (0.5714, 0.2857, 0.1429) \quad (9)$$
$$\mathbf{w_{Spa}} = (0.2857, 0.5714, 0.1429) \quad (10)$$

After getting the weight vector, calculate the dot product of weight vector and the inequity indexes, we can get a weighted inequity index of the higher level.

4.3.2 Temporal validation

- Energy resources distribution
$\looparrowright$ We use the data of the Change of Numbers of Active Exploitation Site with Time[23].

- Nobel metal distribution
$\looparrowright$We use the data of the Change of Amounts of Minerals with time[24].

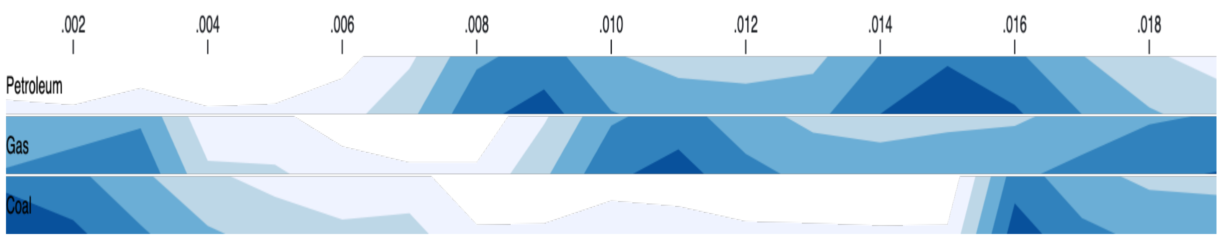

Figure 4: Petroleum, natural gas and coal reserves changes from 2001 to 2019

4.3.3 Results

We get the result of inequity indexes for all indicators at different levels. All indexes are in range of $0 \sim 1$. When the index is approaching 1, samples approach extreme inequity, vice versa. Spatial Equity Index is 0.4291, indicating average inequity in the spatial scale; Temporal Equity Index is 0.6210, which is little higher than in the spatial scale. These conform to the reality where people focus more on inequity in spatial scale than the one in temporal scale. All indexes are shown below in Table 3.

Table 3: Inequity indexes for all indicators

Spatial	Economy		Income distribution	0.3556		0.3194	**0.4291**
			Gender differences in employment	0.2101			
			Portion for GDP	0.3934			
	Basic living resources		Access to food	0.5271		0.4348	
			Access to clean water	0.5024			
			Access to electricity	0.1235			
			Access to clean fuel	0.3151			
			Access to clean air	0.4488			
	Energy and mineral Resources	Nobel metal resources	Gold	0.4225	0.4726	0.6257	
			Silver	0.3691			
			Platinum	0.6072			
			Palladium	0.4914			
		Base metal resources	Copper	0.4265	0.5989		
			Pig iron	0.7651			
			Raw steel	0.6765			
			Zinc	0.4979			
			Aluminium	0.6284			
		Energy resources	Petroleum	0.7804	0.8057		
			Natural gas	0.8638			
			Coal	0.7729			
Temporal	Nobel metal resources		Gold	0.5617		0.6101	**0.6210**
			Silver	0.5552			
			PGM	0.7134			
	Base metal resources		Copper	0.5529		0.5621	
			Zinc	0.5683			
			Nickel	0.5726			
			Plumbum	0.5547			
	Energy resources		Petroleum	0.5384		0.6908	
			Natural gas	0.6098			
			Coal	0.9241			

5 Problem 2:

5.1 Future system:

There will be a market which allows both private and state-owned companies to trade asteroid mineral. This specific market is supervised by an international organisation called World Asteroid Mining Organization (WAMO) , which is affiliated to the United Nations; its job is to evaluate the entry qualification of companies applying to be listed and re-evaluate the qualification of listed companies annually. An appropriate percentage of profits made by companies trading in the market will be given to the organization to support development of poor countries. Poor countries can get the money for free, but the amount each country can get depends on its poverty and how much it has improved in various public sectors compared to the previous year.

There is no restriction on the type of business, but companies applying for a listing must provide WAMO with an overall evaluation report of the company, issued by auditors, law firms and investment banks together. Only when those companies pass the entry evaluation of WAMO can they be admitted to trade in the market. Listed companies are entitled to bid for a limited amount of mining rights on an specific asteroid once over a period of time. When mining rights on some asteroid expire, WAMO will verify and publish the actual mining amount of the company. If the company's actual production value is different from the allowable value, it will be punished accordingly.

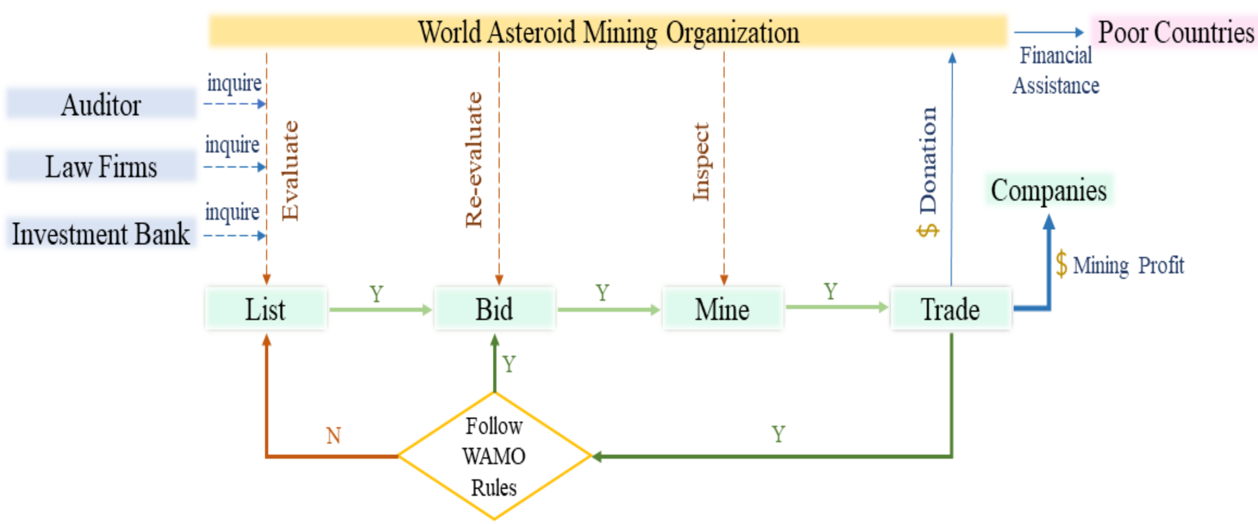

Figure 5: The structure of future asteroid mineral market

5.2 Justification

- **Prediction 1:** Both private and state-owned companies can do the mining and trade asteroid minerals in the market.
  ↪ **Justification:** Since this is a free transaction market, it's natural to say that the more companies take part in it, the more profit will be made as a whole, thus enhancing economic

benefit. Also, since private companies are allowed to mine on asteroids, it's consistent with the concept that asteroids are every human's shared property. They may be funded by companies, organizations, countries worldwide.

- **Prediction 2:** Asteroid minerals will be traded on the free market, with market participants having free access to market price, trading volume and public asteroid mineral information.
  $\hookrightarrow$ **Justification:** Efficient Market Hypothesis(EMH)[25] states that security prices fully reflect all available information. One significant precondition for this statement is that the costs for getting information and trading is 0. According to EMH, with free access to information including market price, trading volume and asteroid mining, the market will become a Semi-efficient Market in which the prices of securities will reflect all publicly available information. So no investor can rely on publicly available information analysis to get abnormal rewards, effectively promoting fair trading.

- **Prediction 3:** WAMO consists of experts from different countries, with an equal ratio of different races and genders.
  $\hookrightarrow$ **Justification:** Since WAMO's job is to evaluate the qualification of companies that can mine on asteroids, its staffs shouldn't be politicians, but need to be experts who know certain knowledge so that asteroids mining can avoid becoming a chip of capital. Also, since the OST stipulates that asteroids don't belong to any nation, it's important to be fair to let all people have equal access to it; therefore, equal ratio of different races and gender will be needed to guarantee this.

- **Prediction 4:** It's stipulated by the WAMO that all companies who have mined on the asteroids should hand over 7% of their mining profits to the WAMO as the fund used to provide financial assistance to poor countries.
  $\hookrightarrow$ **Justification:** WAMO believes that to achieve global equity, the rich countries need to assist the poor ones, so that it can narrow the gap of financial inequality between them. What's more, providing foreign aids to countries in need will have other advantages, such as benefiting aiding countries' domestic economy and creating stronger unity among all countries.[26]

- **Prediction 5:** World's low- and lower-middle income countries can receive financial assistance from WAMO. The money provided to each country is determined by its poverty level and its improvements in its country's public areas, like education, infrastructure and medical treatment.
  $\hookrightarrow$ **Justification:** According to the World Bank[27], countries are divided into four types with respect to their national income per person (GNI per capita): high, upper-middle, lower-middle, and low. Each year, the thresholds to distinguish between the income groups will be adjusted and we can use these thresholds to select countries that can receive WAMO's financial assistance. The equation to calculate the money proportion is:

$$p = \frac{|U - u_i|}{\sum_{i=1}^{n} |U - u_i|} \cdot k \tag{11}$$

  where U is the global mean GNI; u_i is the GNI for each low- and lower-middle income countries; n is the number of all countries waiting for financial assistance, and k is the coefficient determined by its improvements.

- **Prediction 6:** There will be auditors, law firms and investment banks that provide independent and professional reports for companies applying to sell in the market as well as the listing companies annually.
↪ **Justification:** If all evaluation reports of all companies are made by WAMO, it won't have the ability to review each company thoroughly. These independent third party review companies with professional skills can provide a relatively objective and comprehensive evaluation reports and increase the efficiency of WAMO.

- **Prediction 7:** There is a limitation on the amount of mineral that is allowed to be mined on one asteroid at a given period.
↪ **Justification:** [28] In Tragedy of the Commons, when there is no limitation on a public area, the Pure Strategy Nash Equilibrium will be reached when everyone maximizes their own profits, causing the total profit to decrease; but when there is limitation, the Pure Strategy Nash Equilibrium will be reached when the total profit is maximized. Like Tragedy of the Commons, asteroid mineral will be mined excessively if there is no limitation on the mining amounts. Also, the period is calculated according to the detector round trip time and the mining time based on Socially Necessary Labor Time to improve economic efficiency.

- **Prediction 8:** Bidding considerations include the level of mining technology, credit history(default rate, late payment or non-payment of profit sharing, etc.) and other aspects, re-evaluating the auction companies' qualifications and choosing the final company.
↪ **Justification:** Bidding is a totally competitive method, so it can motivate companies to move in the direction of bidding standards, such as improving technical level and maintain a good credit history.

- **Prediction 9:** The detector round-trip time and the socially necessary labor time for this amount of recovery will be considered when setting period limitation on a specific mining right. When a mining right is going to expire, the next round of bidding will be held.
↪ **Justification:** Socially necessary labor hour is the amount of labour time performed by a worker of average skill and productivity, working with tools of the average productive potential, to produce a given commodity. The limitation of period will significantly improve the efficiency and make the mining of asteroid mineral more orderly.

- **Prediction 10:** Companies that doesn't adhere to regulations will be punished. Punishment including fines, declines in their credit degree, ban on their bidding qualification for a period of time. If the companies' circumstances are very serious, their qualifications to bid and sell in the markets will be revoked.
↪ **Justification:** Punishments can curb all kinds of violations towards regulations and protect the legitimate rights and interest of others. Executing different punishments on different levels also embodies equity and justice, which is the core spirit of the law.

5.3 Impact on global equity

Future asteroid mineral sector will mainly impact the global equity on economic aspects and metal mineral resources aspects. First, on the free market for transaction of asteroid minerals, the one who does the mining and selling will benefit a lot, indicating an increase in both GDP and national income for those high-income countries that are most likely to have the ability to mine asteroid minerals. On the other hand, part of the profit gained in transactions on the free market will be appropriately assigned to those lower-middle income countries and low income countries, indicating an increase in both GDP and national income for those countries. So we set the annual increase rates of from high income countries to low income countries to be 1.05%, 1.02%, 1.10% and 1.20% respectively according to the impact degree and their bases.

Second, the asteroid minerals are mainly metal minerals and its volume is assumed to be significantly larger than the volume on earth. Considering the period of the industrial revolutions, we assume that after 50 years, the asteroid mining technology will be mature, and after 100 years, the asteroid minerals on earth can supply all countries' basic need, getting the index of 0.20. So every year, there will be a decrease on each metals' indexes, indicating a trend of equity. All indexes changed and the adjusted spatial index are shown below in Table 4.

Table 4: Impact on different areas

Income distribution		$0.3556 \rightarrow 0.3524$	
Portion for GDP		$0.3934 \rightarrow 0.3912$	
Nobel metal resources	Gold	$0.4225 \rightarrow 0.4203$	
	Silver	$0.3691 \rightarrow 0.3675$	
	Platinum	$0.6072 \rightarrow 0.6031$	
	Palladium	$0.4914 \rightarrow 0.4885$	
Base metal resources	Copper	$0.4265 \rightarrow 0.4242$	
	Pig iron	$0.7651 \rightarrow 0.7594$	
	Raw steel	$0.6765 \rightarrow 0.6718$	
	Zinc	$0.4979 \rightarrow 0.4949$	
	Aluminium	$0.6284 \rightarrow 0.6241$	
Adjusted Spacial Index		$0.4291 \rightarrow 0.4282$	decrease

6 Problem 3: Analytical approaches to the impact of condition changes

Analytical approach[29] is a smart way to solve complicated questions. The general process is to break the original question down into multiple layers of smaller ones, which are easier to solve; when we solve all the small questions, we can then work out the original one. In this part, we are to analyze how the global equity will be affected when changes in certain conditions of our predicted future system arise. Since the question is quite general and implicit, we will apply the analytical approach to find the solution.

According to our predicted future system for the asteroid mineral transaction market, companies of interest will undergo four main processes: listing, bidding, mining and trading; since all the changes of condition will appear in these aspects, we then divide the original question into four smaller ones, or in other words, the changes of condition will all be classified into those four aspects. Then, it's natural to think that since condition changes won't happen themselves, there must be someone who contribute to the changes. Therefore, we link each condition change with the six subjects in our predicted future system and find what subjects may contribute to it. With this information, we find out what other subjects will be affected; Finally, we can get the solution, which is the factors that might be affected by the change in conditions. The figure below show the process of our analytical approach.

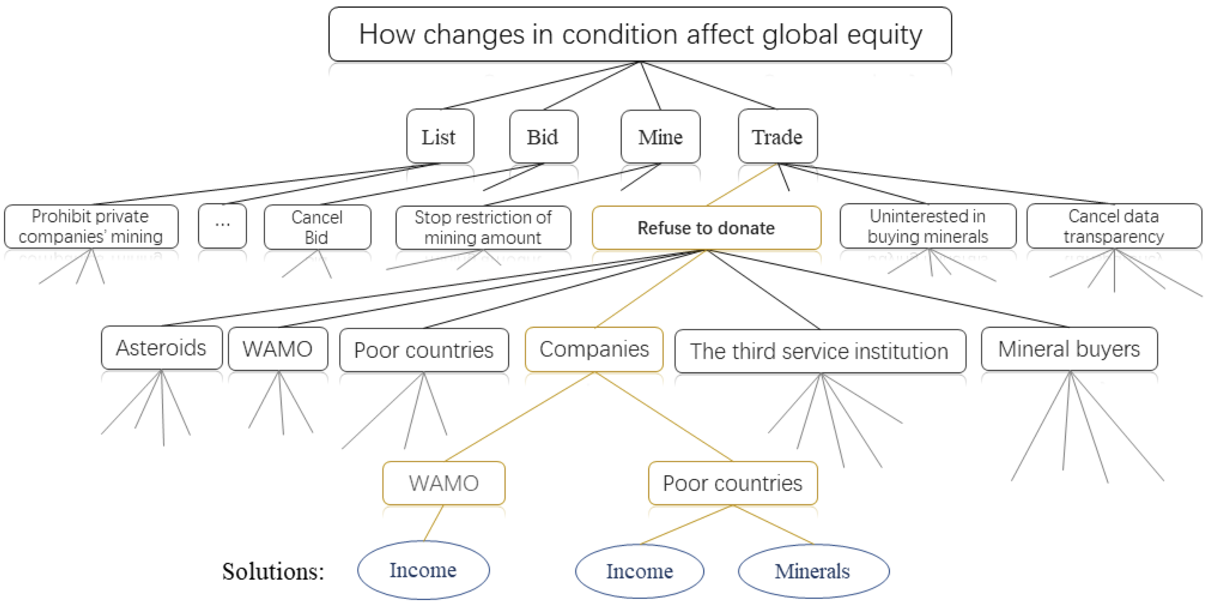

Figure 6: Detailed process of our analytical approach

In the figure, we consider the change that companies won't donate certain amounts of their profits to the World Asteroid Mining Organization. Clearly, this change must be caused by the companies; then we consider if companies no longer donate money to the WAMO, which of the remaining subjects will be affected. The result is WAMO, whose staff's income comes partially from companies' donation; and poor countries, who not only lose the financial assistance, but also don't have money for mineral materials. In summary, the WAMO's and poor countries' income, as well as poor countries access to minerals will be affected. To get quantified result, you can just plug a new value of these two factors and see how the global equity will change.

7 Problem 4: Policies for asteroid mining and explanation

7.1 Our policies concerning asteroid mining

- Article I
  In order to better manage the development of asteroid mining industry, including standardizing the behavior of both the governmental agencies and non-governmental entities, and creating a safe and harmonious space for this new industry, the United Nation especially sets up the World Asteroid Mining Organization (WAMO) to solely be responsible for the overall events concerning asteroid mining.

- Article II
  In order to support the statement that space is a shared property for all humans, and let

everyone have equal access to space resources, all national agencies and private companies of States Parties to the Treaty can launch extractors and mine on the asteroids.

The minerals they get from mining belongs to themselves; they can conduct free transactions with the minerals in the market.

- Article III
  World Asteroid Mining Organization shall set restrictions on how much a company or an agency can mine at one time. This can avoid large amount of resources being claimed by countries who mine first on asteroids, as well as make sure that the asteroid mining industry can be developed in a sustainable manner.

- Article IV
  Each State Party to the Treaty that send extractors or any other machines to the outer space shall always be responsible for them, no matter on Earth or in space. In principle, all mining machines sent to the outer space shall be taken back so as to reduce space trash; State Party to the Treaty shall be prepared to take responsibility for any damage caused by their countries' machines that are stranded in space.

- Article V
  All governmental agencies and non-governmental entities of the State Party to the Treaty should not interfere the normal mining process of other State Party to the Treaty.

7.2 Justification for our policies

- Article I
  If WAMO is responsible for the overall events, they can set policies that will motivate the asteroid mineral sector to develop in the direction of promoting global equity. For example, they can receive part of the profit from the transaction of asteroid minerals and allocate them appropriately to middle-lower income countries and low income countries that will lead to increases in their GDP and national income both. This will lead to a decrease in the Economy index which has been proved in Section 5.3 Impact on global equity.

- Article II
  Private companies and public companies are the same from nature, but just are owned by different main bodies. From the perspective of the free market, all qualified bodies should have the same rights for transaction, so allowing both private and public companies to compete in the market emphasizes equal rights. From the perspective of the world, this method will lead to a higher profit which can be shared globally as has been proved in Section 5.2 Justification of Prediction 1.

- Article III
  If the restriction of the amounts that an asteroid can be mined at a particular time is not settled, then the Tragedy of the Commons will happen since every bodies that have the ability to mining want to maximize their own profit, not total profits, causing inequity at the time scale which has been proved in Section 5.2 Justification of Prediction 7.

- Article IV
  Environmental pollution such as air pollution, water pollution and trash pollution will cause the lower-middle income countries and low income countries to suffer more than others as the data has shown in Section 4.3.1 Basic Living Resources. These factors will also cause the large inequity at the temporal scale since our successors will suffer much by our damages. So let each bodies be responsible for its own space trash will promote equity in both spatial and temporal scales.

- Article V
  As has been stated in Section 5.1 Future System, WAMO has the power to set the limitation amounts of mining for a period but no bodies themselves have the ownership of asteroids, thus no bodies have the right to interfere other bodies normal mining activity.

8 Test the Model

When calculating the Spatial Index(SI), we use AHP to determine the weight vector of three aspects: Basic Living Resources(BLR), Economy(Eco) and Energy and Resources distribution(ERD). The determination of its discriminant matrix is subjective, so we need to analyze if this will change the SI significantly.

We have one indicator unchanged, and traverse the important ratio between other two indicators with center of its original ratio and radius of 5. The result shows that when changing discriminant matrix with a radius of 5, there is no significant changes between the original matrix and the changed one, with a maximum deviation of 4.07%, indicating little impact due to subjectivity.

Different weight vectors and indexes calculated by different discriminant matrix is shown in Table 5-6. Deviation(%) of different determinant matrices from the original determinant matrices are shownbelow in Fig. 6 with the maximum and the minimum marked. This intuitively shows the little rangeof deviation, indicating the low sensitivity of our model.

Table 5: Weight by Sensitivity analysis of AHP

Ratio	Weight vector			Ratio	Weight vector			Ratio	Weight vector		
BLR/ERD	Eco	BLR	ERD	BLR/Eco	Eco	BLR	ERD	Eco/ERD	Eco	BLR	ERD
9	0.25	0.65	0.10	7	CR not pass			7	CR not pass		
8	0.26	0.64	0.10	6	CR not pass			6	CR not pass		
7	0.26	0.63	0.11	5	0.19	0.69	0.13	5	0.36	0.54	0.10
6	0.27	0.61	0.12	4	0.21	0.66	0.13	4	0.34	0.55	0.11
5	0.28	0.60	0.13	3	0.24	0.63	0.14	3	0.32	0.56	0.12
4	0.29	0.57	0.14	2	0.29	0.57	0.14	2	0.29	0.57	0.14
3	0.30	0.54	0.16	1	0.38	0.47	0.15	1	0.23	0.58	0.18
2	0.31	0.49	0.20	1/2	CR not pass			1/2	CR not pass		

Table 6: Indexes by sensitivity analysis of AHP

BLR/ERD	9	8	7	6	5	4	3	2	1	1/2	1/3
Index	0.424	0.425	0.425	0.426	0.427	0.429	0.432	0.436	-	-	-
Deviation(%)	-1.15	-1.03	-0.88	-0.68	-0.39	0.00	0.61	1.68	-	-	-
BLR/Eco	7	6	5	4	3	2	1	1/2	1/3	1/4	1/5
Index	-	-	0.437	0.436	0.433	0.429	0.420	-	-	-	-
Deviation(%)	-	-	1.94	1.56	0.98	0.00	-2.15	-	-	-	-
Eco/ERD	7	6	5	4	3	2	1	1/2	1/3	1/4	1/5
Index	-	-	0.412	0.416	0.421	0.429	0.443	-	-	-	-
Deviation(%)	-	-	-4.07	-3.12	-1.84	0.00	3.28	-	-	-	-

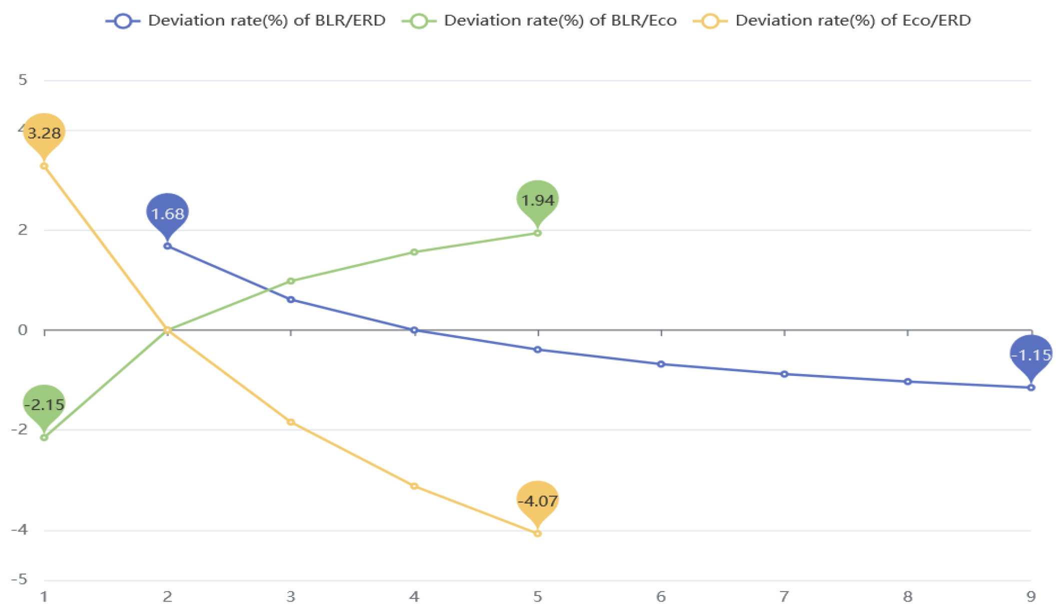

Figure 7: Deviation(%) of different determinant matrices

9 Conclusions

9.1 Summary of Results

9.1.1 Result of Problem 1

After defining the global equity,We choose varied estimators in both spatial and temporal scales to build the ST model. After applying the Gini's index, Theil's index and Deviation index to different estimators and weighting them by using AHP, we obtain the values of Spatial Equity Index and Temporal Equity Index:0.4291,0.6210,which means it exists global inequity to some extent, and the temporal inequity is more severe than the spatial inequity of the world.

9.1.2 Result of Problem 2

Inspired by the structure of the commodity market, we constructed the future system of the asteroid mining based on several economy theories.For problem twowe make ten possible predictions of what will asteroid mining be like in the future and provide corresponding justifications.By using ST model,we calculate the Spatial Equity Index:0.4282,which is lower than the SEI before asteroid mining.It indicates that asteroid mining promotes the global equity.

9.1.3 Result of Problem 3

For problem 3, we construct an analytical approach. We divide all the changes of conditions into four aspects based on the four main processes the companies will undergo according to our system for the asteroid mineral transaction market: listing, bidding, mining and trading. Then, according to who contribute to the changes, we link each condition change with the six subjects in our system and find what subjects may contribute to it. and what other subjects will be affected. Finally, we can get the solutions, which are the factors that might be affected by the change in conditions.

9.1.4 Result of Problem 4

Based on the theoretical foundation mentioned above, We put forward five policies for the UN which are beneficial for the global equity and make corresponding justifications.

9.2 Strengths and Weaknesses

9.2.1 Strengths

- By applying the Theil index, Gini index ,Deviation index and AHP as a method for weighing, we measure the inequity in not only the spatial scale, but also the temporal scale.
- Our predicted future Asteroid Mining Transaction Market is based on the Efficient Market Hypothesis and the theory of Tragedy of the Commons, both of which are applied well in current world. Therefore, our market system may be applied well in reality.
- All data used in the validation of our model are from authoritative global organizations. We also consider a lot of factors and fields, and analyze large quantity of data, aiming to make our model more accurate and comprehensive.
- The sensitivity analysis of our model shows that though parameters change, the results do not change much, showing our model has good robustness.

9.2.2 Weaknesses

- Due to lack of data and time limitation, we simply use the mean of Gini index as the total index of energy and metal resources' upper estimator.
- we assume that WAMO has the absolute authority and power in the field of asteroid mining; countries and regions are under its effective jurisdiction. However, the reality may be more complicated.

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Appendices

Appendix A Tools and Softwares

- Data calculation: Matlab, Python.
- Visualization: Tableau, Python, Echart, D3.js.