Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
F		2200201

Treasure Hunt Off-Earth: Explore the Global Equity While Realizing the Dream of Asteroid Mining

Summary

With the rapid development of modern science and technology and natural science, interstellar exploration is no longer an absurd myth. The rapid consumption of existing resources on Earth has stimulated human desire to seek resources from other planets for help. However, this issue is inextricably linked to the sustainment of global equity. Several models are made in the article to evaluate the global equity and the impacts of changing conditions of the asteroid mining industry.

A few data sources are referred and some authentic previous literatures are reviewed to provide a good foundation for our model constructing process. Several potential visions for the future of asteroid mining are then proposed with reasonable imagination.

To measure global equity, we first set the key parameter **Overall Evaluation Index** (**OEI**), which is related to a total of seven indicators in three categories. We calculate their weights by entropy weighting method to derive the linear relationship between **OEI** and them. Based on this, we build a **global equity model**, which includes **intergenerational equity model** and **intragenerational equity model**. First, we use linear regression to derive the rate of change K of **OEI**. Next, the **Fuzzy Integrated Evaluation Model (FIE)** is used to measure the intergenerational justice index J_1 according to K. After that, we introduce **Coefficient of Variation (CV)** to evaluate the dispersion of **OEI** for each country and region, and again use **FIE** to evaluate the intergenerational justice index J_2.

To better explore how changes in the asteroid mining sector could impact global equity differently, we establish a network model based on **Pearson correlation coefficient**. The model contains three layers, which shows the potential influence between changes and global equity indicators.

After that, we conduct a sensitivity test and further assessments for our designed models. The merits and drawbacks are evaluated carefully in order to offer suggestions for promoting our models in future research.

Finally, the writers made a few feasible policy recommendations for the improvement of relevant UN space laws and regulations. Both intergenerational and regional equity are considered carefully, with the use of some economics models to predict the possible market behavior.

Keywords: Global equity; asteroid mining; Fuzzy Integrated Evaluation Model (FIE); Coefficient of Variation (CV); Pearson coefficient correlation

Contents

1 Introduction

1.1 Problem Background

'Soon, the human species will have to leave Earth and survive and reproduce on spaceships or other planets. If humanity does not make an effort to develop a multi-planetary civilization and settle in other worlds, our species may die out in the next century.'

—Stephen. W. Hawking, Physicist, quoted from his predictions.

With the rapid development of aerospace technology and the appearance of sophisticated spacecrafts, exploring and living on another planet has been gradually walking into the spotlight rather than an odd story from the Arabian Nights. By signing the **Outer Space Treaty of 1967** proposed by the United Nations (UN), most countries had made an agreement on reducing world inequity for the sake of mankind, while exploring the resources on other planets or asteroids.

Undeniably, asteroid mining is still facing practical problems on its way to success. However, enough faith has been given to this promising industry ever since countless outer space miracles were made possible. The core question is that, how can we sustain the health of mining market and furthermore, precious global equity, once the interstellar mineral resources become available.

Figure 1: A fairy-tale vision of asteroid exploring (From the novella ***Le Petit Prince*** [1])

Let alone the technical questions yet to be answered, the post-mining situations are in demand of discussion along with a well-defined metric for global equity. By assuming the feasibility of asteroid mining and a reasonable cost which is financially worth the investment, the vision of asteroid mining should be projected and policies that keep the global equity from some of the negative influences it might bring should be discussed and established. Therefore, when the dream of mining resources in outer space come true, the world can stay organized, just and safe.

1.2 Restatement of the Problem

Task 1 Set up a definition and a measuring instrument for global equity. Validate the model constructed from different perspectives such as historical or regional analysis.

Task 2 Predict the possible visions of asteroid mining and correlated impacts. Despite current difficulties due to unknown mining markets, choose the most likely vision and analyze its impacts on the global justice using description, justification and the constructed model in task1.

Task 3 Determine the impacts on global equity caused by changes in conditions of the mining vision which is set up in task 2. Using analytical model or other methods to illustrate.

Task 4 Help the UN with establishing updating policies in addition to the **Outer Space Treaty of 1967** in order to motivate asteroid mining industry to benefit all humankind, to reduce inequality, to ensure this outer space industry advances in a sustainable way. After evaluating the results of the model, provide the UN with reasonable and feasible policy recommendations to implement in the future.

1.3 Literature Review

When talking of equity or justice, we usually think of regional equity, namely the quality of being fair and allocating resources or chances in hope of achieving similar outcomes. The definition of equity with respect to natural resources is largely the same, but the concept of 'intergenerational equity' should be noticed as well. According to Cao (2016) [2], the principle of equity is supposed to prioritize satisfying the basic needs of humankind. As far as intergenerational equity is concerned, the earth's natural resources should be shared intergenerationally in the intergenerational distribution to avoid the 'ecological deficit'. Therefore, every generation is both a beneficiary, entitled to use and benefit from the planet, and a trustee, in charge of the planet for the next generation.

The asteroid contains rich rare mineral resources and preserves the original components of the early formation of the solar system, which is a living fossil for studying the origin and evolution history of the solar system, and which has great scientific research value. Andrew (2015) [3] suggested in his article that, both energy and technology development are endangered and dragged slower by the depletion of fossil fuels and technology metals, while currently renewable energy could not replace the fossil fuels because most of them either lack of proof or too expensive due to short supply of crucial technology metals.

According to MacWhorter (2016) [4], few people have actually thought of the enormous environmental dividends that asteroid mining could possibly result, since most of the asteroids are lifeless, orbiting the sun, and most importantly, possessing precious mineral resources. Although the **Outer Space Treaty of 1967** put forward by the UN made an effort to link asteroid mining and global equity together, still clearer laws and legislation are in demand to regulate private companies as well as protect their interests.

1.4 Our work

Figure 2 illustrates the process of our work flow. The main body has four parts in general and seven models are used in total. The definition of global equity is considered and examined carefully before the possible visions for asteroid mining were projected. Lastly, the most likely vision is analyzed with the instrument we constructed, which lays the foundation for the policy recommendations for the United Nations to update related legislation.

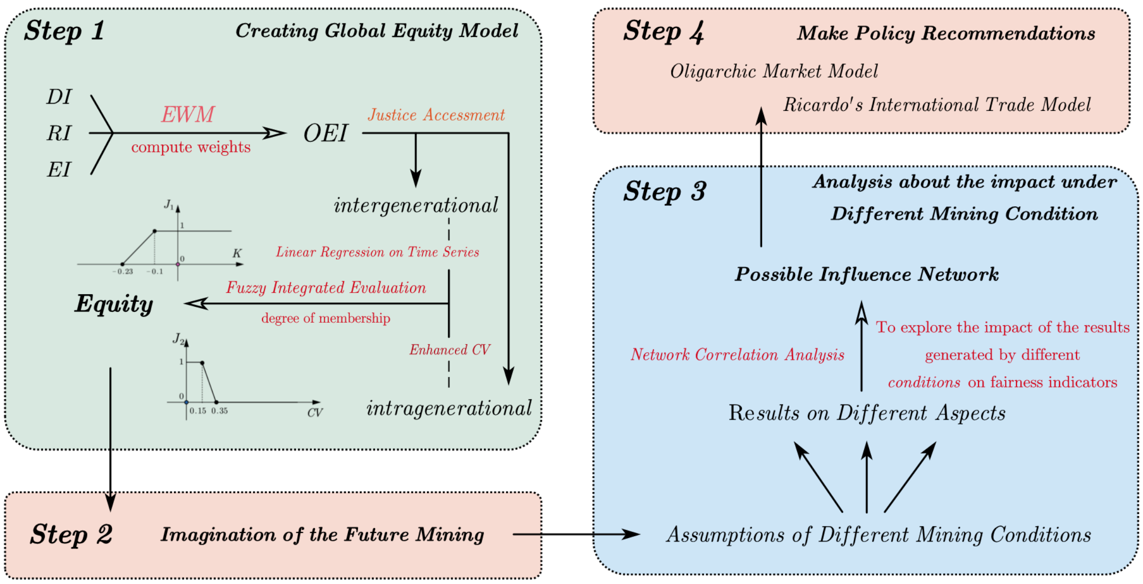

Figure 2: Workflow

2 Assumptions and Justification

In order to simplify the given tasks and to better quantify our models, we made following assumptions. Each of them is justified and consistent with current international situation and basic facts.

1. Currently, not all countries have the ability to conduct the asteroid mining, and those countries that might be able to explore this outer space industry are not technically equal. This kind of inequity could not be eliminated in a short time.

2. Asteroid mining is a long-term process with huge cost, we shall suppose all investment relating to asteroid mining is worthy and achievable. Those countries who are able to go outer space to detect mineral resources will not abort their plan halfway.

3. The astronomy community, the physics community and manufacturing industry will keep making progress in the following generations, this will guarantee human to explore farther outer space for the need of sustainable development.

4. Concerning the intergenerational equity, we supposed that all countries in the world would unite and behave in largely the same direction, for the sake of a healthier and sustainable planet for future generations. However, this could not be fulfilled if some countries do not cooperate forwardly. Legislation might be needed to regulate all countries and obeying the 'ecological constraint' should be made an obligation.

5. Force majeure such as wars, Omicron pandemic, political sanctions are not considered in our research and model constructions.

6. Mineral resources market including all suppliers and demanders and international trade follows the basic assumptions in economics. It should be notice that economical models are abstract and ideal, which might differ to the real-world market. Possible market failures are not considered in this article to simplify the projecting vision.

7. Industries related to the interstellar mining industry, such as interstellar tourism and space archaeology, are presumed to have promising prospects. The interstellar industry will drive the development of human education, science and culture in an extraordinary way.

8. There are many factors that could potentially or directly affect the global equity, including but not limited to income, tax rate, gender equality, wealth, international trade, population, geographical settings, and so on. In this article, we will only discuss those with rather large influences on global equity, in order to simplify the given problem and focus our attention on the relationship between asteroid mining and equity index we set.

3 Notations

Table 1: Notation

Symbol	Notation
J_1	Justice Index (intergenerational)
J_2	Justice Index (intragenerational)
OEI	Overall Evaluation Index

DI	Development Indicators
HDI	Human Development Index
LF	Labor Force as a percentage of total population
UI	Urbanization Index
RI	Resource Indicators
NLR	National Land Resources
RH	Resource Holdings per capita
EI	Equalization Indicators
$CFPS$	Percentage of Companies with Female Participation in Shares
$FMWPR$	Ratio of Female to Male Work Participation Rate

4 Global Justice: A General Blueprint Towards General Well-being

4.1 Two Dimension Justice: Intergenerational and Intragenerational Equity

To measure global equity, we discuss it separately in time and space. In the spatial dimension, global equity is expressed as equity between countries and regions, which is intragenerational equity. In the temporal dimension, the present generation should consider the well-being of future generations when developing a certain resource, which is intergenerational equity.

International equity is not absolute average. Taking asteroid mining as an example, even in a future where humans can already travel to outer space to mine, we cannot guarantee that all countries will have the ability to do so. And for different countries, our distribution of valuable ore from outer space is not simply evenly divided. We believe that this can be solved by a free-trade exchange method, where resources can be distributed according to need. It is worth mentioning that intra-generational equity has priority and determinacy. According to Weiss (1988) [5], intergenerational equity is predicated on intragenerational equity, and that the continuation of intragenerational inequity to future generations will lead to greater inequity.

To achieve intergenerational equity, the present generation needs to ensure that they leave at least as many resources to future generations as previous generations left to them. According to just savings principle proposed by Rawls (1973) [6], in which he emphasized the need to determine a reasonable rate of storage in order to achieve intergenerational reciprocity.

It is difficult to identify an exact dividing line between equity and inequity, whether for intragenerational or intergenerational equity. Therefore, we use **Fuzzy Integrated Evaluation(FIE)** in defining fairness, which means that we consider it equitable when the indicators we set are in a certain range. We will present these indicators in the next subsection and prove that they are reliable.

4.2 Estimating Equity by Using Overall Evaluation Index (OEI)

Introduction of OEI Before we establish the models, we need to calculate the **Overall Evaluation Index**(aka OEI) first, which is the combination of **Development Indicators** (aka DI), **Resource Indicators**(aka RI) and **Equalization Indicators** (aka EI). OEI can reflect on the comprehensive level of a country/region to a certain extent, and it is the base of our estimating methods for both intergenerational equity and intragenerational equity.The component of it is showed in the image below.

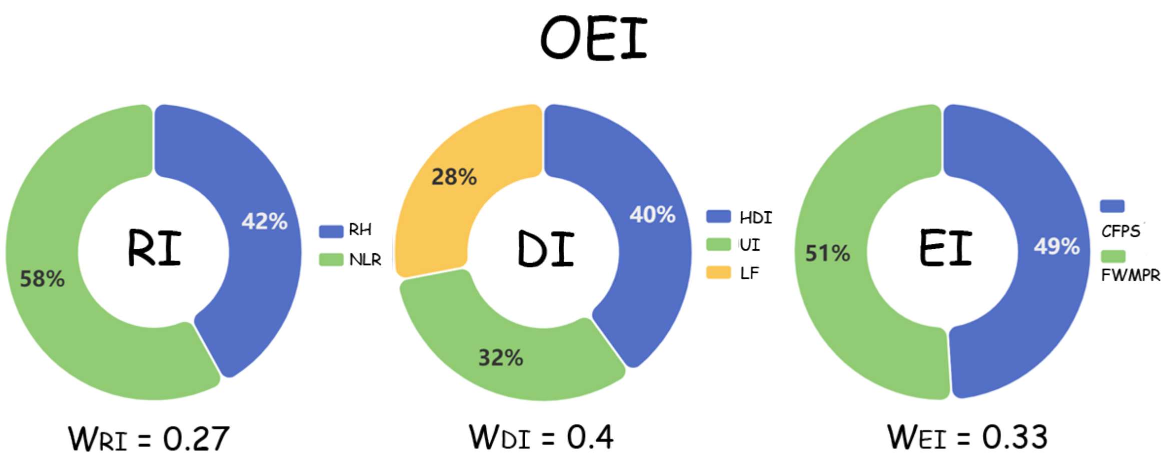

Figure 3: Components of OEI

What should be mentioned is that the weight of OEI is calculated by **the entropy weight method**(**EWM**), the reason why we use the method is out of the consideration of Objectivity. We use the following formulas to compute the weights: (For The needed data to weight calculation, they are replaced by history data [7] in the age we lived in by assuming that the effects of the data to our estimating model is at little difference with actual data in the future.)

1. Data Standardization:

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$

where x_{ij} stands for the i value of j indicator in the data collection matrix x, and matrix z is the standardized matrix.

2. Compute the probability matrix P:

$$p_{ij} = \frac{\tilde{z}_{ij}}{\sum_{i=1}^{n} \tilde{z}_{ij}}$$

3. Calculate the **information entropy**, e_j:

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} p_{ij} \ln(p_{ij}) \; (j = 1, 2, \cdots, m)$$

where m stands for the number of indicators and n stands for the number for countries/regions.

4. get the weight:

$$W_{E_j} = \frac{1 - e_j}{m - \sum_{j=1} e_j}$$

After getting the weights, the whole formula to compute **OEI** is given as below:

$$OEI = 0.55 \times (0.32UI + 0.28LF + 0.4HDI) + 0.45 \times (0.42RH + 0.58NLR)$$

Intergenerational equity For intergenerational justice, we establish **intergenerational justice estimating model**(**IJEM**) to evaluate the intergenerational justice index among the current generation t_{cur} and the history generation $t_1, t_2 \cdots t_n$, where n stands for the time interval we want to study. For instance, here is a result chart for demonstration by using **IJEM**:

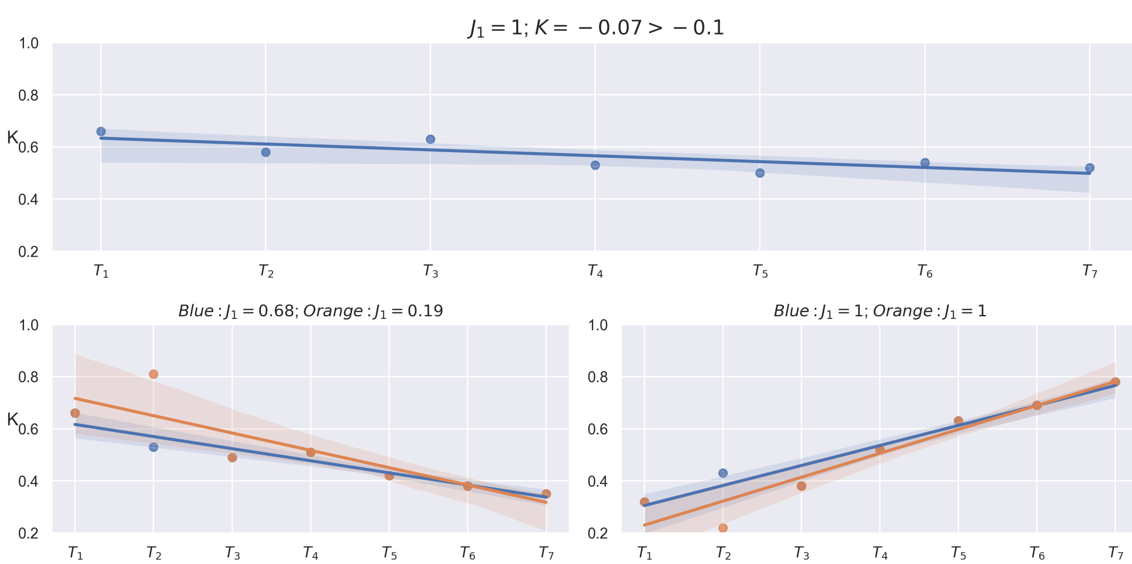

Figure 4: A example using IJEM model

Firstly, we calculate the OEI value for all the generation we want to study. Then we get the slope K of the generated regress curve by using **linear regression** by defining:

$$y_i = \beta + KX$$

and the computing formula:

$$\beta = \frac{\sum Y_i}{n} - a\frac{\sum x_i}{n}$$
$$K = \frac{n\sum x_i Y_i - \sum x_i \sum Y_i}{n\sum x_i^2 - (\sum x_i)^2}$$

After computing the slope K, and confirm that the p value of regression parameter K(i.e. slope K) is acceptable enough, we use **Fuzzy Integrated Evaluation Model**(**FIE**) to estimate the **intergenerational justice index**(i.e. J_1), since this model could help we assess a fuzzy indicator conveniently.

The general idea behind **FIE** is easy to understand: *design a formula to assess the degree of membership to the indicator*.

We creatively design a formula to compute the degree of membership to intergenerational justice, aka $J_1(0 \le J_1 \le 1$; the closer to 1, the greater the degree of membership is). The formula is:

$$J_1(K) = \begin{cases} 1, & K \ge -0.1 \\ \frac{K+0.23}{0.13}, & -0.23 \le K \le -0.1 \\ 0, & K \le -0.23 \end{cases} \tag{1}$$

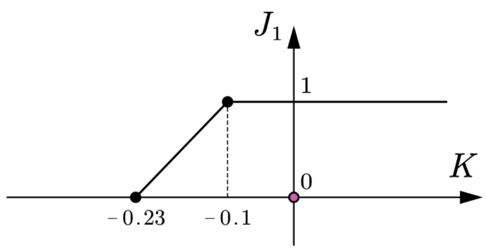

Figure 5: Evaluate J_1 with K

For example, if K of the regression curve generated by the OEI of the recent n generation is less than -0.1 but greater than -0.23, we could use formula $\frac{K+0.23}{0.13}$ to calculate J_1. Let's assume J_1 is equal to 0.68, so we could get the conclusion that the intergenerational justice of the generation intervals is likely to true equity at the possibility of 0.68. The reason why we choose -0.1 as our boundary is to allow errors caused by data fluctuation.

Intragenerational equity To estimate intragenerational equity, we use a similar approach. We collect data on development indicators and resource indicators for each country and work out their OEI.We believe that when different countries and regions tend to have the same level of development, the higher the degree of global equity. Therefore, in order to calculate the intragenerational equity index J_2, we introduce **Coefficient of Variation (CV)** to measure the dispersion of the current degree of development of different countries and regions in the world.

CV is a normalized measure of the degree of dispersion of a probability distribution and is defined as the ratio of the standard deviation σ to the mean ρ, i.e.

$$c_v = \frac{\sigma}{\mu}$$

Similarly, we use the FIE model to evaluate the Intragenerational equity. We evaluate the degree of variation by the value of c_v and thus we evaluate the Intragenerational Justice Index (i.e., J_2). According to Guan and Wang (2012) [8], we obtain the following equation:

$$J_2(CV) = \begin{cases} 1, & CV \geq 0.35 \\ -5CV + 1.75, & 0.15 \leq CV \leq 0.35 \\ 0, & CV \leq 0.15 \end{cases} \tag{2}$$

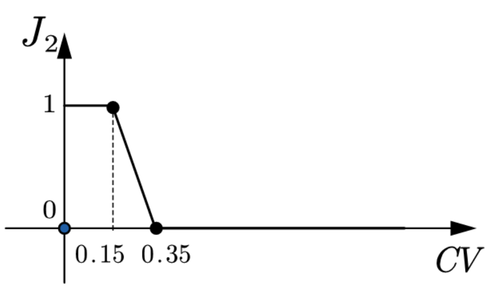

Figure 6: Evaluate J_2 with CV

The closer J_2 is to 1, the more equitable it is. This means that when CV is less than 0.15, the data variability is low and we consider it equitable; when CV is greater than 0.35, the data variability is high and we consider it not equitable. This evaluation criteria could be reliable, and this can be visually proven in our data(Figure 7).It can be seen that when the CV is close to 0.15, the distribution of the original data (respective OEI of the countries we selected) is more concentrated, i.e., more equitable; when the CV is close to 0.35, the situation is just the opposite.

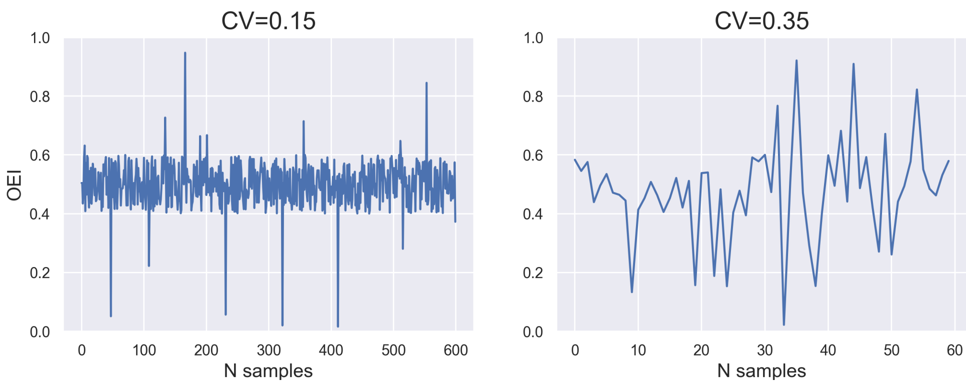

Figure 7: Degree of dispersion with differnt CV

5 Outer Space: Will It Be a Solution of Resources Shortages?

5.1 Mining on Another Asteroid: Vision Description and Proof of Interstellar Excavation

MacWhorter (2016) put forward in his article that, ‘Long a part of the science fiction imagination, mining in the space has attracted interests both seriously and for amusement’. Few private companies, such as Tesla, have obtained a detailed plan of space travelling or other industry development.Despite the potential difficulties and some oddity, the blueprint of the asteroid mining can be visualized with imagination.

Those countries which are able to explore outer space, such as the United States, China, Russia, the United Kingdom and France, will demand financial support from either capital groups or domestic government, that is either private investment or public investment. According to macroeconomic principles, more investment means higher production rate, which could mean higher labor-force participation rate.

Who will be responsible for the mining process? This could be uncertain. If a country is labor force intensive industrialized, it can transport some of its qualified labor force to the asteroid mining industry, whether it’s for domestic or oversea nations; if a country wants to dominate this heavy industry, it could assign its military to extract mineral resources; if a country has enough skillful and comprehensive technology, it can use artificial intelligence to do the tedious and dangerous mining jobs. If human encounter aliens on the targeted planets, we can even trade with them or manage to colonize them (but that is another story).

By the current knowledge and cognizations, most ‘valuable’ asteroids are imbued with iron-group elements, silicate or lanthanon elements. Other asteroids probably store water or noble metal, which are also beneficial to humankind. Moreover, the minerals rich in asteroids can be used as specimens for studying the evolution of the universe, and have high archaeological value and scientific research value.

Figure 8: 951 Gaspra, the first asteroid ever to be closely approached (taken by the *Galileo* spacecraft) [9]

After the spacecraft full of interstellar minerals returned to Earth, the allocation and trading of resources became the primary issue. It is not difficult to find that the biggest shareholders, the exploiting nation itself, could get a largest share of profits from sales. Nevertheless, considering the universe resources which are meant to address 'earthly problems' belong to all humankind, the UN might put forward policies to regulate the monopoly mineral resources market. Therefore, some developing countries could afford the costly interstellar minerals import, this would also benefit their nation development, since the outer space minerals could be invaluable.

Furthermore, the interstellar exploiting industry will definitely have spillover effects, this will be mainly reflected on promoting the related industries, like Interstellar tourism, film and television manufacturing, space archaeology and so on. These related industries will also benefit people from basically all around the world.

5.2 Shareholders Funders and Potential Influences on Global Justice

Next, we will discuss the most likely vision of asteroid mining in the future, before analyzing its possible impacts on global equity using the equity model we have constructed in the part 4 (task 1).

Who will do the exploitation? At this stage, only few countries have developed advanced space exploration technology, but in the coming generations, more nations or districts would probably develop their method to go 'off-Earth' for richer natural resources.

Who will provide funds? Currently, it cost a fortune to have a space exploration. Therefore, joint efforts will be in demand towards a sharing future among countries or planets. Governments, private business groups, community stewardships, non-profit organizations should all play a part.

Who will get profits or merits from the interstellar mining project? Basically, all humankind would be the winners, because of the large extent of globalization. Yet it is noteworthy that the profits allocation is not necessarily equal. For instance, the exploiting nation will naturally get the largest share, and then might be those countries who choose to import the mines form outer space, and then might be the developing countries who received help and guiding experiences from the exploiting countries. As the space exploration technology becomes mature, additional industries might also get dividend from it.

How will the extraterrestrial mining areas be allocated? We came up with a creative solution: divide the mining area into 'donuts' and allocate them to different countries and organizations.There are two points. On the one hand, the 'mining tools' need to conduct mining activities (rockets, base stations, satellites, etc.) will move in an orbit around the Earth. We approximate its orbit as a positive circle. On the other hand, we consider that when a 'mining tool' stays at a certain point at a certain time, its mining area is a circle with itself as the center of the sphere. Thus the reachable range of the 'mining tools' will be the inner space of a torus.

When allocating different 'donuts', we consider their volumes. Suppose the largest ring of the 'donut' is cut off by a plane, we call the outer radius R_1,and the inner radius R_2. Setting an axis which is perpendicular to this plane and go through the core of the earth as the z-axis. We obtain the volume of the 'donut':

$$V_{tor} = \int_{-r}^{r} \pi(R_1^2 - R_2^2)\, dz = 2\pi^2 ar^2 \tag{3}$$

where V_{tor} refers to the volume, d refers to the distance of the 'mining tool' from the core of the earth, and the maximum radius which it can reach is r. It can be seen that the volume of the 'donut' is positive proportional to a and r^2. The explanation for this is that if a country or organization has a greater ability to conduct mining, i.e., a larger value of r, it will be encouraged to go further away to conduct mining, i.e., a larger a. As a compensation (or a kind of reward), we allocate it more mining space.

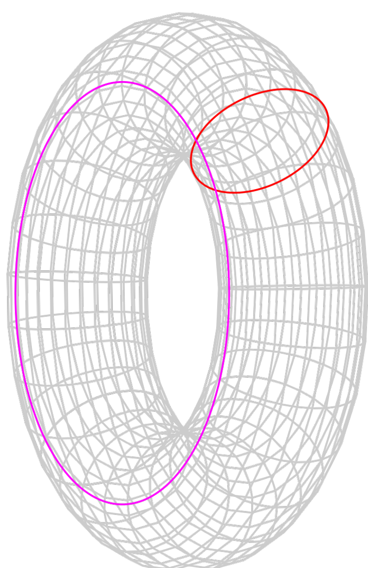

Figure 9: Torus [10]

How do humans conduct the mining process? This would be answered by astrophysicists particularly in the future. However, it is reasonable to presume that machines will possibly help human do part of the dangerous and repetitive jobs. The continuous innovation of mining methods and mining facilities will push the interstellar mining industry in a more convenient and safer direction.

How might the extent of global equity change once the asteroid exploitation is realized? This is a comprehensive question. Under the condition that all market orders are strictly observed, the world will be a win-win situation with the help of its neighbors on earth. New industries related to interstellar mining will emerge in droves, leading to lower unemployment and further alleviation of gender inequality. The level of development in the world will rise rapidly, accompanied by the improvement of global equity and the improvement of people's living standards and happiness. Nevertheless, if entrepreneurs only seek benefits without regard to the common well-being of all mankind, economic inequality and the global gap between rich and poor will further widen, which is not conducive to the sustainable development of the earth's political economy.

6 Discussion on the Global Equity Under Changing Conditions of the Asteroid Mining Industry

6.1 Superficial Thoughts About the Potential Network Effect and Spillover Effect

Let us firstly go over the definition of *network effect* and *spillover effect* respectively.

- In economics, a network effect is a phenomenon in which the value or utility that a user receives from a certain good or service depends on the number of users of a compatible product (Wang, 2021) [11].
- Spillover effect refers to the impact that an organization will not only have the expected effect of the activity when it carries out a certain activity, but also have an impact on people or society outside the organization (You & Lv, 2018) [12].

We might as well imagine that some of the commodities produced by the processing and utilization of minerals mined on asteroids have a realistic star effect in the market for that commodity. Such star products will further attract more attention and investment, which will serve as a powerful driving force for the asteroid mining industry to continue to move forward. Therefore, the reputation of alien mining at this stage is conducive to investors to invest.

On the other hand, once the asteroid mining industry has a sound scientific and technological foundation and equipment base, the marginal cost of human beings entering space will be reduced.

This will promote the development of related interstellar industries and natural sciences, such as interstellar tourism, interstellar film and television manufacturing, extraterrestrial archaeology, astrophysics, extraterrestrial architecture, literature and so on. The names of some interstellar industries may sound ridiculous, but they are not out of the ordinary. The rapid growth of these related industries will, along with the asteroid mining industry, lead to an increase in employment and GDP, as well as a further enrichment of the human imagination.

Based on the above vision, we broadly grouped the future impacts of asteroid mining into three areas: **mine production** (MP), **science development** (SD) and **employment growth**(EG). We then explore the impact of these three aspects on the seven indicators in our equity model, and thus assess the impact of certain future changes in the asteroid mining industry on global equity.

6.2 Further exploration with the model of Network Correlation Analysis (NCA)

First, as showed in Table 2, we explore the factors that affect MP,SD and EG. We select these factors from different perspectives, including some reasonable speculations about the future. For example, we conjecture that in the future, robots will have a non-negligible impact on the asteroid mining industry.

Table 2: Partial Factors

Abbreviation	Factor	Explanation
aero	Aerospace Level	The aerospace capabilities of the country or organization, related to the level of sophistication of equipment, financial support, etc.
pol	Policies	The net result of the simultaneous effect of incentive and restrictive policies
mkt	Markets	Size of the market, including the mineral market and labor market
ai	Artificial Intelligence Development Level	The main focus is on the development level of robots that can replace humans in production activities
rid	Related Industry Development Level	Development of industries in the fields of arts and culture, education, science, etc.

Next, we obtain the NCA model after correlation analysis of the indicators, which are divided into three layers.(Figure 10)

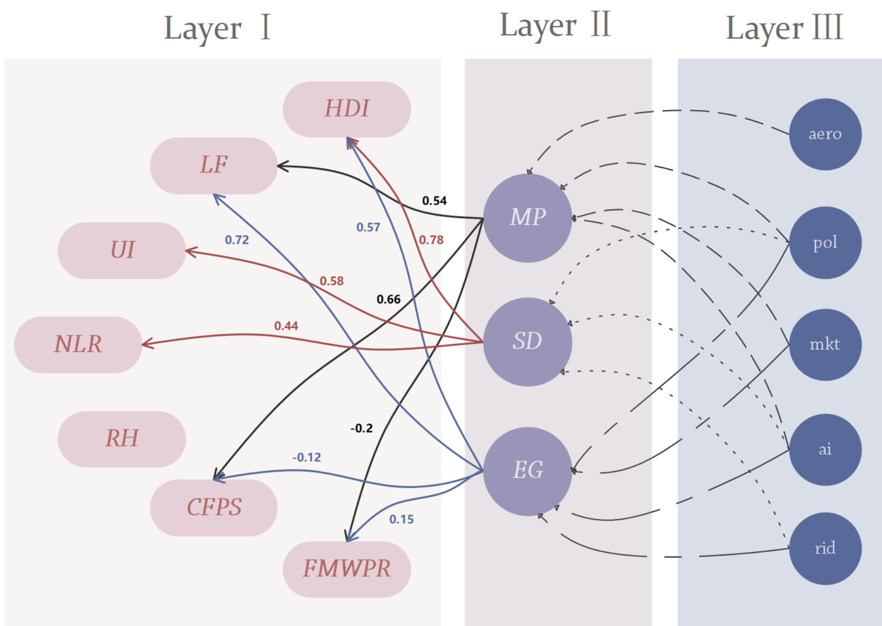

Figure 10: Framework of NCA model

The numbers in Figure 10 are **Pearson correlation coefficient**. The formula to calculate the correlation coefficient of two indicators x and y of the sample (e.g., x for MP,y for LF) is

$$r_{xy} = \frac{\sum x_i y_i - n\bar{x}\bar{y}}{(n-1)s_x s_y} = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n\sum x_i^2 - (\sum x_i)^2}\sqrt{n\sum y_i^2 - (\sum y_i)^2}} \tag{4}$$

where positive and negative signs represent positive or negative correlation, and the magnitude of $|r|$ reflects the degree of correlation: the closer it is to 1, the more correlated it is.For example, we get that the correlation coefficient between MP and LF is 0.54. The correlation coefficient between the second level and all indicators of the first level two by two is shown in the figure below.

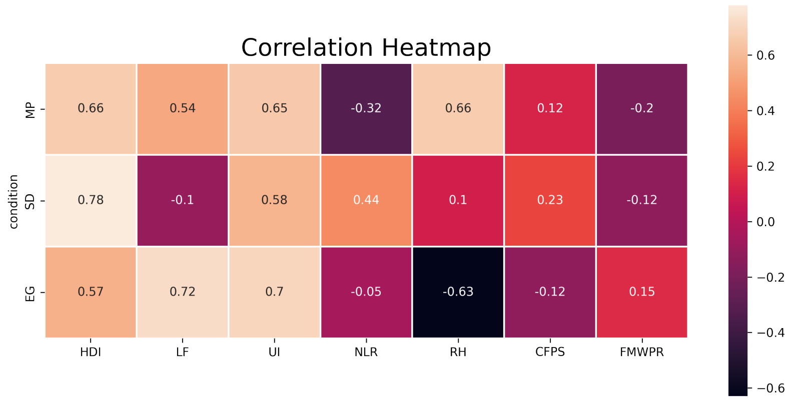

Figure 11: Correlation Coefficient

To test the significance of the correlation coefficients, we performed a P-value test. The p is obtained as shown in Table 3. For robustness reasons, we only consider two sets of variables with p less than 0.01 to be strongly significantly correlated. This gives the NCA model shown in Figure 10.

Table 3: P-value test result

	HDI	LF	UI	NLR	RH	CFPS	FMWPR
MP	0.2076	2.5E-13	0.5245	0.0228	1.1E-08	0.0423	9.6E-09
SD	1.1E-08	0.0223	0.0036	2.4E-13	0.0689	0.2220	0.0502
EG	1.0E-08	1.1E-08	0.0250	0.0320	0.0765	2.3E-13	6.9E-15

7 Possible Solutions and Policies to Maintain Global Justice While Mining in Outer Space

7.1 Guarding Intergenerational Global Equity: Two Sets of Mining Ranges

As said in the literature review, The natural resources on the planet, including climate resources, are shared and managed by all members of humanity, including the previous, this and the next (Cao, 2016). Therefore, in order to keep the intergenerational justice, the UN should update its outer space regulations such as **Outer Space Treaty of 1967** with more constraints on ‘choose the mining volume and mining range wisely’.

‘*Wise mining volume’* is mainly reflected in the limits on the amount of extraterrestrial minerals mined, which have different restrictions for countries with different needs and different levels of technology. This ensures that countries with advanced space exploration levels for the time being will not be overexploited, resulting in a lack of adequate extraterrestrial asteroid resources in other technologically advanced countries several generations later.

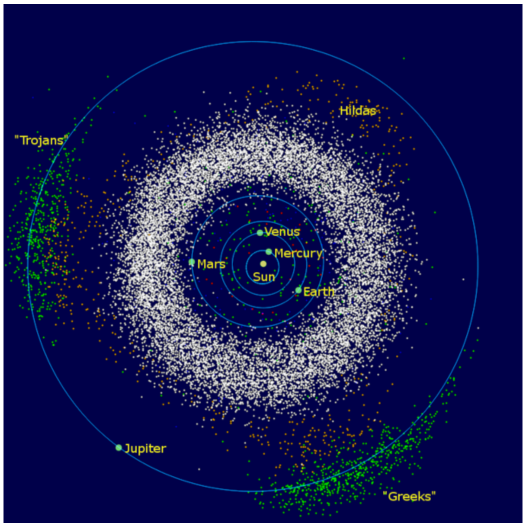

Figure 12: Distribution of asteroids in the solar system [13]

'Wise mining range', on the other hand, could be categorized into two small stages: **near-Earth mining and remote mining**. To demonstrate our recommended policy for near-Earth mining, we have depicted our plan in part 5 (task2). From another perspective, it is not difficult for any astronomy enthusiast to find that the vast asteroid belt of about 400 million kilometers wide between Mars and Saturn also provides an ideal destination for our interstellar mining journey. Although farther from Earth, remote mining does mean more choice and richer resources. Near-Earth resources will be as valuable as the resources of the earth in the coming generations, and it will require human beings to develop sustainable development plans for them, which is also one of the obligations of human beings to be the earth's neighbors (what if the unlikely event that the plan to move to space does materialize, we need to plan ahead for the possibility that is currently small).

7.2 Guarding Regional Global Equity: Using Ricardo's Model and Oligopoly Market Model

Where resources are available, there is competition, and whether or not the competition is fierce, we also need to develop policies to ensure that regional equity is not violated. Our recommendations for relevant United Nations policy updates which could directly influence regional equity in the following three ways.

- The UN ought to establish a more complete system of space laws to ensure interstellar security and political stability. Interstellar mining teams of multiple countries might inevitably arise when operating at the same time, and a complete set of human space agreements is needed then to ensure that asteroid mining can be carried out safely and decently by humans. For example, how the nations' previous mining order is determined according to their exploiting process or starting time, how to deal with waste and mining tools, and so on. After all, no one hopes both sides of the Star Wars are humankind. Sound and sufficient interstellar legislation will also bring benefits to future generations and help maintain intergenerational fairness.

- When the asteroid minerals are shipped back to Earth, the UN should exercise the function of a national government to macro-regulate the asteroid mineral market to ensure regional fairness and the common human *'interstellar claim'*. According to **Ricardo's International Trade Model**, trade patterns depend on comparative advantage rather than absolute advantage. Most countries, after mining interstellar minerals, choose to export some of them to other countries. In order to consider the global regional fairness and the protection of poor countries and less developed countries, the United Nations should make some hard regulations on the international trade of interstellar minerals, such as tariff ceilings, price ceilings and so on. These practices can effectively prevent the occurrence of vicious international trade and even trade wars.

  Due to the peculiarity and non-renewable nature of interstellar minerals, most countries have a high demand for this extraterrestrial resource. At this time, a small number of countries with interstellar geological exploration and excavation formed an oligarchy in the market. According to the definition of modern Western economics, the essence of the **oligarchic market model** is that there are only a few sellers, so the behavior of any one seller in the market has the potential to have a great influence on the profits of all other enterprises (Mankiw, 2018) [14]. According to **Game Theory**, oligarchs will conspire against prices in order to maximize their common interests, as shown in Figure 13,

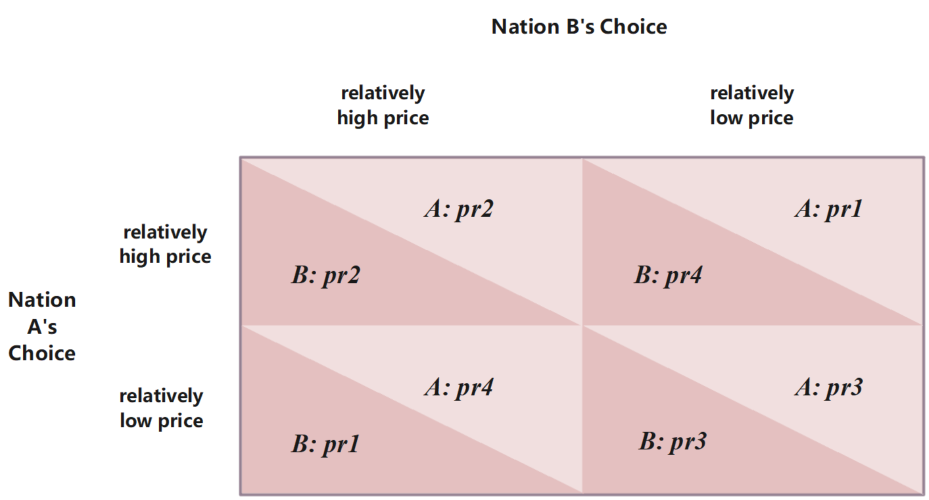

Figure 13: Predominance Strategy Model

where pr means profit,and $pr1 \geq pr2 \geq pr3 \geq pr4$. How to control minerals without being at excessive monopoly prices requires effective consultation between politicians and business groups. At the same time, laws such as **Antitrust Laws** need to be enforced to prevent excessive distortions in market structures.

- The United Nations should stipulate that, countries which have exploited asteroid minerals should reserve at least a certain percentage (for example, 10%) of valuable minerals as aid and support to countries that are temporarily unable to go to asteroid surveys. This is ethically plausible, because interstellar resources, especially those of near-Earth lifeless asteroids, are supposed to belong to all mankind and should be shared by all people on Earth. However, such provisions are relatively flexible and allow for negotiation and consultation without undue loss of the interests of nations or regional groups. For example, if the *'kind mineral reserves'* are not claimed or purchased by underdeveloped countries, the mining nation has the right to use them after all the minerals belonging to it have been depleted.

  The above proposed improvement policies are only the personal opinion of the writers of the article, and there may be a certain gap with the real-world situation. What is certain, nevertheless, is that the United Nations, in updating its outer space agreement such as the **Outer Space Treaty of 1967**, will need to consider in detail the multidimensional impacts of the asteroid mining project on global equity.

7.3 Further Thoughts: An Open Globe and Sharing the Future

'We've always defined ourselves by the ability to overcome the impossible. And we count these moments. These moments when we dare to aim higher, to break barriers, to reach for the stars, to make the unknown known.'

*—'Cooper' in the film **Interstellar**, directed by Christopher Nolan in 2015*

As the most special planet in the vast and empty solar system, the earth should actively explore and fulfill its cosmic obligations while extracting resources from other planets. For example, how to make life continue in the universe, how to give birth to new forms of life, how to live with potential extraterrestrial life in peace, how to assist or dedicate as an earth, and so on.

While we use the beautiful vision of asteroid mining to explore how to ensure global fairness, we should appropriately look beyond our horizons and consider the moral and ethical issues of humanity's future as a member of the stars. How humans can maintain overall fairness on other planets, how humans can redefine fairness in other environments where the allocation of resources is not the same as that of the earth, and how humans can live in peace with creatures on other planets as much as possible are all propositions that future generations need to think about while continuously developing science and technology.

Figure 14: *'Endurance'* (From the film ***Interstellar***)

8 Error Analysis and Sensitivity Analysis

We performed a sensitivity analysis for the seven indicators: The values of each indicator were changed by from 1% to 5%, and we obtain a new score for each condition with only one indicator changes at a time. This process showed a linear relationship between the scores and the values of the indicators. And the total score of the higher equity system responds linearly to the seven scores.

9 Model Evaluation and Further Discussion

9.1 Model Evaluation

9.1.1 Advantages of the Model

- In *Global Equity Module*, we use *Entropy Weight Method* to calculate the weight of each indicator, which is relatively objective when compared with *Analytic Hierarchy Process* or *Delphi method*. This mean our weight is This shows that our data is credible to some extent.

- The *Fuzzy Integrated Evaluation* is perfectly suitable to evaluate a fuzzy index. In this case, we build micro model for both intergenerational equity and intragenerational equity, combing with it to estimate the equity.

- To access the different impact on global equity caused by various conditions in *task 3*, we creatively build the *Network Correlation Analysis Model*, which could show intrinsic links between indicators and variables. This enables us to dive into a more comprehensive area behind the analysis.

9.1.2 Shortcomings of the Model

- Owing to shortage of future data, we use history data(in the times we live in) to conduct analysis in some model. So the result may look different to some extent when compared with result from actual data.

- In the *intergenerational equity analysis* section, we use the slope of regression curve as the X variable in *Fuzzy Integrated Model* curve. The information of intergenerational equity presented by slope is limited, so it doesn't always make sense in any situation.

9.2 Promotion of the Model

- In consideration of analysis convenience and relevance of topic, we only choose seven indicators from three aspects to build *Global Equity Model*. Though these indicators are relevant to global equity, we'd like to add more metrics or find more representative metrics in the future in order to strengthen our model, making it more sound.

- To a large extent we have simplified the physics of the universe, in order to make our model more realistic, we can study this aspect more in the future.

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Appendices

```
def genData(cv, error=0.01):
  actualCV = 200
  porp = 0
  while abs(actualCV - cv) / cv > error:
    if actualCV > cv:
      porp += 1
    else:
      porp -= 1
    data = np.random.rand(20)
    data = list(data)
    scale = 0.2
    data.extend(list(np.random.rand(20*porp)*0.2+(0.5-scale/2)))
    data = np.array(data)
    np.random.shuffle(data)
    mean = data.mean()
    std = data.std()
    actualCV = std / mean
  return data, actualCV
```